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IDENTIFICATION OF CARBON SEGREGATION IN NODULAR CAST IRONS BY THERMAL ANALYSIS

by

© Spiro Buj

A Thesis
Submitted to the Faculty of Graduate Studies
Through the Department of Engineering Materials
In Partial Fulfillment of the Requirements
For the Degree of Master of Applied Science
at the University of Windsor

Windsor, Ontario
1982

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ABSTRACT

A thermal analysis method is developed to study the influence of various processing variables such as metal chemistry, inoculation procedure, pouring temperature, solidification rate, etc. on extent of carbon macrosegregation in commercially produced nodular cast iron. The processing variables directly affect solidification mechanisms, and thus carbon macrosegregation.

The procedure for evaluating the solidification history of the sample ingot involves:

1) Pouring the metal sample into a measuring cup equipped with a sensitive thermocouple, and recording the cooling curve during solidification of the sample ingot.
2) Sectioning the sample ingot, performing a chemical analysis (spectroscopically), and examining metallographically the ingot structure.
3) Determining the parameters for fitting a fundamentally derived equation to the cooling curve and relating the values of the parameters to carbon macrosegregation tendency.

A special mathematical procedure and computer program is developed for translating the temperature-time data obtained into sets of solidification parameters. The thermal analysis method, when combined with the chemical analysis, successfully predicts carbon macrosegregation tendency in commercial nodular cast irons.

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I am extremely grateful to my dear wife Nella for her encouragement and generosity, which took so many different forms and made it so much easier for me to undertake this work.

Most of the experimental work, i.e., the chemical analysis and cooling curve measurements, were performed at the Ford Motor Company of Canada, Windsor Casting Plant, where I am employed. The author gratefully acknowledges the contribution of Ford Motor Company in providing the time, materials, and facilities for the realization of this project.

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CHAPTER 1.

Introduction

This study is undertaken to identify the effect of processing variables on carbon macrosegregation in commercially produced nodular cast irons. Carbon macrosegregation in its severest form is commonly referred to as carbon flotation. A thermal analysis method is developed which gives reliable predictions on the influence of various processing variables on carbon macrosegregation.

The principal processing variables are metal chemistry, pouring temperature, magnesium nodularization treatment, inoculation treatment, and holding time of the treated metal (1,2). The heavy production schedules in nodular cast iron foundry practice require tight control of the variables and the maintenance of the prescribed pouring specificiations, if maximum efficiency and product quality are to be achieved. The usual foundry practice for continuous production of nodular cast iron consists of the following:

(1) base metal transfer from a basic slag cupola into an electric arc holding furnace or a gas preheated forehearth;

(2) transfer (when required) of the base metal from the holding furnace or forehearth into a treatment ladle containing magnesium nodularization alloy and other required ferroalloys;

(3) transfer of the treated metal into pouring

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ladles during which inoculation with ferrosilicon is performed;

(4) pouring the inoculated metal into moulds.

An efficient and reliable melting operation is essential in maintaining stable metal chemistry and temperature. This, however, is not always realized, and metal chemistry fluctuations beyond acceptable limits occasionally occur. Since the metal chemistry specifications are quite stringent (e.g., final carbon content is to be held within a 0.30% range*), any deviation outside of the prescribed limits results in most instances in costly production downtime and scrap; the latter frequently the result of severe carbon flotation. However, in some instances, castings poured using metal outside the prescribed chemistry limits do not show a significant amount of carbon flotation as might be expected, and thus additional data are required if more reliable processing specifications are to be established. It may be possible to accept carbon levels (or carbon equivalents) outside specified limits by adjusting other processing variables in compensation, which would be of considerable economic benefit to foundry operations. This requires a more comprehensive analysis of the processing variables, and thermal history of the metal during solidification appears to have this comprehensiveness.

In this investigation a method is developed for predicting carbon macrosegregation from an analysis of cooling

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curves. The metal samples for this purpose were taken immediately before the metal was poured into moulds, and thus all the processing variables (together with other intrinsic characteristics of the metal not normally monitored in conventional control practices) contribute to determining the cooling curve and thus the solidification parameters used in the analysis.

Since the net effect of processing variables on carbon macrosegregation is indirectly related to the temperature vs. time values of the cooling curve, the design of a simple analytical method based on the cooling curve, combined with digital processor, would provide a powerful tool for controlling process parameters for production of castings if rapidity and relative accuracy in predicting the macrosegregation tendency in nodular cast iron castings could be demonstrated.

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CHAPTER 2

Literature Review

2.1 Carbon Macrosegregation

Carbon flotation frequently occurs in heavy sections of nodular iron castings of hypereutectic compositions, i.e., where cooling and solidification rates are generally slow. The flotation effect is usually observed as a loosely packed, relatively thick layer of graphite nodules at the cope (upper) surface of castings, which greatly reduces surface quality. The thickness of the segregated layer depends on metal chemistry, pouring temperature, solidification mechanism, cooling rates, etc., and in extreme cases reaches several millimeters in depth (1,3).

Carbon macrosegregation, which is incipient carbon flotation, originates in the melt (4). The decrease in interfacial energy is the driving force for carbon macrosegregation, and results in clustering of the graphite nodules. The subsequent carbon flotation is due to the low density of the free graphite compared to that of the surrounding liquid iron. During solidification of hypereutectic nodular iron, graphite nodules are first precipitated and grow until sufficiently large to overcome the viscous forces, whereupon they rise in the liquid giving the segregated regions (4,5). As solidification progresses, and subsequent eutectic solidification takes place, the newly precipitated (eutectic stage) nodules, together with some of the nodules

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precipitated earlier, become entrapped by growing austenite dendrites, thereby preventing flotation (6,7). Thus, carbon macrosegregation is an early solidification period phenomenon. Also, since the number of nodules progressively increases with the increase in the carbon equivalent level (carbon plus one third silicon content), a severe graphite nodule agglomeration will occur in extremely high carbon equivalent irons. The so-called kish carbon is the most severe form of graphite agglomeration.

Magnesium is the element in the nodularization alloy which is primarily responsible for initial nucleation of the graphite nodules, but cerium and other rare earth metals usually contained in some nodularization alloys also decrease the flotation tendency through an increase in the nucleation rate (8-11). The increased nucleation rate results in a greater number of nodules of decreased size, and thus the viscous force may be sufficient to overcome the buoyancy force to prevent or significantly retard graphite flotation. The degree of graphite flotation can also be controlled to some extent by adjusting the amount and grade of ferrosilicon inoculant used. The function of the inoculant is to enhance the graphite nodule nucleation, and such elements as aluminum, calcium, and strontium normally present in ferrosilicon inoculant significantly improve the effectiveness of the inoculant (8,12-14). In general, faster cooling rates are preferred since less time is available for growth and flotation of nodules. The cooling rates are directly affected

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by casting size and mould material. A significant reduction in flotation zone depth can also be achieved by maintaining lower pouring temperature (4).

2.2 Thermal Analysis Method

Thermal or cooling curve analysis of nodular cast iron has been extensively reported in the literature in recent years. Although there is some disagreement and controversy, it is evident from the studies reported that the shape of the cooling curves is primarily dependent on the solidification mechanisms, which in turn is dependent on metal chemistry and to a lesser extent on nodularization and inoculation treatment (4,15,17,18). Since it is not practicable to incorporate a comprehensive chemical analysis into a quick routine quality test during production, the goal of various investigators has been to develop a thermal analysis method which proves to be an adequate and effective substitute.

In conventional practice cooling curves are obtained by recording the temperature vs. time variations during cooling and solidification of a liquid metal specimen. The temperature variations are monitored by a sensitive thermocouple suitably located in a specimen receptacle, and traced on a strip chart recorder. The design of the receptacle allows for either vertical or horizontal positioning of the thermocouple, and depending on sampling device and purpose, sample receptacles can be filled by pouring metal into it or by immersing the entire sampler in the molten metal (15-17,19).

Features of the cooling curves, such as variations in

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slopes, thermal arrests, undercooling, and recalescence, can be associated with the initial precipitation of proeutectic graphite, the start and end of the eutectic solidification stage, and other solid state phase transformations, which in turn can be related to the metal chemistry, general as-cast matrix structure, graphite morphology, nodule distribution and count, and carbide formation (17). Due to this fact the thermal analysis method has become in recent years an essential part of the cast iron process and quality control.

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CHAPTER 3

Experimental Procedure

The sampling device used in this study consisted of a conventional foundry carbon equivalent measuring cup and a cooling curve (strip chart) recorder. The measuring cup is a commercial type, shell-moulded sand cup containing an axially positioned chromel-alumel thermocouple.* The thermocouple is enclosed in a protective ceramic tube, with only the thermocouple tip exposed to the liquid metal. The interior surface of the cup, along with the ceramic tube and thermocouple tip, are coated with ceramic wash for additional protection. The measuring cup is mounted on a suitable holder, and its terminals are connected through the holder to the strip chart recorder (19). A schematic representation of the measuring cup and thermocouple is shown in Figure 1.

All nodular iron samples for this study were taken from regular production runs immediately prior to pouring into moulds. They were either extracted from pouring ladles using a dipping spoon, or taken directly from the metal stream during pouring (teapot-type spout ladles) of the metal into the moulds. The dipping (sampling) spoon holds approximately 5 kg. of metal. It is made of mild carbon steel, with the interior and exterior surface coated with a clay wash for protection.

Samples taken from the liquid metal were quickly poured into the measuring cup to minimize temperature losses. Solidification of the melt sample was generally completed within

* Accuracy +-2.2°F @ 2012°F

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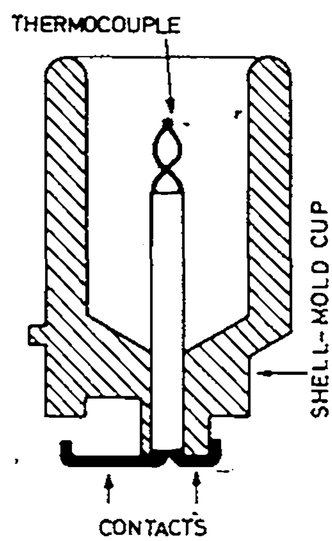

Figure 1 Section of the measuring cup with axial thermocouple.

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three to four minutes after pouring into the measuring cup. The ingot sample dimensions are approximately 35 mm dia. x 47 mm length, giving a weight of approximately 350 grams. After solidification was completed and the cooling curve recorded, the ingot was removed and vertically sectioned for microstructural examination.

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CHAPTER 4

Collection of Data

Characteristic cooling curves recorded for hypoeutectic, near-eutectic, and hypereutectic nodular cast iron compositions are shown in Figure 2 with the corresponding processing variables indicated. The influence of chemical composition and/or processing variables on cooling curve shapes is evident from these curves, although no clear transition point from hypoeutectic to hypereutectic composition is evident. The difference in the shape of the cooling curve for near-eutectic compositions may be attributed to different solidification mechanisms, which ultimately produce different carbon macrosegregational tendencies.

The ingots were sectioned vertically through the thermocouple ceramic protective tube, and an area of approximately one square cm. in the vicinity of the thermocouple tip was metallographically examined. Photomicrographs were examined for relevant structural features and nodule distribution and count, and the results correlated with the corresponding cooling curves.

Disc and/or pin chill samples were poured for spectrochemical analysis from the same metal sample used in pouring the ingot for thermal analysis. Other processing variables, such as pouring temperature, nodularization and inoculation practices, together with composition and other relevant observations, were recorded for each sample taken. The magnesium alloy added for nodularization was a ferrosilicon

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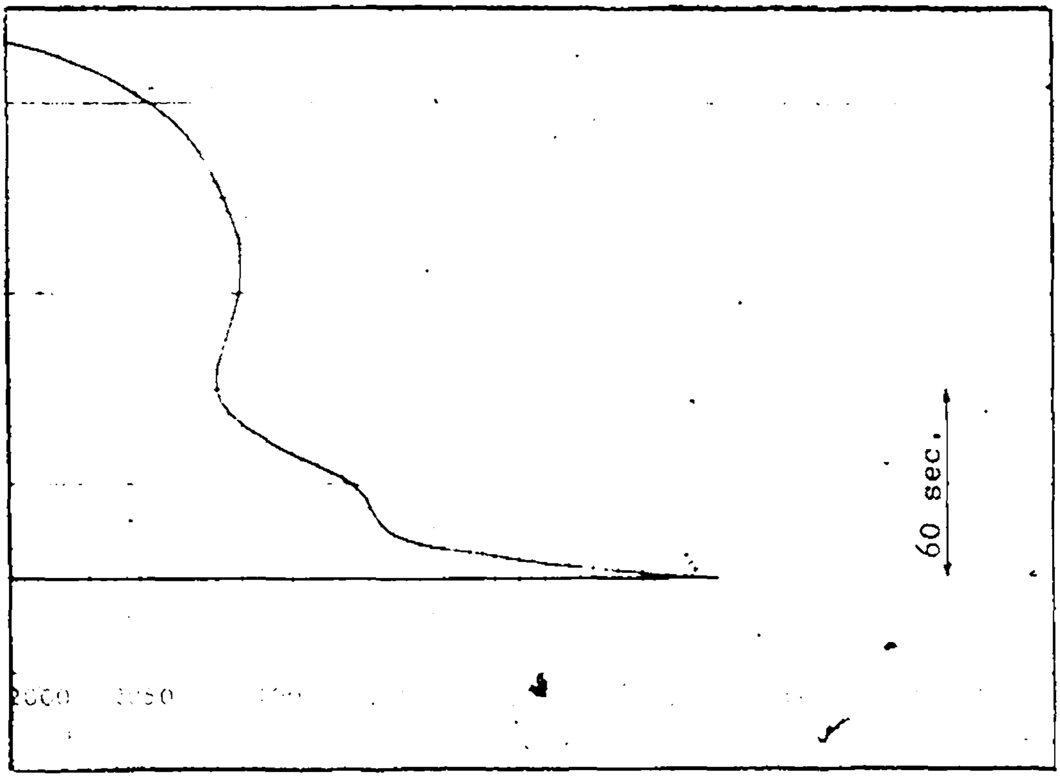

Metal Chemistry	Metal Treatment (sandwich method)	Pouring Temperature
C 3.55 %	80 lbs. Mg-alloy	2570 °F
Si 2.45 %	12 lbs. FeSi(75)*	
C.E. 4.37 %	20 lbs. FeMn(75)**	
Mn 0.65 %	per 6000 lbs. metal .	
Cr 0.13 %		
Cu 0.14 %	Inoculation:	
Al 0.018 %		
Mg 0.036 %	8 lbs. FeSi(75)*	
S 0.006 %	per 2000 lbs. metal	

* 75% Si
**75% Mn

Figure 2(a) Cooling curve and processing variables for hypoeutectic nodular cast iron; ingot 5.

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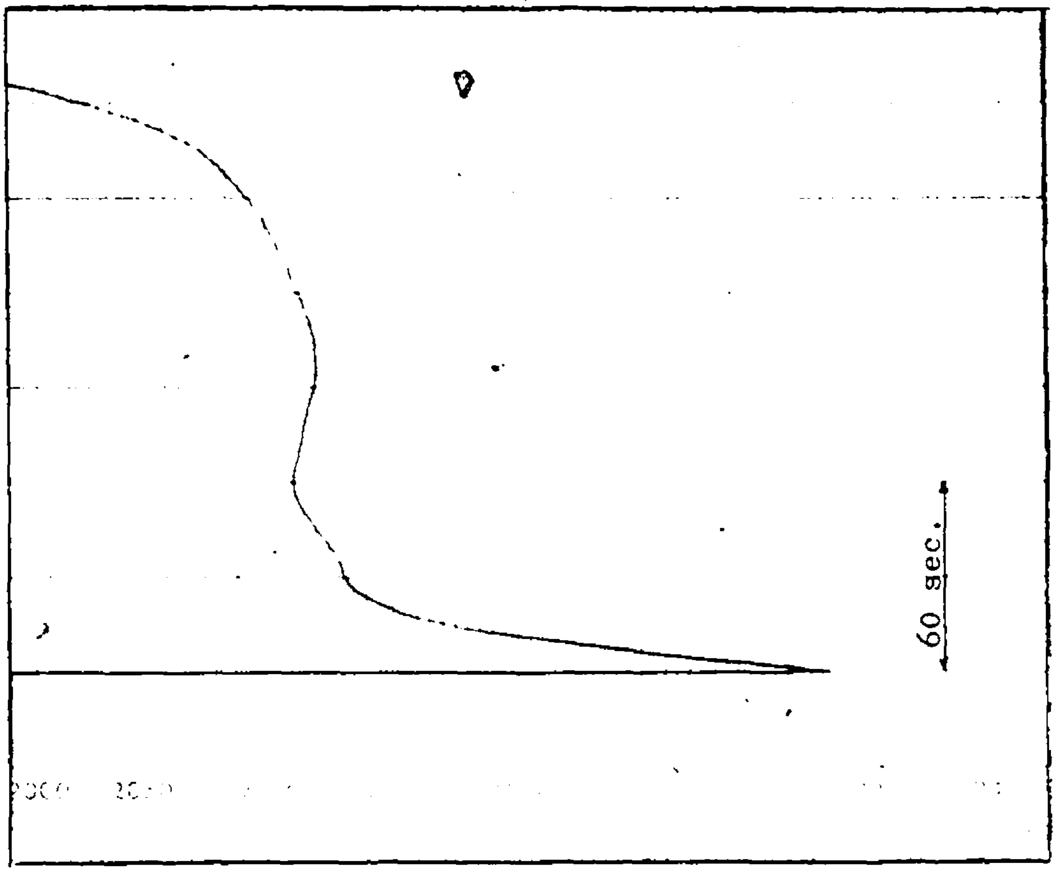

Metal Chemistry			Metal Treatment (sandwich method)	Pouring Temperature
C	3.64	%	95 lbs. Mg-alloy	2565 °F
Si	2.86	%	9 lbs. FeSi(75)	
C.E.	4.59	%	18 lbs. FeMn(75)	
Mn	0.75	%	per 6000 lbs. metal	
Cr	0.16	%		
Cu	0.11	%	Inoculation:	
Al	0.022	%	6 lbs. FeSi(75)	
Mg	0.042	%	per 2000 lbs. metal	
S	0.006	%		

Figure 2(b) Cooling curve and processing variables for near eutectic nodular cast iron; ingot 21.

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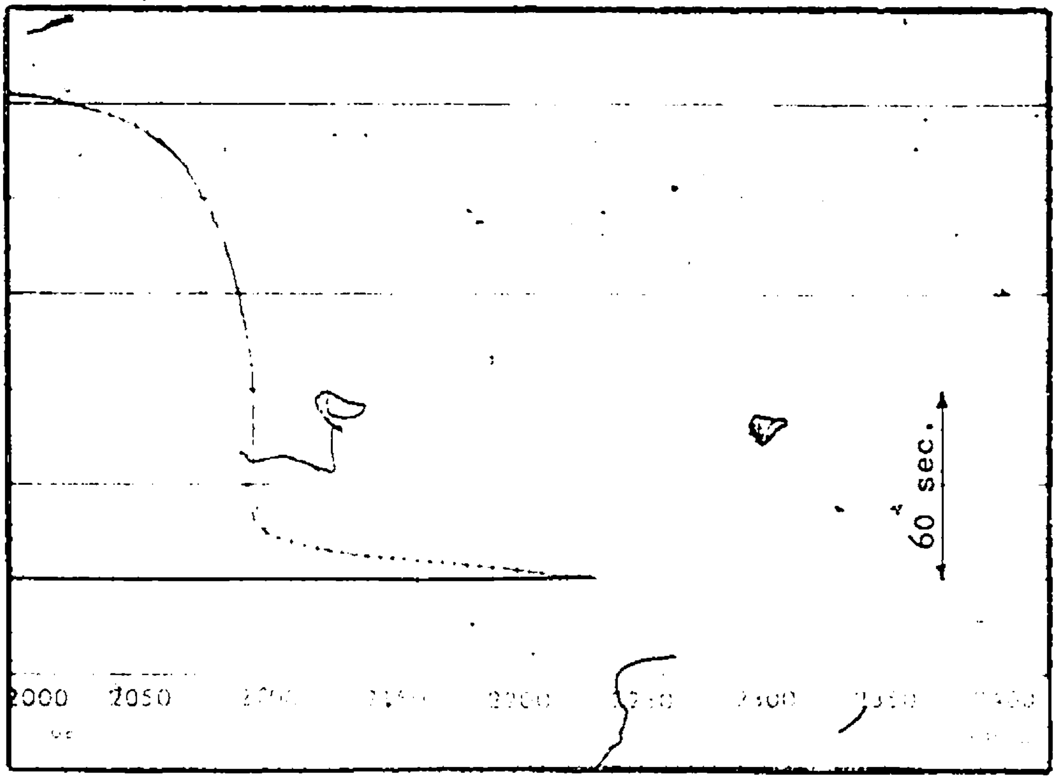

Metal Chemistry			Metal Treatment (sandwich method)	Pouring Temperature
C	3.77	%	95 lbs. Mg-alloy	2545 °F
Si	2.35	%	6 lbs. FeSi(75)	
C.E.	4.55	%	15 lbs. FeMn(75)	
Mn	0.65	%	per 6000 lbs. metal	
Cr	0.12	%		
Cu	0.12	%	Inoculation:	
Al	0.023	%		
Mg	0.036	%	6 lbs. FeSi(75)	
S	0.007	%	per 2000 lbs. metal	

Figure 2(c) Cooling curve and processing variables for mild hypereutectic nodular cast iron; ingot 9.

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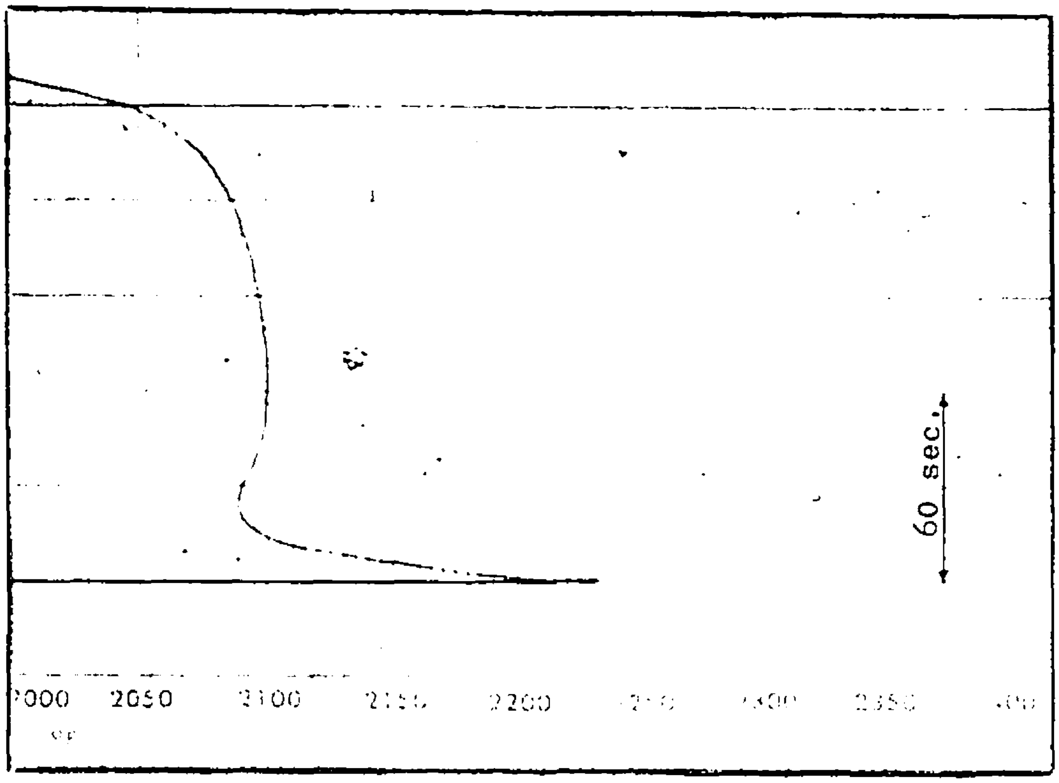

Metal Chemistry			Metal Treatment (sandwich method)	Pouring Temperature
C	3.77	%	85 lbs. Mg-alloy	2540 °F
Si	2.65	%	12 lbs. FeSi(75)	
C.E.	4.65	%	18 lbs. FeMn(75)	
Mn	0.61	%	per 6000 lbs. metal	
Cr	0.14	%		
Cu	0.13	%	Inoculation:	
Al	0.20	%		
Mg	0.032	%	6 lbs. FeSi(75)	
S	0.006	%	per 2000 lbs. metal	

Figure 2(d) Cooling curve and processing variables for hypereutectic nodular cast iron; ingot 7.

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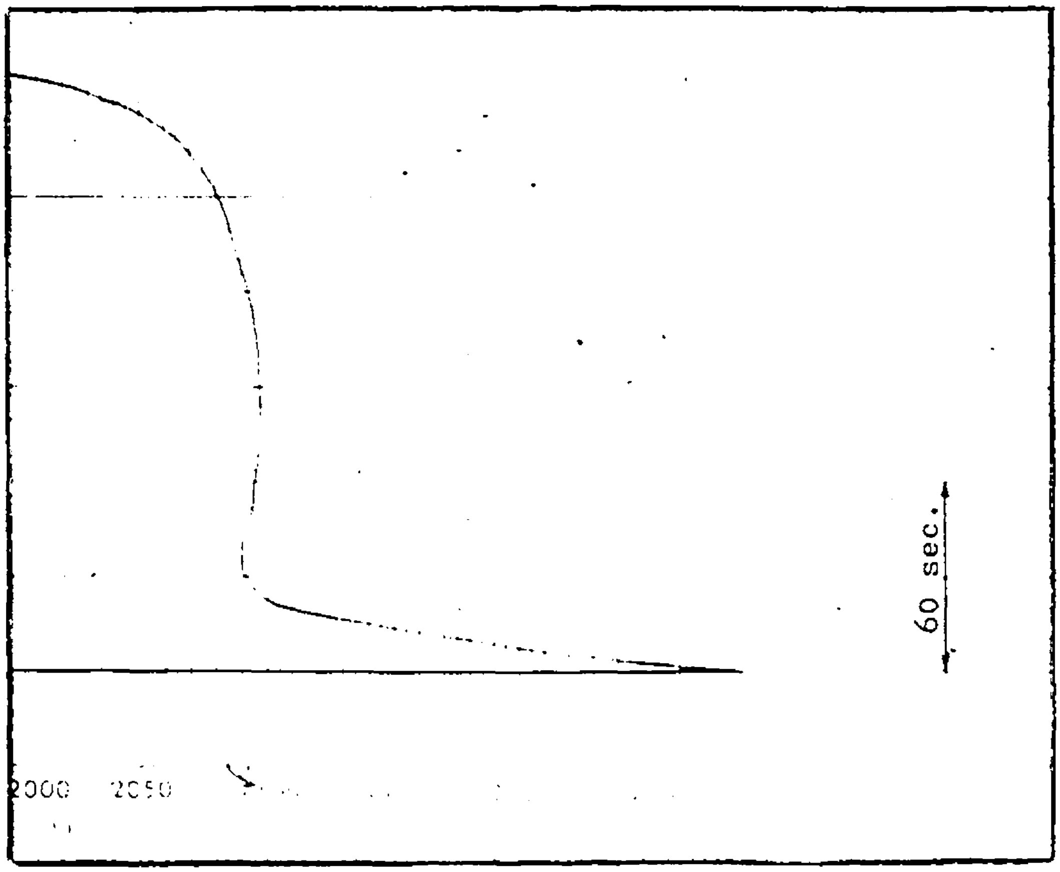

Metal Chemistry			Metal Treatment (sandwich method)	Pouring Temperature
C	3.99	%	90 lbs. Mg-alloy	2560°F
Si	2.53	%	6 lbs. FeSi(75)	
C.E.	4.76	%	20 lbs. FeMn(75)	
Mn	0.76	%	per 6000 lbs. metal	
Cr	0.14	%		
Cu	0.13	%	Inoculation:	
Al	0.022	%		
Mg	0.034	%	6 lbs. FeSi(75)	
S	0.008	%	per 2000 lbs. metal	

Figure 2(e) Cooling curve and processing variables for strong hypereutectic nodular cast iron; ingot 4.

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alloy containing 44-48%Si, 4.75-6.25%Mg, 0.3%Ce, and the remainder Fe.

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CHAPTER 5

Cooling Curve Analysis

5.1 General Considerations

The correlation of cooling curves with the microstructure is obtained by translating cooling curves into sets of numerical values of parameters appearing in the general mathematical description for the temperature vs. time variation, rather than using the absolute values of the temperature and time from the cooling curves. The advantage of such a method, in developing a more reliable routine sampling procedure, is based on the fact that the general and specific cooling curve characteristics are more telling about the solidification process than singular values of temperature and time.

In order to correlate a section of the cooling curve for the casting to its respective microstructure, a special mathematical procedure is developed here so that every region of the curve is translated into sets of values of the solidification parameters appearing in the mathematical equations describing the cooling curve. The translation is performed using a computer (Fortran) program developed for this purpose.

Since the shape of any cooling curve is an array of temperature vs. time relations, and since the parameters for the temperature vs. time relation at any given point on the curve are unique for that segment of the curve, the parameters can be used to characterize and amplify distinct stages in the solidification process which may not be readily discerned

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from the normal cooling curve itself.

In order to standardize temperature and time data collecting, each curve is plotted so that the lowest undercooling point on the curve is placed at the origin of the coordinate axes as shown in Figure 3. The X-axis represents time in seconds relative to the time at which maximum undercooling occurred. The Y-axis represents relative temperature in °F, also with reference to the maximum undercooling temperature. The point of maximum undercooling is arbitrarily assigned coordinates (0,1). The values for times to the right of this point are positive and the values for times to the left are negative. For convenience, the value of the ordinate at X=0 is conveniently set to unity, since it is the logarithmic form of the temperature vs. time relationship that is considered. All temperature values below the relative zero temperature point are taken as negative, and as such these negative values of the ordinate are considered in further calculations in terms of negative logarithmic functions, which are mirror images of the corresponding positive logarithmic functions. By arranging the temperature and time values in this manner, the point of origin for each cooling curve is placed immediately before the start of bulk eutectic solidification (though not at the very start of eutectic solidification, since after maximum undercooling and start of recalescence eutectic solidification has already commenced). This is a convenient datum point, since the rate of bulk eutectic solidification is believed to be a critical factor

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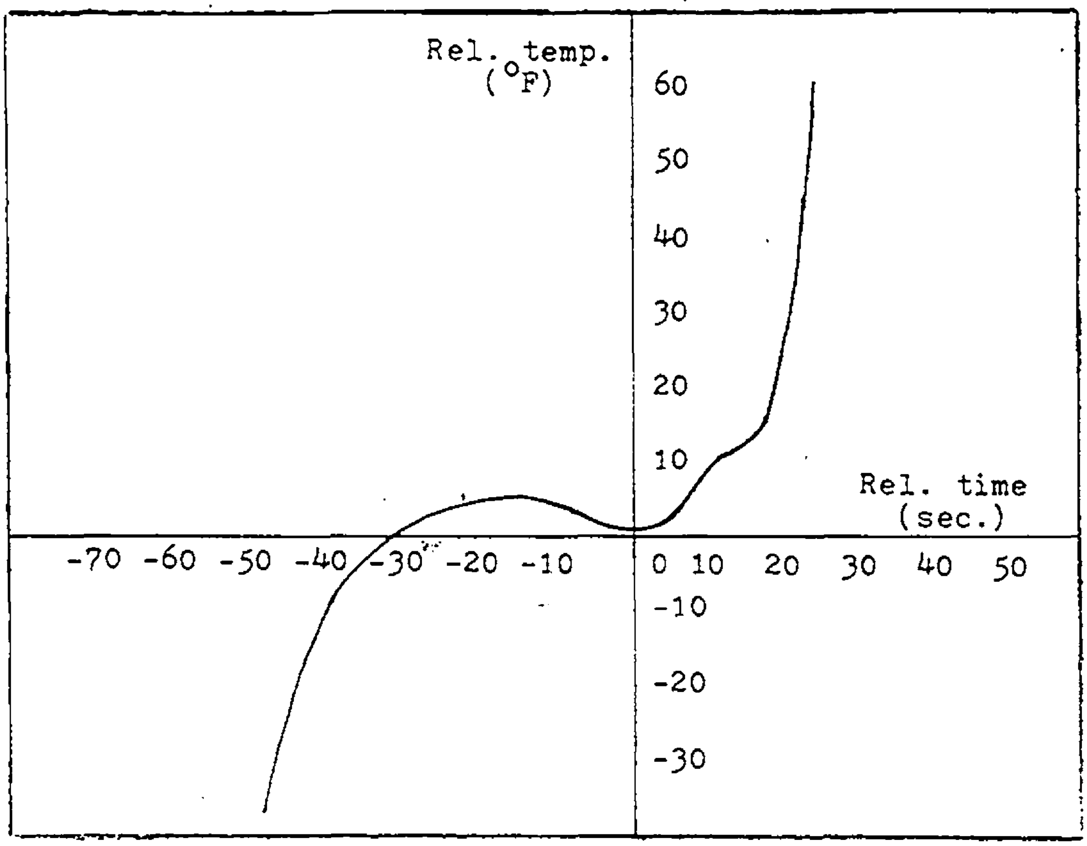

Figure 3 Cooling curve plotted relative to the lowest undercooling point recorded.

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in the carbon macrosegregation process (besides the rate of proeutectic graphite precipitation).

The errors generated by the measuring and recording equipment are relatively consistent throughout a given test, and the effect of these recurring errors in interpreting the cooling curves may be assumed to be minimal in the procedure adopted here, i.e., the experimental errors will have little or no effect in determining the values of the parameters characterizing the functional relation describing a particular segment of the cooling curve.

5.2 Mathematical Procedure

The purpose of the mathematical procedure developed here is to fit to the cooling curve a function that permits each point on the cooling curve to be defined in terms of an arbitrarily selected number of characteristic parameters. This is best attained by starting from the fundamental Taylor series representation and integrating to obtain the final functional relationship. The detailed mathematical development and solution of the basic equations are given in Appendix A, of which only a summary is presented here. In the following, Y represents the relative temperature, and X the relative time (both variables relative to the maximum undercooling point).

5.2.1 Development of The Basic Relations

The value of any function, $Y_n = f(X_n)$, in the neighbourhood of X_n, e.g., from X_0 to X_1, can be approximated by the Taylor series expansion:

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$$Y_1 = Y_0 + (X_1-X_0)*f'(X_0) + [(X_1-X_0)^2/2!]*f''(X_0) +$$
$$+ [(X_1-X_0)3/3!]*f'''(X_0) + ... +$$
$$+ [(X_1-X_0)^n/n!]*f^{(n)}(X_0).$$

If the function is approximated by taking only the first three members of the series, the rearrangement of terms gives:

$$(Y_1-Y_0)/(X_1-X_0) = [(X_1-X_0)/2]*f''(X_0) + f'(X_0) \quad 1$$

Letting $(Y_1-Y_0)/(X_1-X_0) = A$, and rearranging terms, Eq. 1 may be expressed as:

$$[(X_1-X_0)/2]*f''(X_0) + f'(X_0) - A = 0 \quad 2$$

If X_1-X_0 is arbitrarily assumed to have a positive unit value (1 sec.), the function becomes in the forward difference mode (20):

$$(1/2)*f''(X_0) + f'(X_0) - A = 0 \quad 2a$$

The backward difference mode considers a negative unit value of X_1-X_0 (20), so that Eq. 2 becomes:

$$(-1/2)*f''(X_0) + f'(X_0) - A = 0 \quad 2b$$

Both Eqs. 2a and 2b can also be written as:

$$(+-1/2)*d^2Y/dX^2 + (dY/dX) - A = 0$$

which, after multiplication of the third term by Y/Y, letting A/Y = Z, and dividing by (+-1/2), becomes:

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$$d^2Y/dX^2 \pm 2*(dY/dX) \mp 2*Z*Y = 0 \qquad 3$$

where the double sign refers to the forward and backward difference mode respectively.

If Z is constant, Eq. 3 represents a first degree, second order, homogeneous differential equation for which the general solution is:

$$Y = C_1*\exp(M_1*X) + C_2*\exp(M_2*X) \qquad 4$$

where C_1 and C_2 are the integration constants. M_1 and M_2 are the roots of the auxiliary quadratic equation (21,22):

$$M^2 \pm 2*M \mp 2*Z = 0$$

and are given by:

$$M_{1,2} = \mp 1 \pm (1 \pm 2*Z)^{1/2} \qquad 5$$

where the double signs in front of 1 and under the square root are indicative of the forward and backward differentiation mode respectively.

Eq. 4 may also be represented in hyperbolic form (21):

$$Y = K_1*\exp(\mp X) * \cosh(K_2+R*X) \qquad 6$$

where $K_1 = 2*(C_1*C_2)^{1/2}$ and $K_2 = (1/2)*\ln(C_1/C_2)$ are the odd and even subscripted constants respectively, and $R = (1 \pm 2*Z)^{1/2}$ is the exponential coefficient (c.f. Appendix A, A.1.2,b).

The significant feature of Eq. 6 is that, for sufficiently large X values (time in sec.), and depending on the magnitude of K_2 and R, it may be simplified to:

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$$Y = (K_1/2)*\exp\pm\left[K_2+(R-1)*X\right], \text{ for } R > 0$$

$$Y = \left[K_1*\exp(\mp X)\right]*\cosh(K_2), \quad \text{for } R = 0 \qquad 7$$

$$Y = (K_1/2)*\exp\mp\left[K_2+(R+1)*X\right], \text{ for } R < 0$$

The above simplifications are obtained through the exponential representations of the cosh functions, and neglecting the relatively small values of those members having exponential functions in the denominator.

The logarithmic form of Eq. 7 is a straight line, which for the forward and backward difference mode, and for $R \neq 0$, is given by:

$$\ln(Y) = \ln(K_1/2) \pm K_2 \pm (R\pm 1)*X \qquad 8$$

and for R = 0 by

$$\ln(Y) = \ln\left[K_1*\cosh(K_2)\right] \pm X \qquad 8a$$

5.2.2 Basic Curve Fitting Equation

The basic relation given by Eq. 7 can be applied to any (X_n, Y_n) point on the cooling curve. Therefore, for m number of points considered, there will be an equal number of equations on hand, each representing the basic relation given by Eq. 7. For each point considered the values of K_1 and K_2 must satisfy all the points, and thus a comprehensive equation must be developed which incorporates all the constants corresponding to the m points. The logarithmic form of Eq. 7 (i.e., Eq. 8) is used to obtain the values of the constants, the general form given by (c.f. Appendix A, A.2.1):

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$$\ln(Y_n) = \left[\ln(k_1/2) \pm k_2\right] \mp \left[\ln(k_3/2) \pm k_4\right] \mp \left[\ln(k_5/2) \pm k_6\right] \mp$$
$$\mp \ldots \mp \left[\ln(k_{2m-1}/2) \pm k_{2m}\right] \pm (R_n \pm 1) * X_n \quad (9)$$

where m is the total number of points considered, n is the subscript of each point, and where the odd and even subscripted constants, $k_1, k_3, k_5, \ldots, k_{2m-1}$ and $k_2, k_4, k_6, \ldots, k_{2m}$ respectively, correspond to K_1 and K_2 for each point considered. The absolute values of the constants are the same for all the points, whereas the value of the exponential coefficient $R_n \pm 1$ differs from point to point. The double signs in the square brackets signify the differentiation modes adopted in the development of the basic functional relation (Eq. 7), whereas the double signs preceding the square brackets indicate the progressive change in sign from - to + for each successive member in square brackets as n increases. This sign change is the result of the curve fitting process designed for computation of the value of each constant appearing in the equations (Eq. 9) established for each point (c.f. Appendix A, A.2.1) Eq. 9 is the basic curve fitting equation, defining each point on the curve. Thus if a particular segment of the cooling curve is defined by an arbitrary number of points, there will be an equal number of basic equations, and thus an equal number of both the odd and even subscripted constants, the signs of which are changed progressively on moving from one point to the next. The +- sign in the parentheses containing the R_n parameter corresponds to $R_n < 0$ and $R_n > 0$ respectively. The k

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and R values obtained by the curve fitting process numerically characterize the segment of the cooling curve considered.

5.2.3 Curve Fitting Method and the Solidification Parameters

Each point on the cooling curve can be represented by Eq. 9, so that for m number of points considered a set of m equations is formed, which in symbolic form is given by:

$$\ln(Y_0) = [c_o+-c_e]_1-[c_o+-c_e]_2-\ldots-[c_o+-c_e]_m+-(R_o+-1)*X_0 \quad 1$$

$$\ln(Y_1) = [c_o+-c_e]_1+[c_o+-c_e]_2-\ldots-[c_o+-c_e]_m+-(R_1+-1)*X_1 \quad 2$$

$$\ln(Y_2) = [c_o+-c_e]_1+[c_o+-c_e]_2+\ldots-[c_o+-c_e]_m+-(R_2+-1)*X_2 \quad 3$$

$$\ln(Y_n) = [c_o+-c_e]_1-[c_o+-c_e]_2+\ldots+[c_o+-c_e]_m+-(R_n+-1)*X_n \quad m$$

where c_o and c_e are the odd and even subscripted constants, respectively, or:

$$[c_o+-c_e]_1 = [\ln(k_1/2)+-k_2]$$

$$[c_o+-c_e]_2 = [\ln(k_3/2)+-k_4]$$

$$[c_o+-c_e]_3 = [\ln(k_5/2)+-k_6]$$

$$[c_o+-c_e]_m = [\ln(k_{2m-1}/2)+-k_{2m}]$$

Note the successive sign change from negative to positive from the top left hand corner to the bottom right hand corner of the set on moving from one point to the next progressively toward higher subscript numbers.

By transferring all the variable members to the left hand side, and leaving all the constants on the right hand side, the above set of equations can be treated as a

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square matrix, from which the value of each constant can be computed by applying a suitable iterative method capable of making each constant converge to a definite value:

$$L_0 = \left[c_{o1} +- c_{e1} - c_{o2} -+ c_{e2} - c_{o3} -+ c_{e3} - \ldots - c_{om} -+ c_{em}\right] \quad 1$$

$$L_1 = \left[c_{o1} +- c_{e1} + c_{o2} +- c_{e2} - c_{o3} -+ c_{e3} - \ldots - c_{om} -+ c_{em}\right] \quad 2$$

$$L_2 = \left[c_{o1} +- c_{e1} + c_{o2} +- c_{e2} + c_{o3} +- c_{e3} - \ldots - c_{om} -+ c_{em}\right] \quad 3$$

$$L_n = \left[c_{o1} +- c_{e1} + c_{o2} +- c_{e2} + c_{o3} +- c_{e3} + \ldots + c_{om} +- c_{em}\right] \quad m$$

where $L_n = \ln(Y_n) - (R_n +- 1) * X_n$, and $C_{o1}, \ldots, c_{om}$ and $c_{e1}, \ldots, c_{em}$ are the odd and even subscripted constants respectively. By arbitrarily setting the values of the even subscripted constants, the values of odd subscripted constants can be calculated from Eq. 8.

The values of both the odd and even subscripted constants thus obtained are considered as initial approximations, which on introduction into the square matrix undergo successive modifications through the iterative convergence process until complete convergence is achieved. The final equation obtained upon completion of the iterative convergence process, which satisfies all the points considered, is given by:

$$\ln(Y_n) = \left[C_o + C_e\right]_1 -+ \left[C_o + C_e\right]_2 -+ \left[C_o + C_e\right]_3 -+ \ldots$$

$$\ldots -+ \left[C_o + C_e\right]_m +- (R_n +- 1) * X_n \quad 10$$

where C_o and C_e are referred to as the odd and even subscripted parameters respectively, possessing definite values character-

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izing each cooling curve segment considered, and which together with the values of exponential parameters (R_n+-1), hereafter referred to as the variable solidification parameters, uniquely characterize the cooling curve. Note that the even subscripted constants already include the sign indicative of the differentiation mode adopted in developing the basic relation (no double sign in square brackets). The detailed curve fitting method by which Eq. 10 is derived is given in Appendix A.

Eq. 10 is an expanded representation, since all constant parameters are explicitly shown. A condensed form of Eq. 10 may be expressed as:

$$\ln(Y_n) = SC_n+-(R_n+-1)*X_n \qquad 11$$

where the symbol SC_n represents the summation of all the constant parameters. It is evident from the square matrix that the values of SC_n differ from one point to the next, e.g., from n to n+1, by the amount of $2*\left[C_o+C_e\right]_{n+2}$ by virtue of the successive sign change from - to + toward higher subscript numbers. Eqs. 10 and 11 are straight lines with (R_n+-1) being slope values, and the intercepts on ordinate axis are represented by the sum of all the constant parameters in either the expanded or condensed form. A set of straight lines is obtained corresponding to the number of points comprising the curve segment, from which the functional relationship of the points is established. Eqs. 10 or 11 are the basic equations containing necessary information describing the metal

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solidification process, i.e., the constant (solidification) parameters ($[C_o+C_e]_{n+1}$, SC_n), and the variable (solidification) parameter (R_n+-1), which can be used to determine and predict the extent of carbon macrosegregation. For the purpose of digital computation and representation the set of constants comprising the square matrix is considered as a one dimensional array of numbers.

5.2.4 Exponential Parameter R

In the above theoretical treatment the exponential parameter R (or R_n) is assumed to be a constant in the close neighbourhood of the point considered. For infinitesimal (X_1-X_0) distances the symbol Z in Eq. 3 can be replaced by (dY/dX)/Y . The expression for the exponential parameter becomes:

$$R = \left[1+-2*(dY/dX)/Y\right]^{1/2} \qquad 12$$

which on rearrangement and integration gives:

$$R = \left[1+-2*\ln(Y)/X\right]^{1/2} + C_n \qquad 13$$

where C_n is the integration constant, and the double sign in the square bracket denotes the forward and backward mode differentiation mode respectively.

It is obvious from Eq. 13 that R is a function of two variables, namely, R = F(X,Y), which by implicit differentiation gives (21,23):

$$dY/dX = -(\partial F/\partial X)/(\partial F/\partial Y) \qquad 14$$

However, R may also be considered as a function of

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A(=dY/dX) and Y, i.e., R = f(A,Y), (c.f. Eq. 12). Thus:

$$dR/dX = (\partial R/\partial A)*(dA/dX) + (\partial R/\partial Y)*(dY/dX)$$

which becomes:

$$dR/dX = (\partial f/\partial A)*(d^2Y/dX^2) + (\partial f/\partial Y)*(dY/dX) \qquad 15$$

since dA/dX is the second derivative of the function describing R. Substitution of Eq. 14 into the second member on the right hand side of Eq. 15 results in:

$$dR/dX = (\partial f/\partial A)*(d^2Y/dX^2) - (\partial f/\partial Y)*(\partial F/\partial X)/(\partial F/\partial Y) \qquad 15a$$

It is evident from the above that if the segment of the cooling curve is large, R can vary significantly, and for greater accuracy this variation is incorporated into the curve fitting process. From Eqs. 12 and 13, $(\partial f/\partial Y) = (\partial F/\partial Y)$, and assuming that $(\partial f/\partial A) \sim (\partial F/\partial X)$, Eq. 15a can be simplified to give:

$$dR/dX = (\partial R/\partial X)*(d^2Y/dX^2-1) \qquad 16$$

It follows from Eq. 13 that:

$$\partial R/\partial X = -+[\ln(Y)/X^2]*[1+-2*\ln(Y)/X]^{-1/2} \qquad 17$$

and,

$$\partial R/\partial Y = +-[1/(X*Y)]*[1+-2*\ln(Y)/X]^{-1/2} \qquad 18$$

Substituting Eqs. 17 and 18 into Eq. 14 gives:

$$dY/dX = +-Y*\ln(Y)/X \qquad 19$$

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for which the second derivative is:

$$d^2Y/dX^2 = Y*\ln^2(Y)/X^2 \qquad 20$$

Introducing Eq. 17 and Eq. 20 into Eq. 16 gives:

$$dR/dX = -+\left[\ln(Y)/X^2\right]*\left[1+-2*\ln(Y)/X\right]^{-1/2} * \left[Y*\ln^2(Y)/X^2 - 1\right] \qquad 21$$

Transferring dX to the right hand side and integrating, gives the final expression for R (both differentiation modes), viz.

$$R = \left[1+-2*\ln(Y)/X\right]^{1/2} * \left[(Y/5)*\ln^2(Y)/X^2+- (2*Y/15)* * (\ln(Y)/X + 1) - 1\right]+C_n \qquad 22$$

The detailed integration of Eq. 21 is given in Appendix A. Eq. 22 is the integral form of R for R ≠ const., and as such is used in this study for calculation of all the variable solidification parameters. In the iterative procedure for the calculation of the parameters, C_n in Eq. 22 is arbitrarily set to zero, which is compensated for by adjusting the constants in Eqs. 10 and 11.

5.3 Computer Aided Calculations of Solidification Parameters

The computation of the odd and even subscripted constant solidification parameters C_o and C_e, and their sums $(C_o+C_e)_{n+1}$ and SC_n, by means of the proposed iterative cycle of the matrix convergence process, as well as the calculation of the variable solidification parameter values R_n, is performed using a computer (Fortran) program. The computer program performs computations of the parameters using the time and temperature input data obtained from the cooling curves. The relative time and temperature data are obtained from the cooling curves as described earlier (section 2.1)

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prior to their introduction into the computer program. A further improvement in the data processing method would include automatic input of the time and temperature data directly from the measuring instrument.

The location and number of points on the cooling curve for which time and temperature data are collected is arbitrarily selected to best represent characteristic segments and features of the cooling curve. The distribution of selected points is chosen as even as possible, though not necessarily evenly spaced. The forward difference mode has been used in computations performed on data collected from the cooling curve segments in the positive time region, i.e., to the right of the origin which is coincidental with the lowest undercooling point, and the backward difference mode has been applied for computations respective to the negative time segments, i.e., to the left of the origin.

The detailed computer program, together with the input data for a typical hypereutectic nodular cast iron cooling curve is given in Appendix B. The comment statements provided in the text render the program self explanatory.

The computer output data for the cooling curves considered in this study are found in Appendix C. They contain the relative time (X_n) and temperature (Y_n) values, the values of variable parameters (R_n), as well as the odd and even subscripted constant parameter values in their expanded and condensed form for every point considered on the curve.

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CHAPTER 6

Correlation of Cooling Curves with Carbon Macrosegregation

The constant (solidification) parameters vs. relative time curves (in either their expanded or condensed form), namely $(C_o+C_e)_{n+1}$ vs. X_n and SC_n vs. X_n, provide valuable information on solidification mechanisms and carbon macrosegregation. In contrast, the identification of carbon macrosegregation from the cooling curve itself is considerably less accurate and often ambiguous. As noted earlier, any small segment of the cooling curve expressed in parameter form is essentially a straight line (c.f. Eqs. 10 and 11). The magnitude of every particular $(C_o+C_e)_{n+1}$ value is dependent on all relative logarithmic temperature values ($\ln(Y_o)$, ..., $\ln(Y_n)$), as well as on all the variable parameter values (R_o+-1,...,R_n+-1) determined by the iterative procedure described earlier (c.f., 5.2.3 and Appendix A).. The (R_{n+-1}) values are the slopes for the straight lines, Eqs. 10 and 11, and are related to the changes in cooling rates. The constant (solidification) parameters $(C_o+C_e)_{n+1}$ and SC_n are obtained from the intercepts of the straight lines (Eqs. 10 and 11), and as such are related to the temperatures of specific events occurring during solidification of the ingot.

6.1 Carbon Macrosegragation in Mild Hypereutectic Compositions

Carbon macrosegregation has not been detected in significant amounts in nodular cast irons below a carbon equivalent of approximately 4.6%, and this chemistry effect

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will be important in correlating the cooling curve characteristics to the degree of carbon macrosegregation (17,18,24). To illustrate the method by which the segments of cooling curves are interpreted using the values of the parameters obtained, the cooling curves for ingots 2, 22 and 9 are given in Figures 4(a) to 4(c) and analyzed. The array of $(C_o+C_e)_{n+1}$ values for each cooling curve, obtained from the computer output data given in Appendix C, are also plotted against relative times (X_n) for comparison.

The $(C_o+C_e)_{n+1}$ vs. relative time curve (the subscript number is indicative of the point at which relative time and temperature data are collected) for ingot 2 has the relative maximum at X_n = +28 sec., situated between the relative minimum at X_n = +32.5 sec. and the relative minimum at X_n = +18 sec.. Positive times denote solidification events taking place before maximum undercooling is reached. The $(C_o+C_e)_{n+1}$ curve for ingot 22 has similar but less distinctive features, with the relative maximum at X_n = +16.5 sec. between the relative minima at X_n = +20.5 sec. and X_n = +12 sec. Ingot 22 has a smaller relative maximum value than ingot 2, and the distance between its two relative minima is also less. The $(C_o+C_e)_{n+1}$ curve for ingot 9 does not show any distinctive maximum to the right of the maximum undercooling point, and both minima have merged into a single minimum point at X_n = +10 sec.

The positions and the magnitudes of the relative maxima and the minima of the $(C_o+C_e)_{n+1}$ vs. relative time

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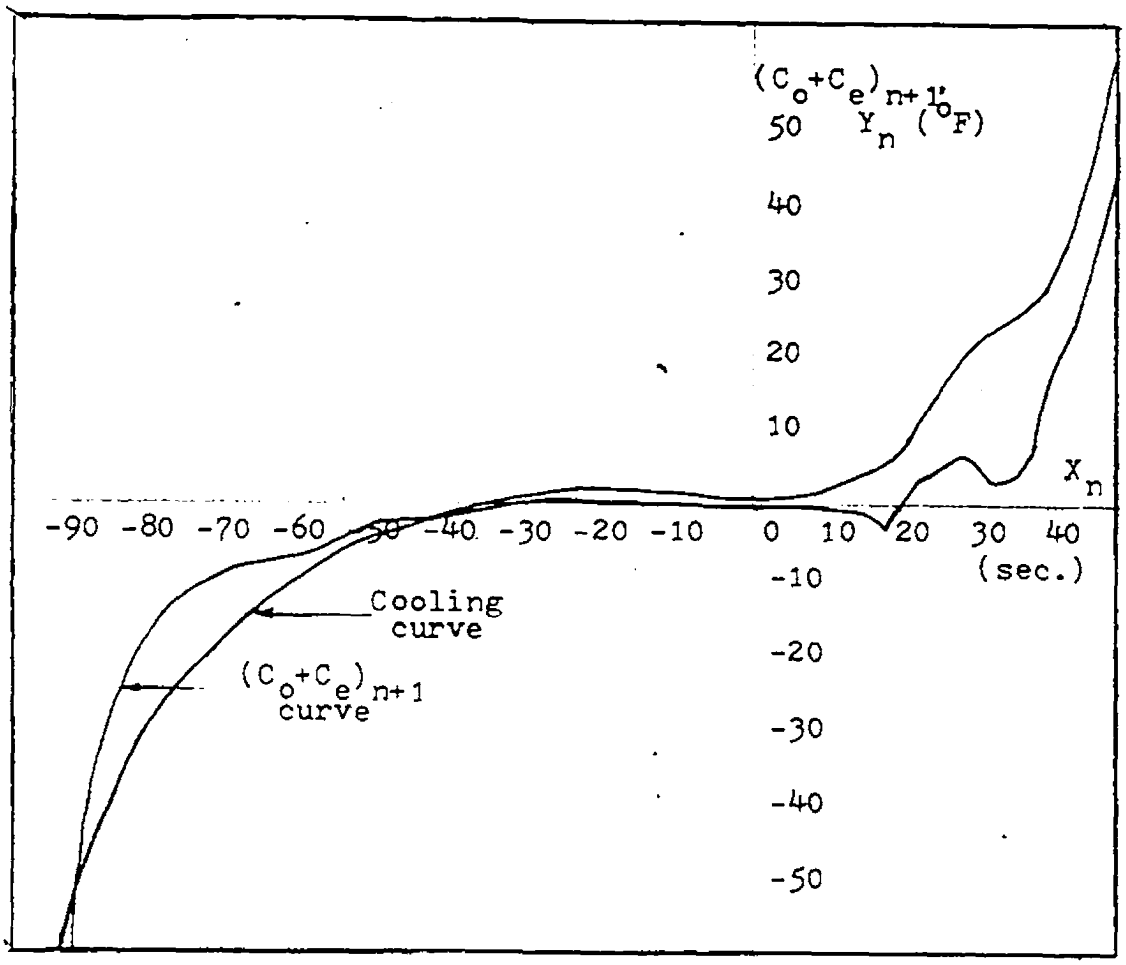

Metal Chemistry		
C	3.54	%
Si	3.02	%
C.E.	4.55	%
Mn	0.66	%
Cr	0.12	%
Cu	0.10	%
Al	0.020	%
Mg	0.055	%
S	0.009	%

Figure 4(a) Cooling curve, $(C_o+C_e)_{n+1}$ curve, and chemistry for mild hypereutectic nodular cast iron; sample ingot 2.

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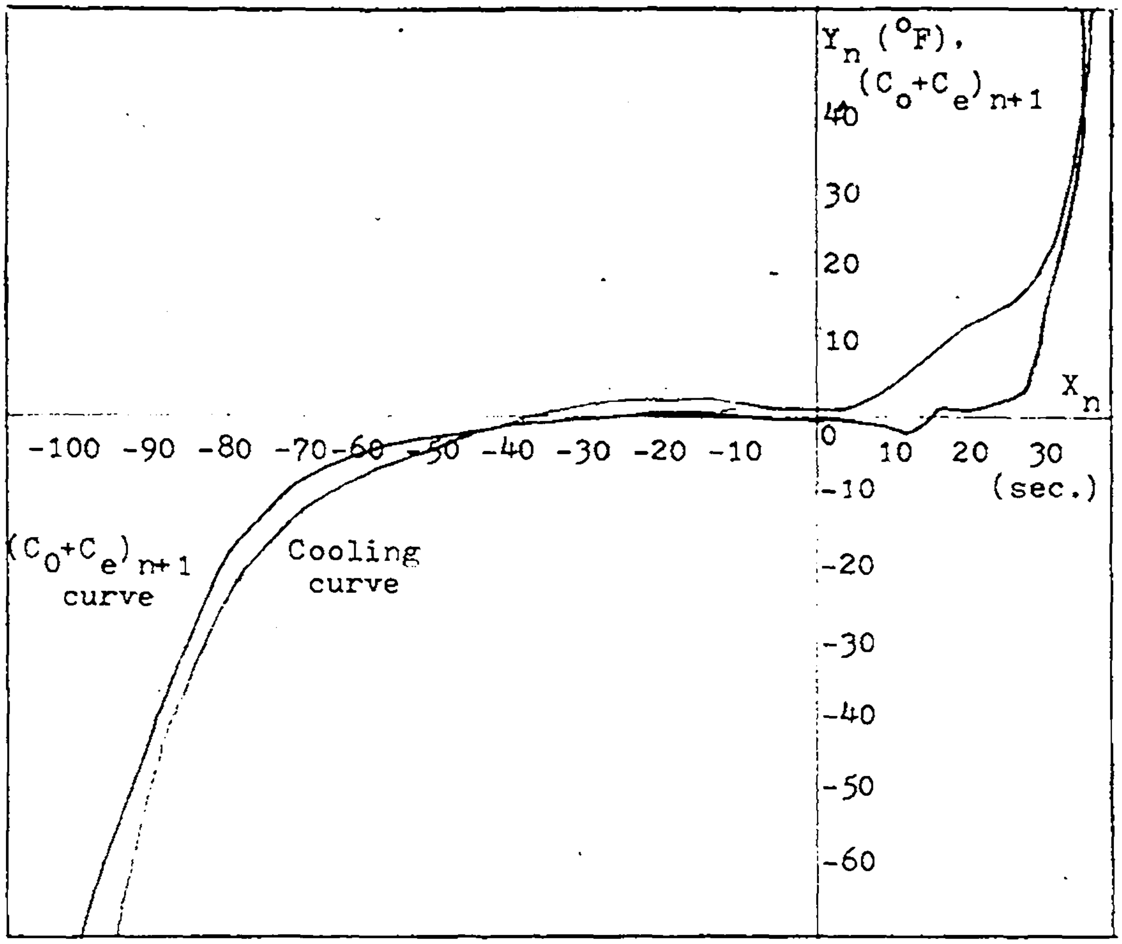

Metal Chemistry		
C	3.77	%
Si	2.47	%
C.E.	4.59	%
Mn	0.62	%
Cr	0.15	%
Cu	0.09	%
Al	0.020	%
Mg	0.036	%
S	0.008	%

Figure 4(b) Cooling curve, $(C_o+C_e)_{n+1}$ curve, and chemistry for mild hypereutectic nodular cast iron; sample ingot 22.

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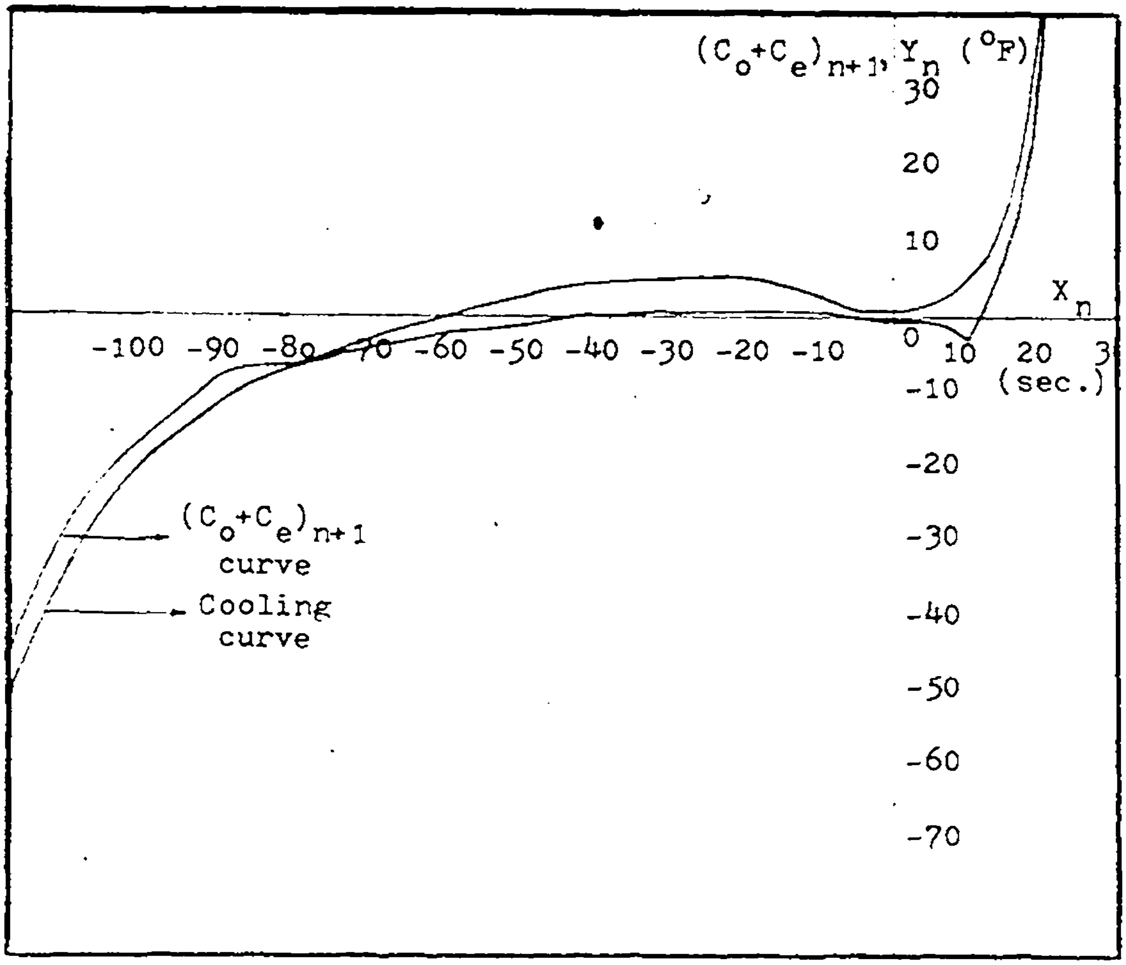

Metal Chemistry		
C	3.77	%
Si	2.35	%
C.E.	4.55	%
Mn	0.65	%
Cr	0.12	%
Cu	0.12	%
Al	0.023	%
Mg	0.036	%
S	0.007	%

Figure 4(c) Cooling curve, $(C_o+C_e)_{n+1}$ curve, and chemistry for mild hypereutectic nodular cast iron; sample ingot 9.

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curves are functions of both metal composition and solidification mode. The start of proeutectic graphite nucleation and growth of austenite (pendulum effect (15)) coincides approximately with the appearance of the first minimum in the $(C_o+C_e)_{n+1}$ curve. The relative maximum is the recalescence resulting from the latent heat released on the nucleation and initial growth of the austenite. The precipitation of proeutectic graphite would not in itself liberate sufficient heat for the observed recalescence (18) corresponding to the first relative maximum in the $(C_o+C_e)_{n+1}$ curve. The start of bulk eutectic solidification is approximately coincident with the second minimum for the $(C_o+C_e)_{n+1}$ curve, which precedes the second relative or plateau of the $(C_o+C_e)_{n+1}$ curve (or the single recalescence in the cooling curve itself in the negative time region). Thus it is evident that recasting the cooling curves according to the $(C_o+C_e)_{n+1}$ values has the effect of accentuating the significant solidification events (e.g., undercooling and recalescence) not sufficiently evident from the cooling curves themselves.

It is important to note that melts with quite similar chemistries (and having only moderately different cooling curves) can show significantly different $(C_o+C_e)_{n+1}$ curves (c.f., ingots 22 and 9). This indicates that other factors beside composition determine the solidification mode. If the solidification mode includes a very gradual initial eutectic solidification, then there will not be a distinct maximum in the positive time region (to the right of the

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maximum undercooling point) of the $(C_o+C_e)_{n+1}$ curve. This is evident from the $(C_o+C_e)_{n+1}$ curve (and to a lesser extent from the cooling curve) for ingot 9. The absence of a relative maximum and the first minimum suggests a rather slow initial solidification rate, and this promotes carbon macro-segregation since the proeutectic graphite nodules are free for a longer period of time to grow, combine, and then rise to the surface. This will favor fewer but larger nodules and more clustering. On the other hand, the presence of the relative maximum and double minima for the $(C_o+C_e)_{n+1}$ curve for ingot 22 , and particularly for ingot 2 , indicates a fast initial solidification rate, resulting in an increased number of graphite nodules of generally smaller size (18). The microstructures shown in Figure 5 are in agreement with the above hypothesis.

The differences in the $(C_o+C_e)_{n+1}$ curves for ingots 9 and 22 indicate that other processing variables (perhaps trace amounts of some tramp elements) in addition to carbon equivalent are the determining factors in the solidification process. This is particularly important when dealing with border line compositions such as near-eutectic or mild hypereutectic compositions (e.g., ingots 2, 22 and 9). These factors are not easily identified, although they greatly affect the solidification mechanism. The advantage of the present method of thermal analysis is that the shape of the $(C_o+C_e)_{n+1}$ curve, when correctly interpreted, characterizes the mode of solidification, from which the degree of carbon macrosegregation can be inferred. The predictions

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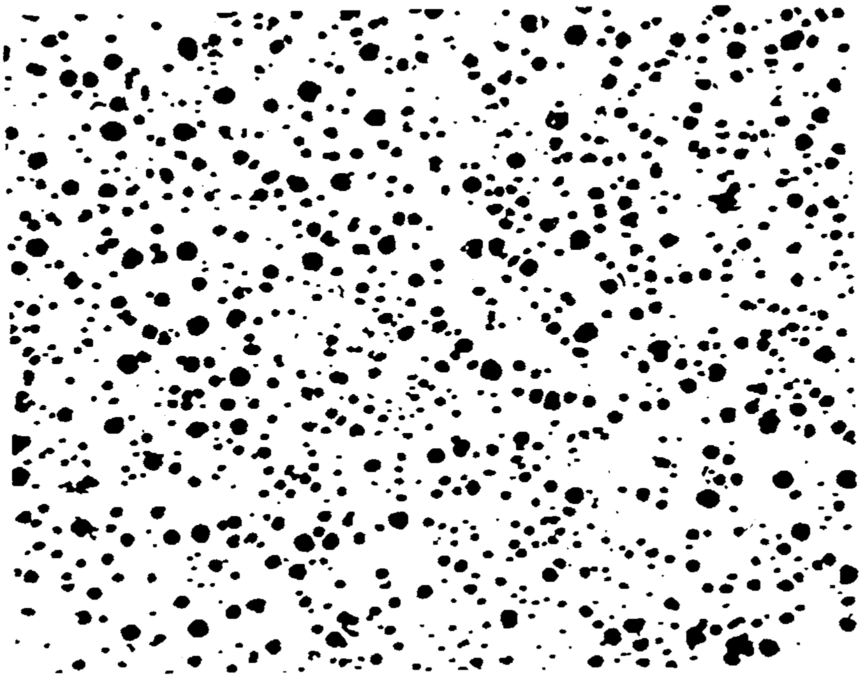

Figure 5(a) Unetched microstructure of ingot 2, (50x).

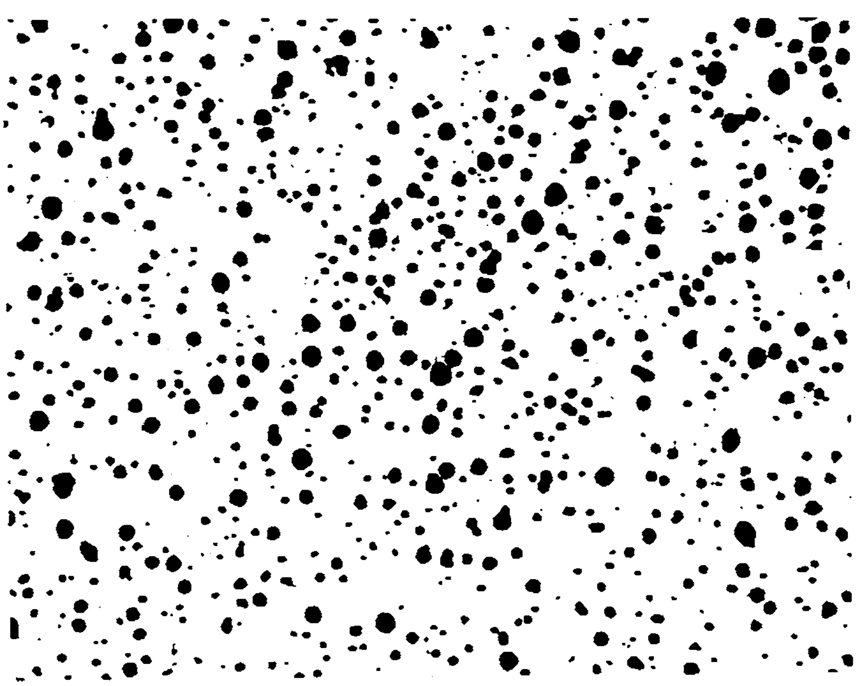

Figure 5(b) Unetched microstructure of ingot 22, (50x).

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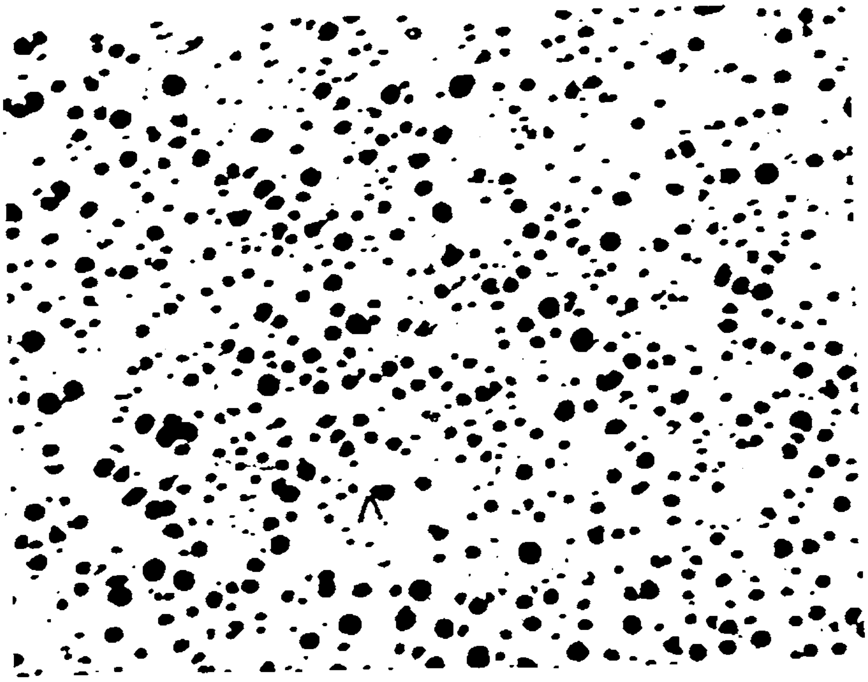

Figure 5(c) Unetched microstructure of ingot 9, (50x).

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are based not only on one aspect, i.e., the temperature read from the cooling curve, but incorporate the effects of all the processing variables, including metal chemistry, since all of these affect the shape of $(C_o+C_e)_{n+1}$ curve, and are more effectively included in the $(C_o+C_e)_{n+1}$ curve compared to the simple cooling curve by the very process of its synthesis.

It is interesting at this point to consider ingot 42, which has the carbon equivalent approximately that of ingots 9 and 22, but a significant difference in the actual carbon and silicon contents. The cooling and $(C_o+C_e)_{n+1}$ curves for ingot 42 along with metal chemistry are given in Figure 6. There is only one distinctive minimum on the $(C_o+C_e)_{n+1}$ curve in the domain of the positive time values for ingot 42, which indicates a slow start of the bulk eutectic solidification. This can be corroborated from the microstructure of ingot 42 shown in Figure 7, viz. the presence of a greater number of much larger nodules than in the two former cases is evident. The location of the relative minimum for ingot 42 is at X_n = +26 sec., while the minimum for ingot 9 is at X_n = +10 sec., which may be taken as further evidence that bulk eutectic solidification is slower in ingot 42 relative to ingot 9, thus giving more time for the proeutectic graphite nodules to grow and cluster. In the above analysis, the implication is that the eutectic solidification has commenced before the second maximum or plateau in the $(C_o+C_e)_{n+1}$ curve has occurred, and perhaps even before the maximum undercooling temperature

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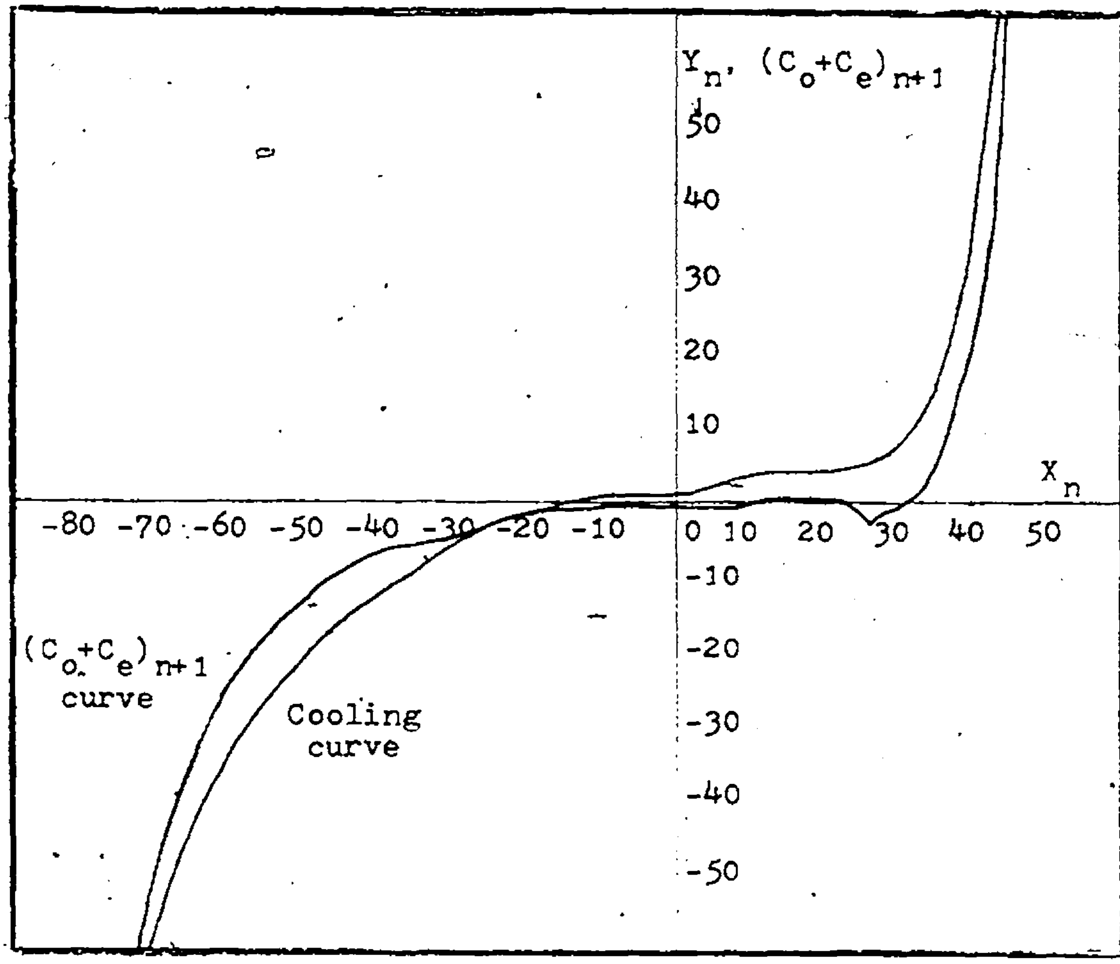

Metal Chemistry		
C	3.68	%
Si	3.02	%
C.E.	4.59	%
Mn	0.70	%
Cr	0.12	%
Cu	0.13	%
Al	0.020	%
Mg	0.050	%
S	0.007	%

Figure 6 Cooling curve, $(C_o+C_e)_{n+1}$ curve, and metal chemistry for near-eutectic nodular cast iron; sample ingot 42.

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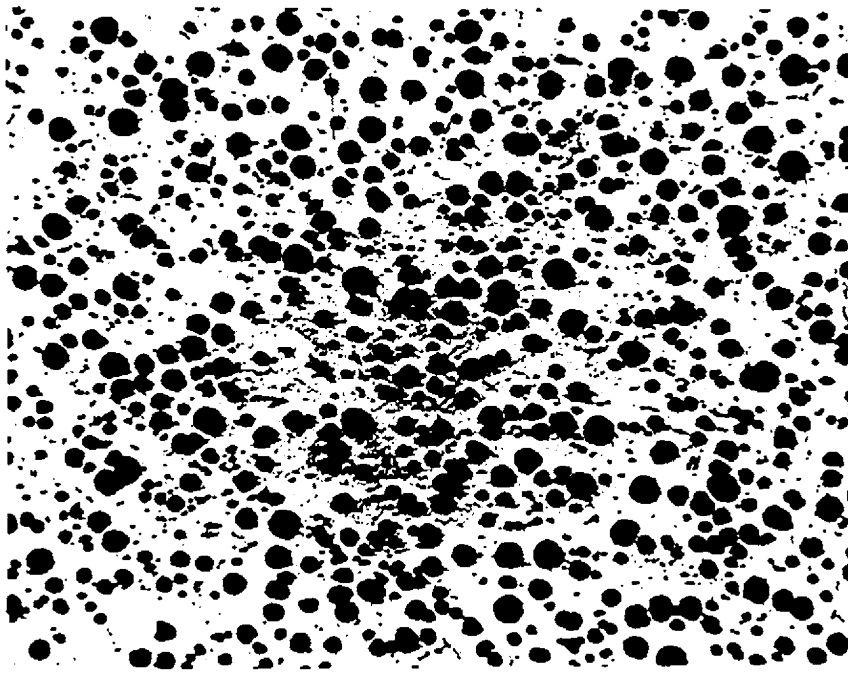

Figure 7 Unetched microstructure of ingot 42, (50x).

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was reached, because recalescence will occur only after the solidification rate and consequent release of latent heat is sufficiently fast to overcome the imposed rate of heat withdrawal.

It is to be expected that the incidence of carbon macrosegregation and flotation will be more pronounced in irons in which proeutectic precipitation of graphite occurs, and this is found to be the case in ingots 9 and 42. For irons showing predominantly early eutectic solidification, carbon macrosegregation is expected to be minimal. The incidence of carbon macrosegregation and ultimately carbon flotation is the greatest in strong hypereutectic compositions, all showing single minima to the right of the origin on the $(C_o+C_e)_{n+1}$ curves. Accordingly, further discussions of carbon macrosegregation in relation to the solidification parameters will be directed to these irons.

6.2 Carbon Macrosegregation in Hypereutectic Compositions

The precipitation of proetuctic nodular graphite preceding bulk eutectic solidification becomes more pronounced with increasing carbon equivalent (and thus time available) before the start of bulk eutectic precipitation. After the onset of eutectic solidification the proeutectic nodules tend to be trapped by the dendrites of the growing eutectic crystals. The degree of restriction of nodule movement, and thus the extent of carbon macrosegregation, is therefore also dependent on the rate of eutectic crystal growth, and a prolonged eutectic solidification stage increases the chances of nodule flotation.

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The effect of the eutectic solidification rate on carbon macrosegregation is evident in the cooling curves for ingots 4 and 38. The different carbon macrosegregation degrees, as evident from the significantly greater number of clusters for ingot 38 compared to ingot 4 (cf. Figure 9), cannot be attributed to the very small difference in their metal chemistries (c.f. Figure 8).

The SC_n curves obtained by plotting the values of SC_n (solidification parameter obtained according to Eq. 11) versus relative times (corresponding to the successive subscript numbers for the temperature and time data) are shown in Figure 8. The significance of the SC_n values, representing the summation of all the $(C_o+C_e)_{n+1}$ values for the points selected to define the curve segment (c.f. Eqs. 10 and 11), gives an integrated and therefore more comprehensive (numerical) characterization of the solidification event at each point in time. Again, as with the $(C_o+C_e)_{n+1}$ curves, the SC_n curves further amplify solidification events such as undercooling and recalescence, particularly in the negative time regions corresponding to the bulk eutectic solidification stage.

It is evident from Figure 8 that the start of eutectic solidification is coincidental with the appearance of the maximum on SC_n curve in the positive time region, and that the bulk of eutectic solidification is carried to the left of the origin in the negative time region. As far as ingots 4 and 38 are concerned, the undercooling is considerably

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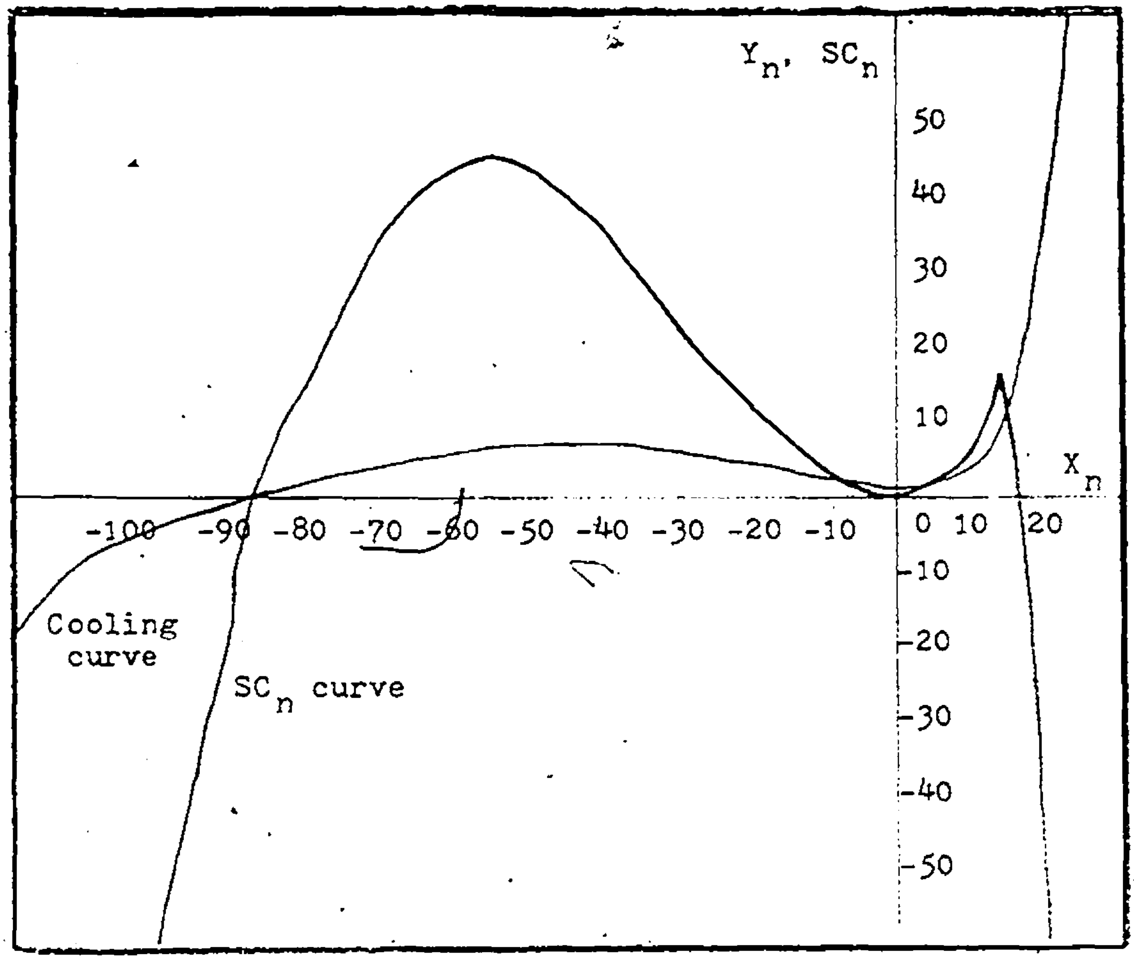

Metal Chemistry		
C	3.92	%
Si	2.53	%
C.E.	4.76	%
Mn	0.76	%
Cr	0.14	%
Cu	0.13	%
Al	0.022	%
Mg	0.034	%
S	0.008	%

Figure 8(a) Cooling curve, SC_n curve, and metal chemistry for hypereutectic nodular cast iron; sample ingot 4.

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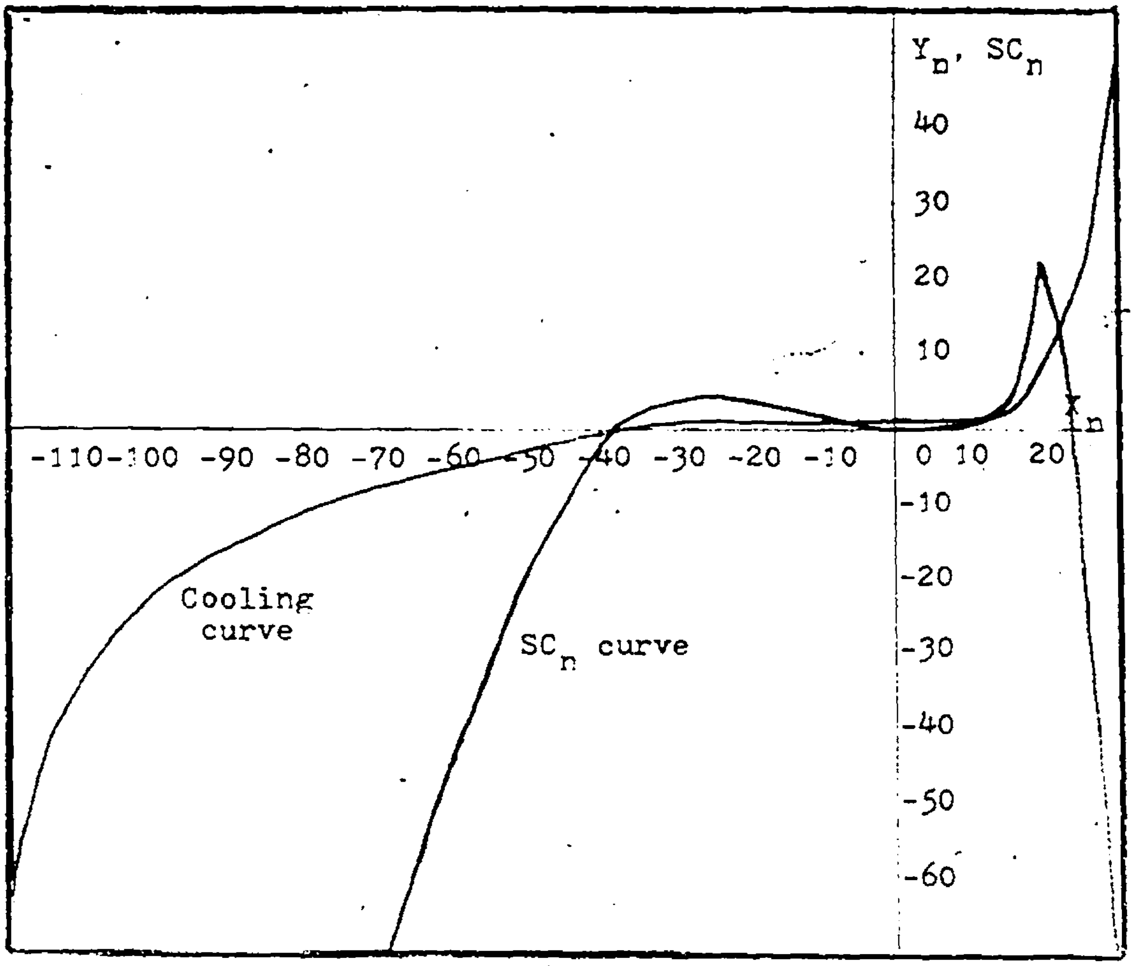

Metal Chemistry		
C	3.98	%
Si	2.32	%
C.E.	4.75	%
Mn	0.60	%
Cr	0.10	%
Cu	0.05	%
Al	0.015	%
Mg	0.023	%
S	0.004	%

Figure 8(b) Cooling curve, SC_n curve, and metal chemistry for hypereutectic nodular cast iron; sample ingot 38.

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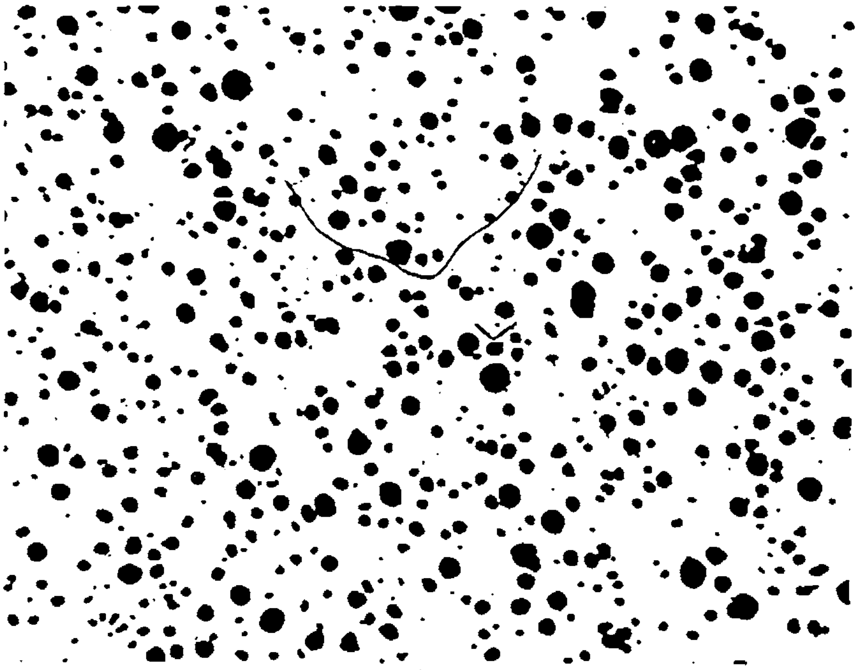

Figure 9(a) Unetched microstructure of ingot 4, (50x).

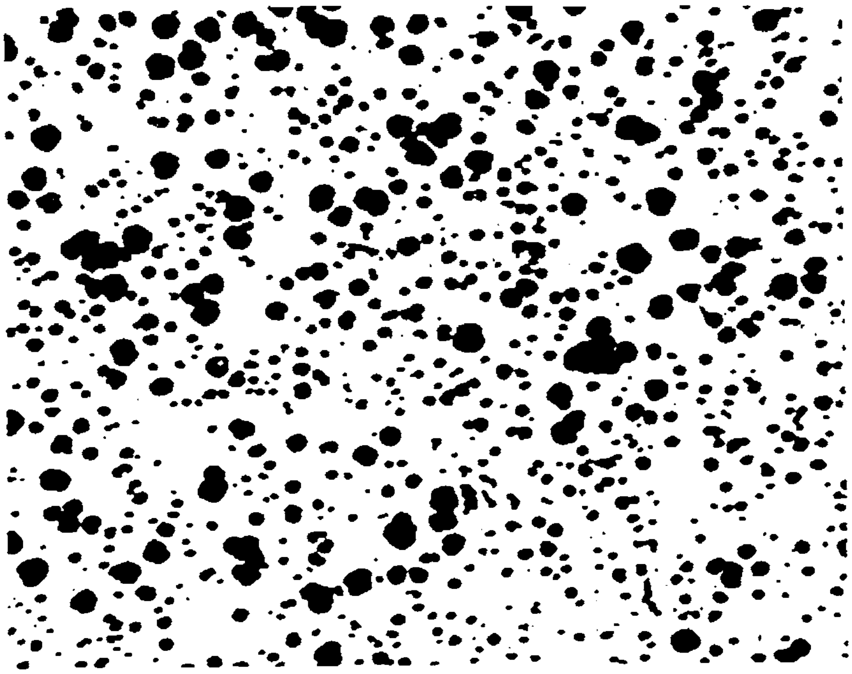

Figure 9(b) Unetched microstructure of ingot 38, (50x).

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greater for ingot 4 than for ingot 38. The rate of recalescence after the lowest undercooling point has been reached is also much faster for ingot 4. These two phenomena are much more evident from the SC_n curves than from the original cooling curves. The SC_n curve for ingot 38 suggests rather gradual and relatively slow bulk eutectic solidification process compared to ingot 4. Consequently, a higher carbon macrosegregation tendency is expected for ingot 38 compared to ingot 4. The micrographs given in Figure 9 show this to be the case, with ingot 38 showing significantly more graphite nodule clusters than does ingot 4.

Eq. 11, on dividing by X_n, becomes:

$$SC_n/X_n = -+(R_n+-1) + \ln(Y_n)/X_n \qquad 23$$

The left hand side is related to the relative solidification rate (R+-1), so that SC_n is related to the increment in the amount of eutectic solidified at any given time. In Table 1, the values for relative time (X_n), logarithms of relative temperature (Y_n), $\ln(Y_n)/X_n$, slope (R_n+1), increment in relative amount solidified (SC_n), and relative solidification rate (SC_n/X_n) are compared for both ingots 4 and 38. It is noteworthy that relative solidification rates, represented by Eq. 23, in both cases peak before the maximum value for SC_n is reached, which is a consequence of the delayed heat transfer to the surroundings during solidification of the sample ingot.

In the context of the above interpretation of the SC_n

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curve, SC_n/X_n values in the negative time region can be considered as the relative rates of bulk eutectic formation. It is expected that the rate values will vary during the solidification process, as indeed it can be demonstrated from the data given in Table 1. If for simplification only the maximum value for SC_n in relation to the time of its occurrence X_n is considered, the relative maximum value $(SC_n/X_n)_{max}$ for ingot 4 is 0.8451, while for ingot 38 is 0.1559. These relative maximum values indicate the faster solidification rates for ingot 4, and are in agreement with the above interpretations of the significance of the parameter SC_n.

In considering the relative eutectic (bulk) solidification rate and the relative amount of etuectic formed, it is important to emphasize that the numerical values obtained are based on arbitrarily choosing zero for their values at the points $X_n = 0$ and $Y_n = 1$ for convenience. In fact, some eutectic solidification has probably already occurred, but insufficient in rate for the latent heat release to overcome the imposed cooling rate. If the beginning and/or the end of eutectic solidification were more precisely determined, the translation of the axes from their original positions would correct for this difference.

The total amount of the eutectic formed in irons having virtually identical compositions must be approximately the same, so that the slower initial rate of eutectic formation for ingot 38 must be made up in later stages of the solidification process. This is evident from levelling of

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Table 1

Ingot Solidification Parameters
During Earlier Stages of Solidification for Ingots 4 and 38

X_n	$\ln(Y_n)$		$\ln(Y_n)/X_n$		R_n+1		SC_n		SC_n/X_n	
sec	Ingot 4	Ingot 38	Ingot 4	Ingot 38	Ingot 4	Ingot 38	Ingot 4	Ingot 38	Ingot 4	Ingot 38
-10	0.7929	+0.0728	-0.0793	-0.0073	0.2186	+0.1361	3.6809	+2.0282	-0.3681	-0.2028
-20	1.4355	-0.0061	-0.0718	+0.0003	0.4914	+0.1328	11.9648	+3.3524	-0.5982	-0.1676
-26	1.6176	-0.0337	-0.0622	+0.0013	0.6121	+0.1302	18.2338	+4.0546*	-0.7013	-0.1559
-30	1.6903	-0.4436	-0.0563	+0.0148	0.6683	+0.1005	22.4399	+3.2727	-0.7480	-0.1091
-40	1.8673	+0.5523	-0.0467	-0.0138	0.8174	-0.0905	35.2638	-2.3637	-0.8816	+0.0591
-50	1.8578		-0.0372		0.8338		43.4696		-0.8694	
-54	1.8053		-0.0334		0.7781		44.5240*		-0.8245	
-60	1.6708		-0.0278		0.6814		43.2560		-0.7209	
-70	1.2976		-0.0185		0.4697		34.8773		-0.4982	

* denotes the maximum point in the negative time region on SC_n curve.

the cooling curve for ingot 38 immediately past the maximum. The small temperature drop through this straight portion indicates that eutectic solidification, after a rather slow start, has gained momentum. The increased solidification rate at this stage decreases nodule flotation; however, the slow initial start of bulk eutectic solidification gives a net increase and carbon macrosegregation relative to ingot 4.

In Table 2 the relative time X_n, relative temperature Y_n, slope R_n+1, and SC_n/X_n values for ingots 4 and 38 are compared to show the difference in rate of the relative amounts solidified during the later stages of eutectic solidification. The time span between $R_n+1=0$ and $R_n+1=-1$ for ingot 4 is 23 sec. During this time period SC_n/X_n has increased from 0 to 1. For ingot 38 the drop of R_n+1 from 0 to -1 requires 32 sec. In this same time period SC_n/X_n has increased from 0 to +1. For R_n+1 to decrease from -1 to -2 requires approximately 10 sec. for ingot 4, during which SC_n/X_n has increased from 1 to 2. For ingot 38 the drop in R_n+1 requires approximately 18 sec., during which SC_n/X_n has also increased by one unit. It is evident from these figures that for an equal drop in either one of the parameters, the times involved for ingot 38 exceed those required for ingot 4 by 60% or more, showing that longer solidification times for ingot 38 result from the slower rates of eutectic solidification.

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Table 2

Ingot Solidification Parameters
During Latter Stages of Solidification
for Ingots 4 and 38

X_n	Y_n		R_n+1		SC_n/X_n	
sec	Ingot 4	Ingot 38	Ingot 4	Ingot 38	Ingot 4	Ingot 38
- 38		0.00		0.0000		0.0000
- 46		- 2.21		-0.2779		0.2799
- 52		- 3.57		-0.4507		0.4616
- 60		- 5.66		-0.7250		0.7422
- 70		- 7.95		-1.0304		1.0500
- 78		-10.56		-1.3769		1.3982
- 85	0.00	-13.65	0.0000	-1.7730	0.0000	1.8109
- 90	- 1.51	-16.08	-0.1965	-2.1124	0.1933	2.1355
- 98	- 3.92	-20.26	-0.5095	-2.6695	0.5150	2.6930
-104	- 5.84	-24.05	-0.7611	-3.1749	0.7713	3.1987
-108	- 7.76	-26.88	-1.0154	-3.8183	1.0278	3.8429
-110	- 9.00	-38.17	-1.1798	-4.2568	1.1934	4.2820
-118	-15.66		-2.0644		2.0817	
-122	-19.52		-2.5780		2.5666	
-125	-23.20		-3.0102		3.0886	
-130	-31.17		-4.1288		4.1498	

CHAPTER 7

Discussion

The dependence of carbon macrosegregation on carbon equivalent has already been emphasized. It was also shown that nodular cast irons exhibiting close metal chemistries can also assume different solidification mechanisms, and thus manifest different carbon macrosegregation tendencies. In the following the different degrees of carbon macrosegregation tendency, as determined from microstructures observed in samples of similar compositions (carbon equivalents), will be compared against the values of the respective solidification parameters. The solidification parameters considered are the relative maximum rate of eutectic solidification $(SC_n/X_n)_{max}$, the relative maximum (incremental) amount of eutectic formation $(SC_n)_{max}$, and the slope $(R_n+1)_{max}$ of the straight line which represents the temperature vs. time relation (c.f. Eqs. 11 and 23) at the time of its occurrence $(X_n)_{max}$.

7.1 Relationship of Solidification Parameters to Carbon Macrosegregation

In Table 3 samples are arranged in decreasing order of their values for $(SC_n/X_n)_{max}$. The increase in the size and number of the larger nodules with the decrease in the numerical values of solidification parameters is evident from Figure 10, and is in agreement with the previously given interpretation, viz., that a decrease in $(SC_n/X_n)_{max}$ and $(SC_n)_{max}$ values corresponds to a decrease in the relative rate of eutectic formation, which increases the time for graphite precipitation

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Table 3

Ingot Solidification Parameters

(Carbon equivalent: 4.61-4.65%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)_{max}$	$(SC_n/X_n)_{max}$
7	3.77	2.64	4.65	-54	1.5367	86.1575	-1.5955
41	3.76	2.60	4.63	-78	1.0583	[illegible]2.6505	-0.9314
1	3.84	2.32	4.61	-40	0.8457	36.4317	-0.9108
39	3.80	2.50	4.63	-54	0.2862	16.9677	-0.3142

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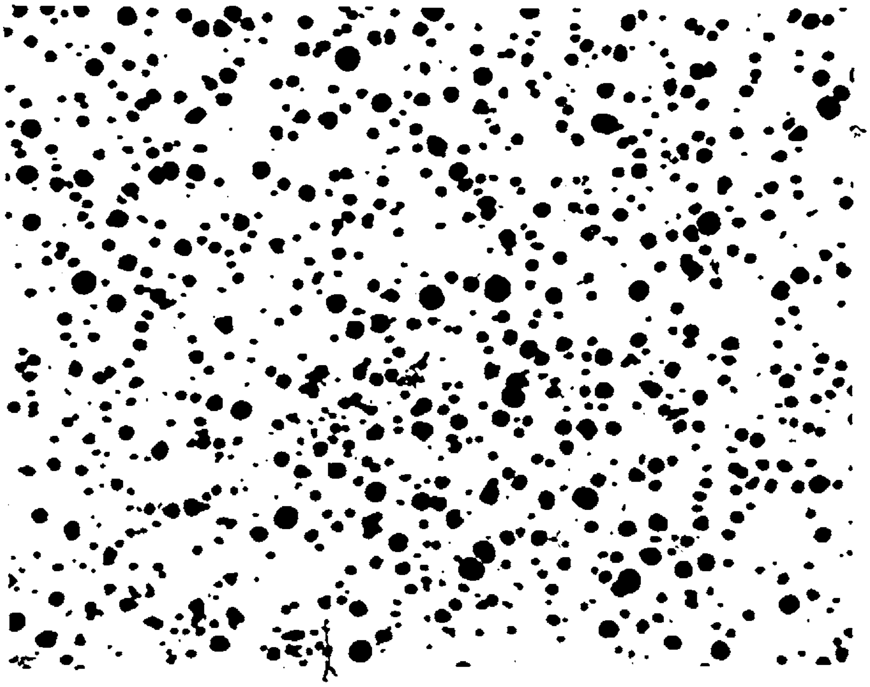

Figure 10(a) Unetched microstructure of ingot 7, (50x).

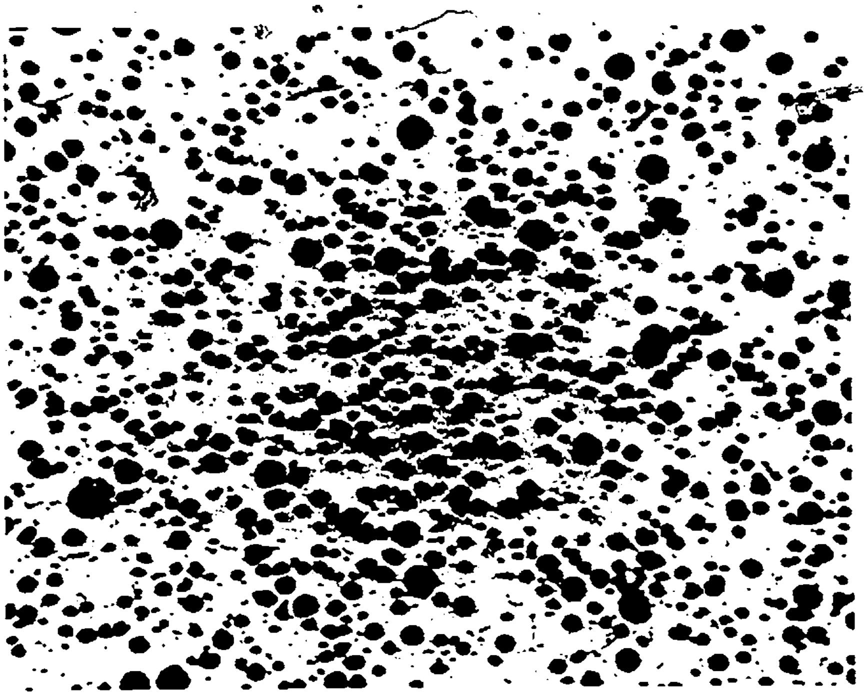

Figure 10(b) Unetched microstructure of ingot 41, (50x).

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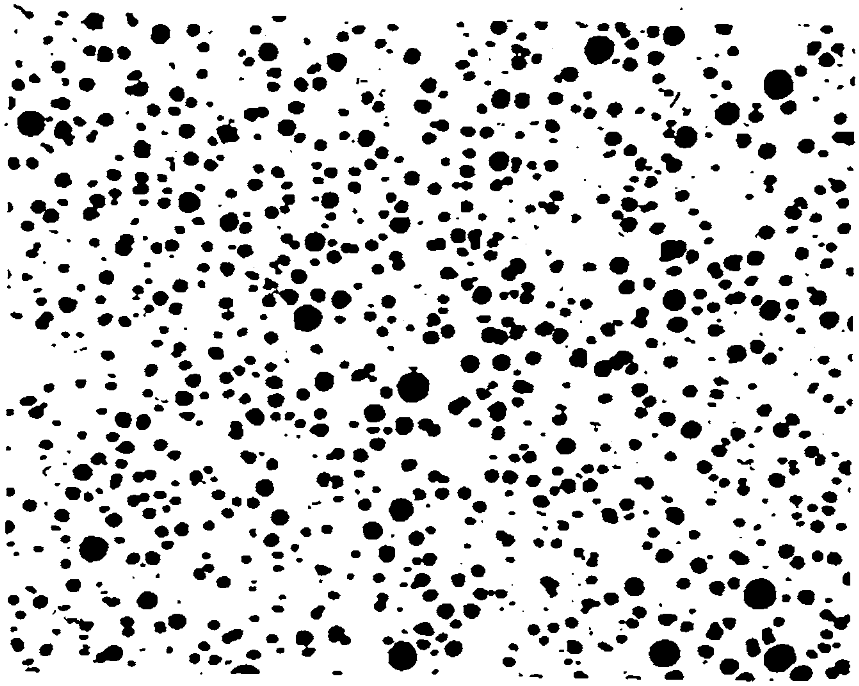

Figure 10(c) Unetched microstructure of ingot 1, (50x).

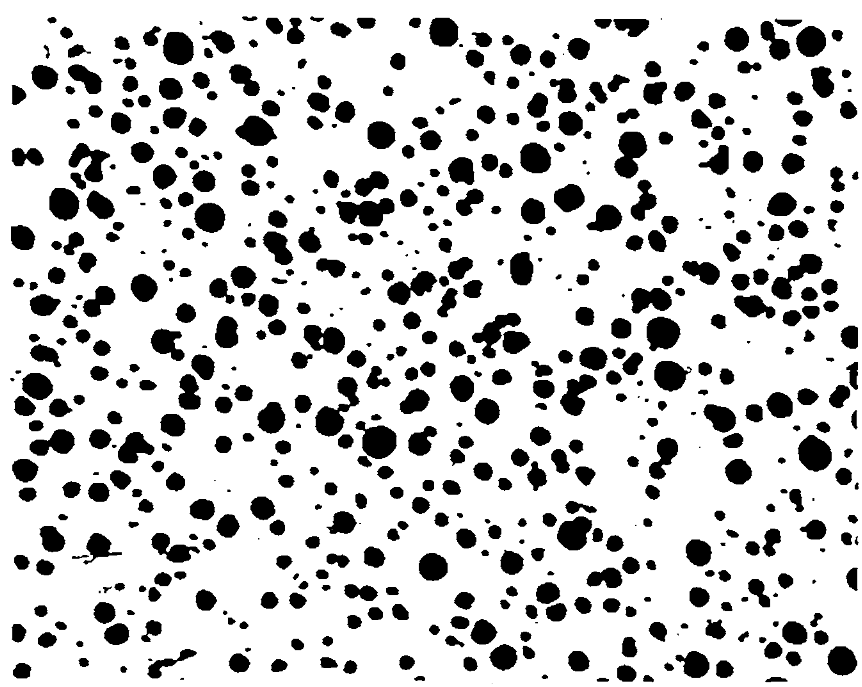

Figure 10(d) Unetched microstructure of ingot 39, (50x).

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and nodule growth. However, due to the size of sample ingot and low carbon equivalent levels, nodule clusters did not form. The presence of large number of smaller nodules in ingot 7, and particularly in ingots 1 and 41, is consistent with their relatively high solidification rates (compared to ingot 39). The similarity in their microstructures is also suggested by the relatively small difference in $(R_n+1)_{max}$ and $(SC_n/X_n)_{max}$ values for ingots 1 and 41. The higher nodule count in these ingots can be attributed to the faster rate of graphite nodule formation during the eutectic solidification stage, since the nucleation rate of the graphite phase is generally taken to be the rate controlling factor of the eutectic solidification process (4,15). In contrast to ingots 1 and 41, the eutectic solidification rate for ingot 39 is considerably slower as indicated by considerably smaller values of solidification parameters. The lower nodular count and larger nodule size is in agreement with the slower nucleation rate of graphite nodules.

The observations and conclusions made regarding the ingots in Table 3 can be applied to the ingots in Table 4, with the exception of ingot 33, which exhibits vermicular graphite forms. The ingots in Table 4 have higher carbon equivalents and smaller solidification parameter values suggesting a higher tendency for nodule clustering. The increased carbon macrosegregation tendency is evident in the nodule clusters that are observed. The microstructure of ingot 38, which is shown in Figure 9b, has the greatest

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Table 4

Ingot Solidification Parameters

(Carbon equivalent: 4.74-4.76%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)_{max}$	$(SC_n/X_n)_{max}$
4	3.92	2.53	4.76	-54	0.7781	44.5240	-0.8245
23	3.94	2.40	4.74	-28	0.5935	18.9001	-0.6750
33	3.89	2.58	4.75	-26	0.4470	13.6348	-0.5244
38	3.96	2.32	4.75	-26	0.1302	4.0546	-0.1559

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number of clusters, and correspondingly the smallest values of solidification parameters. The microstructure of ingot 4 is shown in Figure 9(b), and the microstructure of ingots 23 and 33 are shown in Figure 11. The degree of nodule clustering evident from these micrographs is in agreement with the values of solidification parameters and the above hypothesis regarding their interpretation.

The set of ingots in Table 5 with their respective microstructures shown in Figure 12 are yet another example of the increase of carbon macrosegregation with the decrease in solidification parameters values. The number and size of clusters are inversely proportional to the values of solidification parameters, as evident from the corresponding microstructures.

7.2 Effect of Increasing Carbon Equivalent

In Table 6 and Figure 13 the solidification parameters and corresponding microstructures are shown for a series of nodular cast irons having still higher carbon equivalents (4.81 - 4.90%). Again, the increase in carbon macrosegregation with decrease in solidification parameter values is clearly evident. The increased carbon equivalent levels, compared to the set of ingots in Table 5, results in a higher nodule density and general decrease in nodule size. Also, the generally lower values of solidification parameters due to the higher carbon equivalent levels, and thus far more gradual eutectic solidification rates, are consistent with the greater incidence of carbon macrosegregation in

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Table 5

Ingot Solidification Parameters

(Carbon equivalent: 4.68-4.74%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)_{max}$	$(SC_n/X_n)_{max}$
17	3.96	2.17	4.68	-30	0.8671	28.6539	-0.9551
32	4.02	2.13	4.74	-26	0.5380	16.1821	-0.6224
27	4.00	2.18	4.73	-32	0.5058	18.2996	-0.5719

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Table 6

Ingot Solidification Parameters

(Carbon equivalent: 4.81~4.90%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)_{max}$	$(SC_n/X_n)_{max}$
18	3.98	2.48	4.81	-22	0.7752	19.6219	-0.8910
30	4.00	2.49	4.83	-30	0.5755	19.5107	-0.6514
36	4.04	2.52	4.88	-24	0.4813	12.1353	-0.5056
35	4.01	2.67	4.90	-24	0.3057	8.9848	-0.3744
25	4.02	2.43	4.83	-38	0.1333	5.7686	-0.1518
13	4.07	2.28	4.83	-20	0.4981	12.1086	-0.6054

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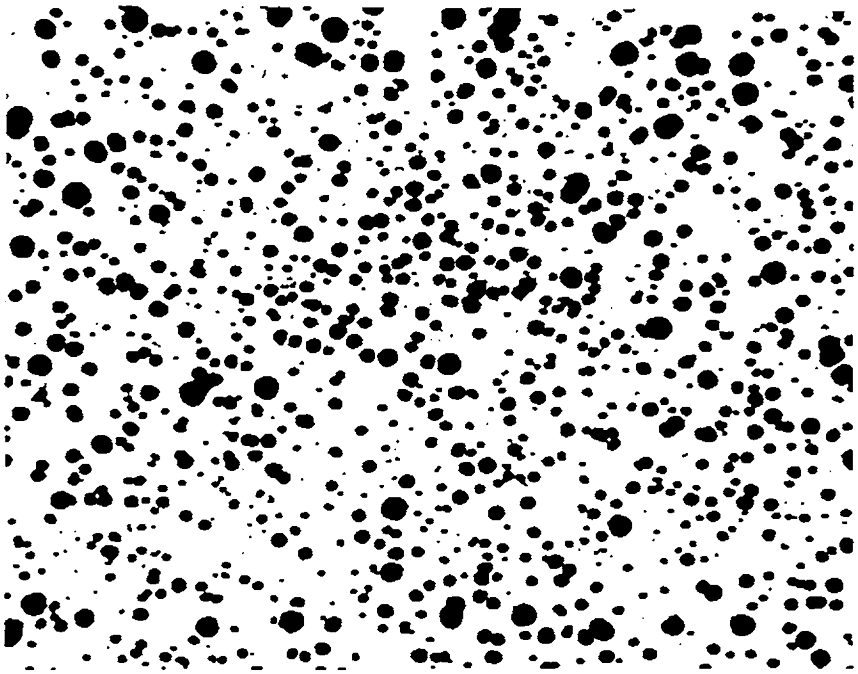

Figure 11(a) Unetched microstructure of ingot 23, (50x)

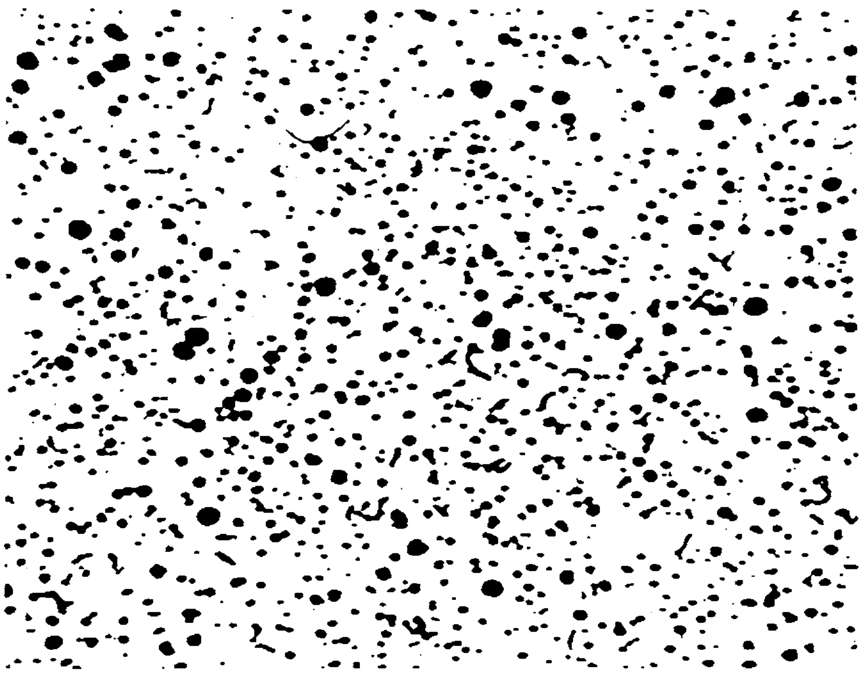

Figure 11(b) Unetched microstructure of ingot 33, (50x).

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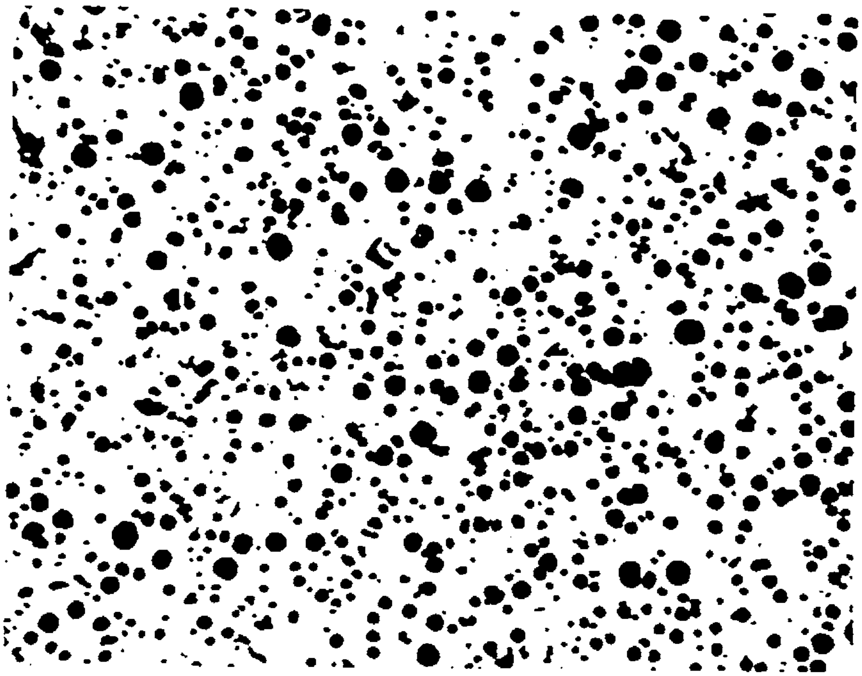

Figure 12(a) Unetched microstructure of ingot 17, (50x).

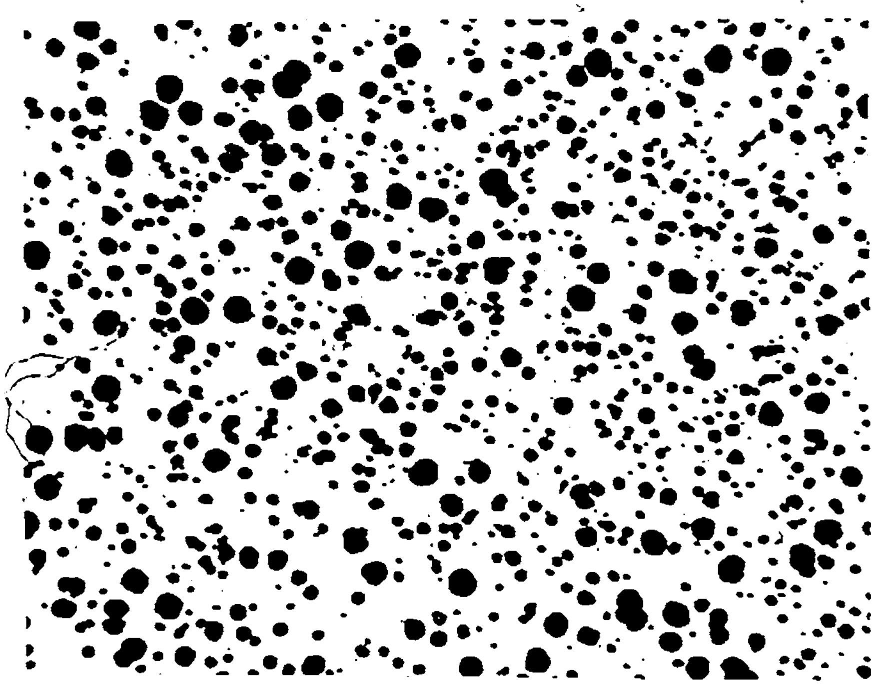

Figure 12(b) Unetched microstructure of ingot 32, (50x).

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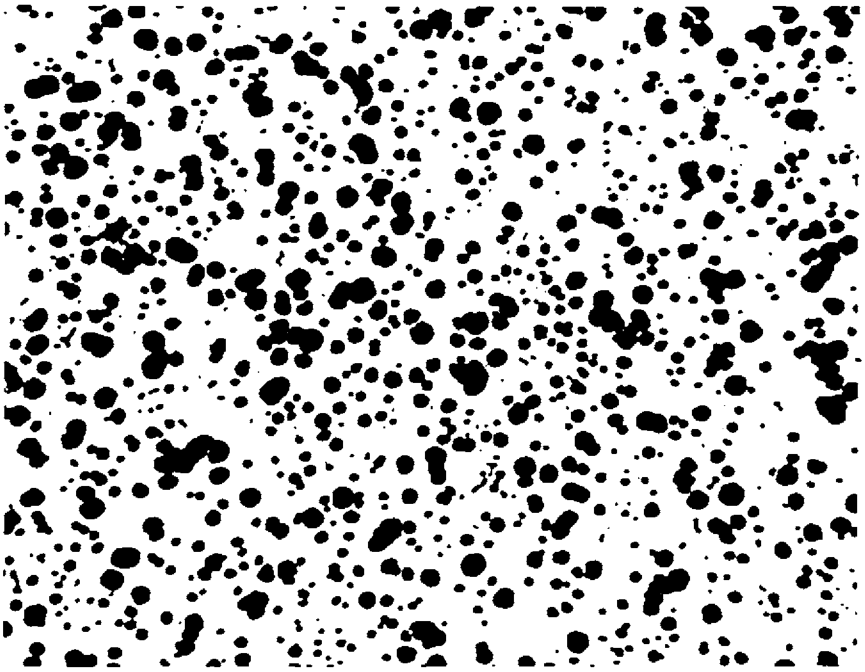

Figure 12(c) Unetched microstructure of ingot 27, (50x).

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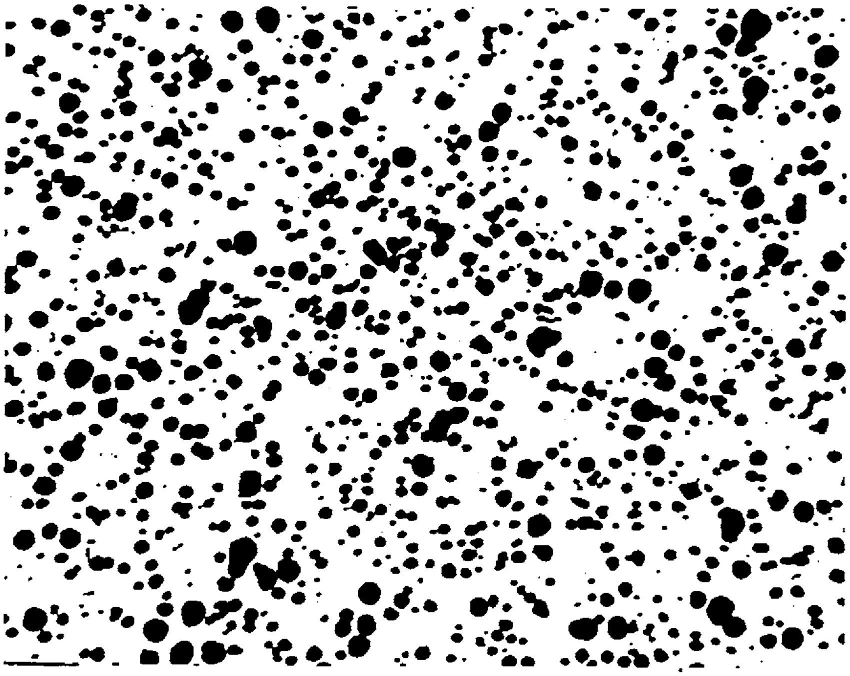

Figure 13(a) Unetched microstructure of ingot 18, (50x).

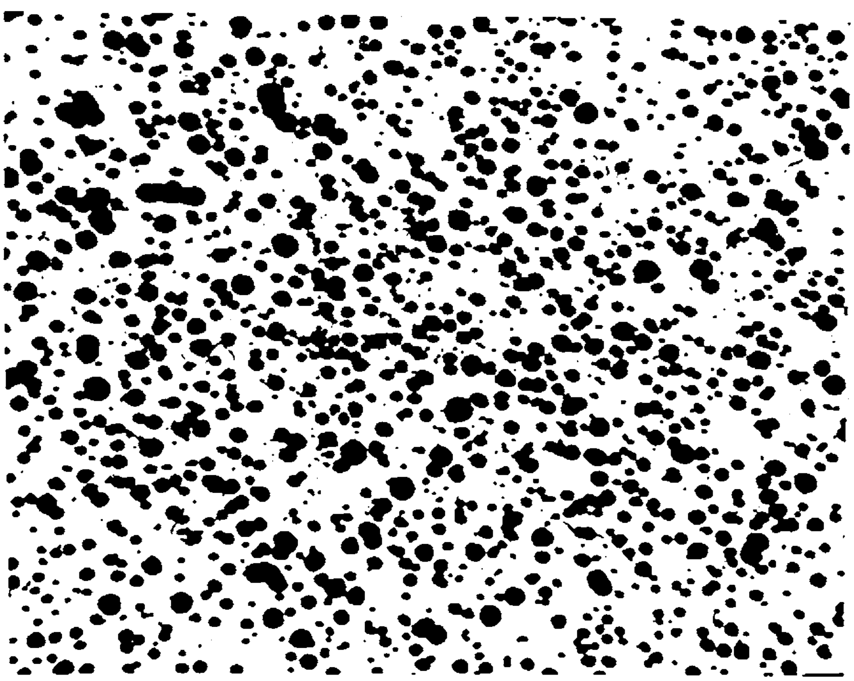

Figure 13(b) Unetched microstructure of ingot 30, (50x).

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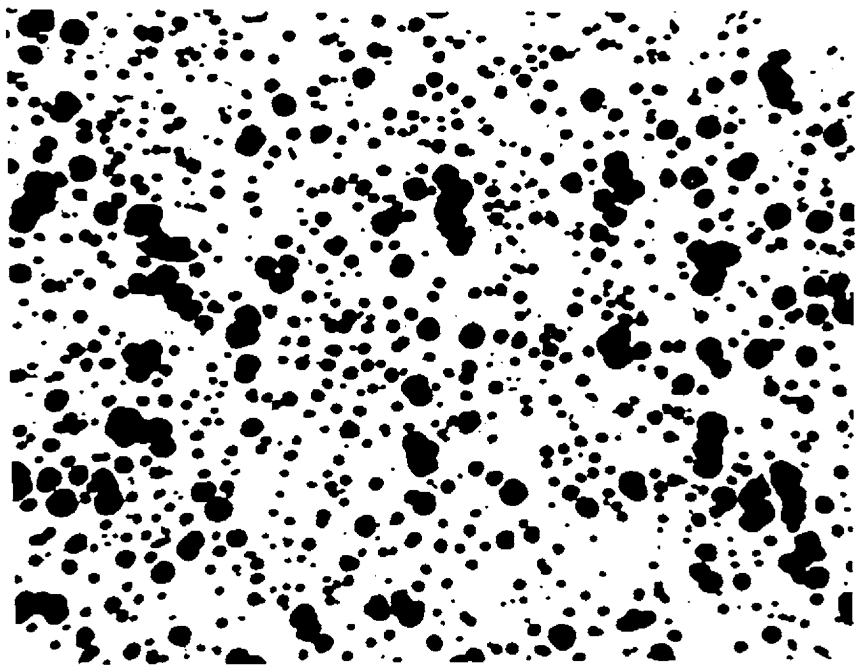

Figure 13(c) Unetched microstructure of ingot 36, (50x).

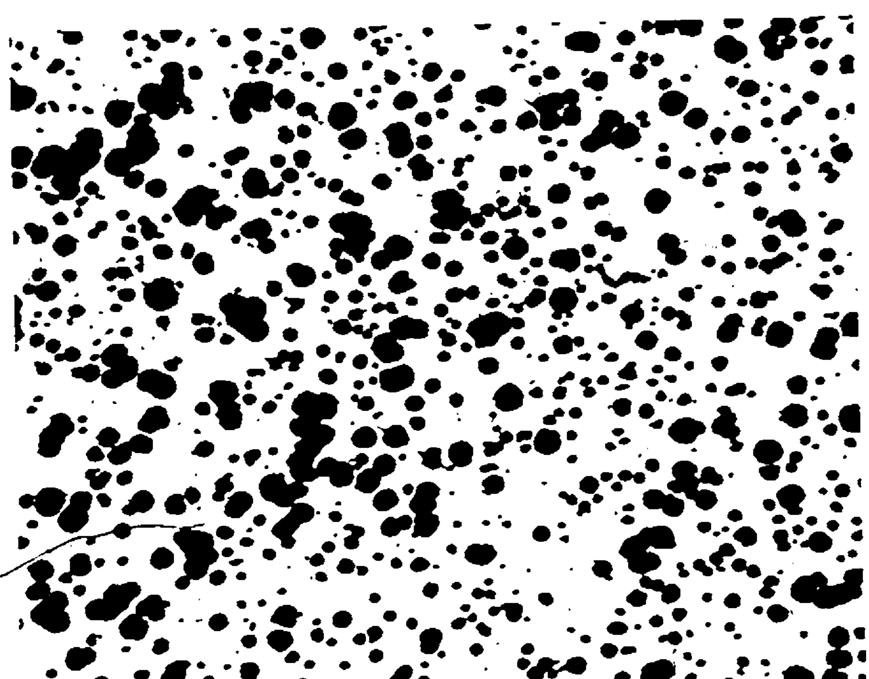

Figure 13(d) Unetched microstructure of ingot 35, (50x).

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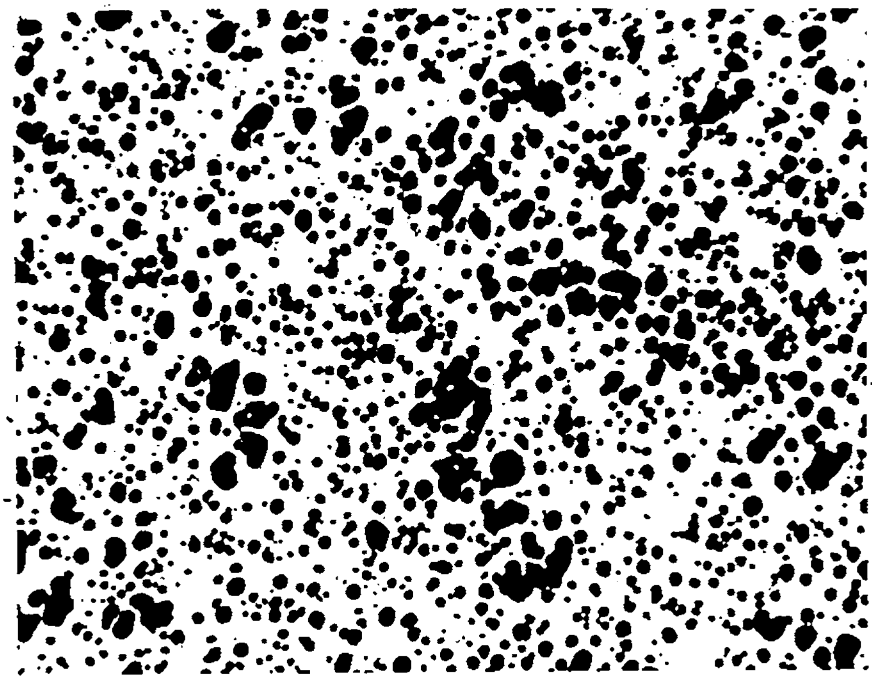

Figure 13(e) Unetched microstructure of ingot 25, (50x).

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this group of ingots compared to those in Table 5, although nodule size has generally decreased. Due to the high carbon equivalent levels (also higher carbon levels) proeutectic graphite precipitation is greatly increased. It has been proposed that the resulting carbon depletion in the liquid promotes a slow, gradual eutectic solidification stage (15, 25), thereby enhancing nodule growth and clustering.

Ingot 13, which stands apart from the rest of the ingots in Table 6, shows the presence of considerable amount of intercellular carbides (c.f. Figure 14). This could be the result of an inefficient or improper inoculation practice (note the relatively low silicon content), and/or to some other undefined intrinsic metal property. The stronger tendency of carbon to stay in solution finally resulted in most of the carbon precipitating as intercellular carbides. If ingot 13 is classified according to the silicon content, it could equally be placed in Table 5. However, the carbon equivalent is significantly higher than the carbon equivalents of other ingots in Table 5. The extent of carbon macrosegregation for ingot 13 is in agreement with the magnitude of solidification parameters, but with a lower nodule count due to the presence of intercellular carbides.

It should be reiterated that the values of solidification parameters, being strictly relative and depending on metal composition and other processing variables, as such should not be expected to predict the microstructure precisely

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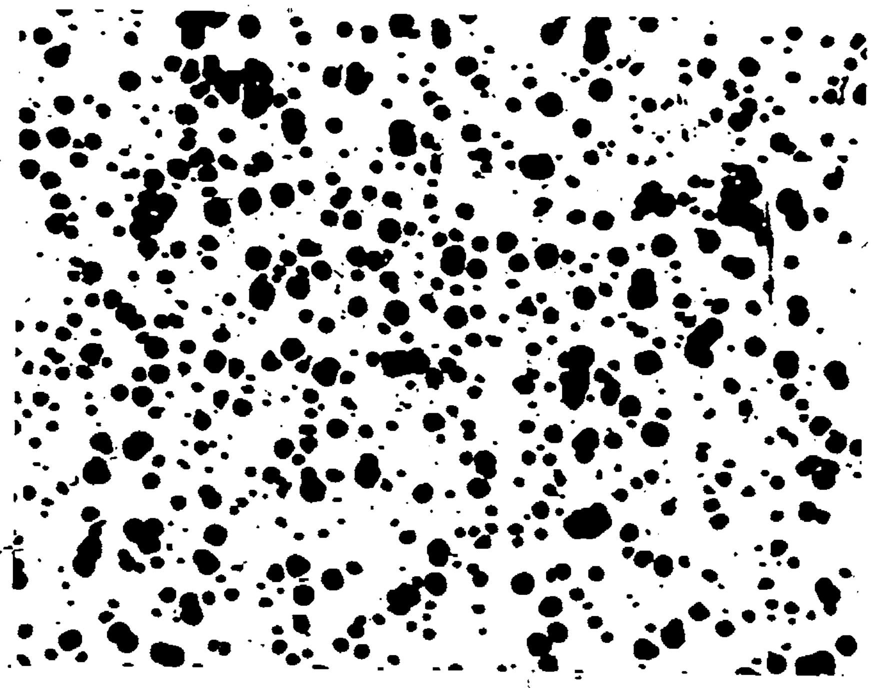

Figure 14(a) Unetched microstructure of ingot 13, (50x).

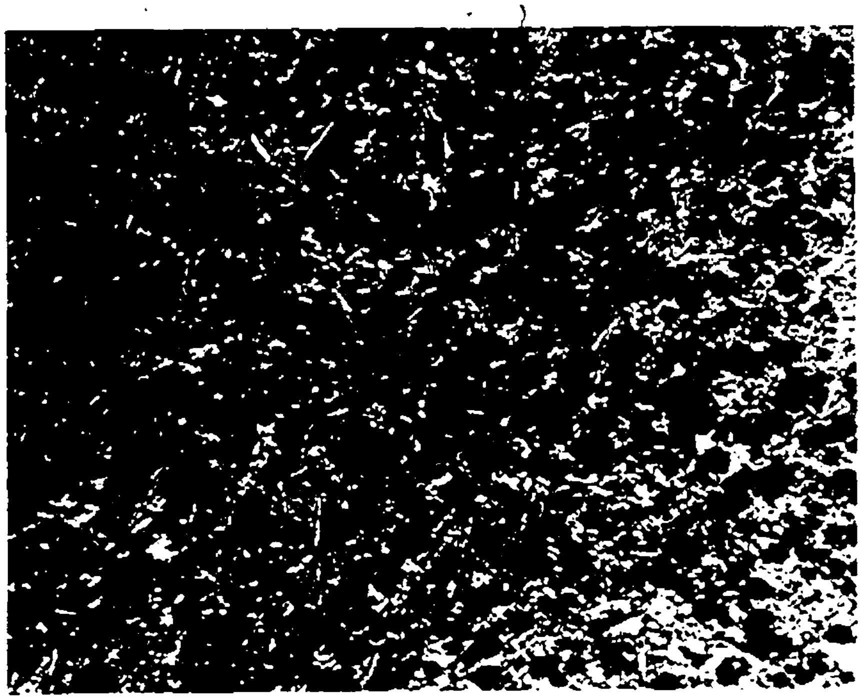

Figure 14(b) Etched microstructure (2% nital) of ingot 13, (50x).

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and quantitatively. What is evident from the results of this study is a general and consistent relationship, viz. decreasing the values for solidification parameters, e.g., $(R_n+1)_{max}$ and $(SC_n/X_n)_{max}$, results in an increasing tendency for carbon macrosegregation and ultimately carbon flotation.

7.3 Effect of High Silicon Content

The ingots in Table 7 are characterized by relatively high silicon contents. The variation in carbon macrosegregation (in particular nodule clustering) with decrease in solidification parameter values is less pronounced for the ingots in Table 7 (c.f., Figure 15) than for those in Table 6. This is consistent with the relatively smaller change in the solidification parameter values between ingots at the top and those at the bottom of Table 7 compared to the ingots in Table 6. The higher final silicon content of the ingots in Table 7 is not necessarily due to an increased ferrosilicon inoculation, but may be due to a higher silicon content of the base metal. Regular foundry practice calls for reducing the amount of ferrosilicon inoculant if the base metal is high in silicon, although base silicon content itself is generally assumed to have no significant inoculant effect. The exceptionally high silicon content in ingot 28 may be the prime cause for the relatively low incidence of nodule clustering. However, considerably more results with high silicon irons are required before a causal relationship between silicon content and carbon macrosegregation can be established.

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Table 7

Ingot Solidification Parameters

(Carbon equivalent: 4.76-4.93%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)'_{max}$	$(SC_n/X_n)_{max}$
24	3.86	2.70	4.76	-30	0.8094	29.8578	-0.8953
31	3.93	2.81	4.87	-32	0.6389	22.7873	-0.7121
29	3.90	2.70	4.80	-26	0.5325	16.0296	-0.6165
34	3.90	2.75	4.82	-24	0.5253	14.7855	-0.6161
28	3.91	3.06	4.93	-30	0.5487	18.6613	-0.6220

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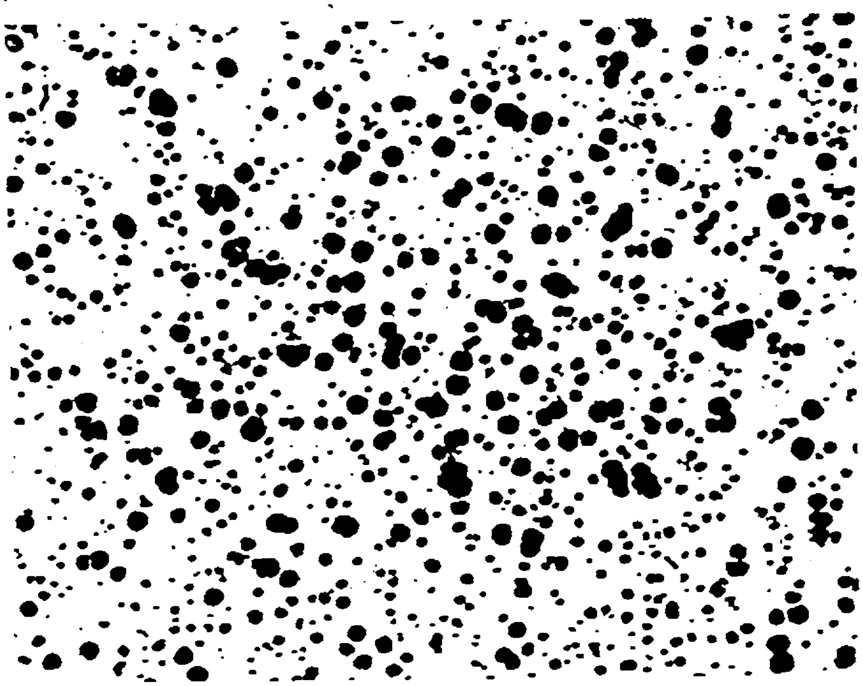

Figure 15(a) Unetched microstructure of ingot 24, (50x).

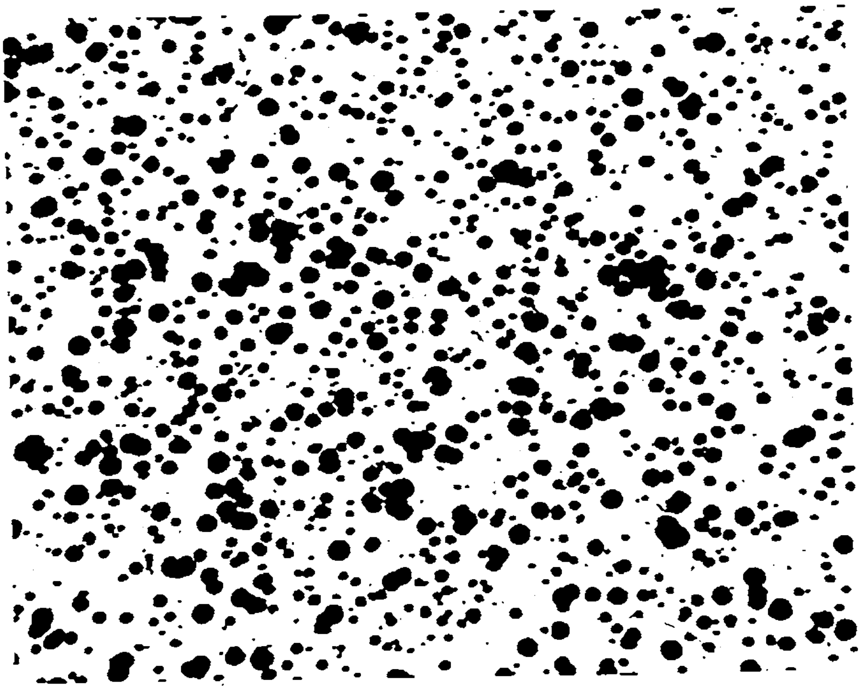

Figure 15(b) Unetched microstructure of ingot 31, (50x).

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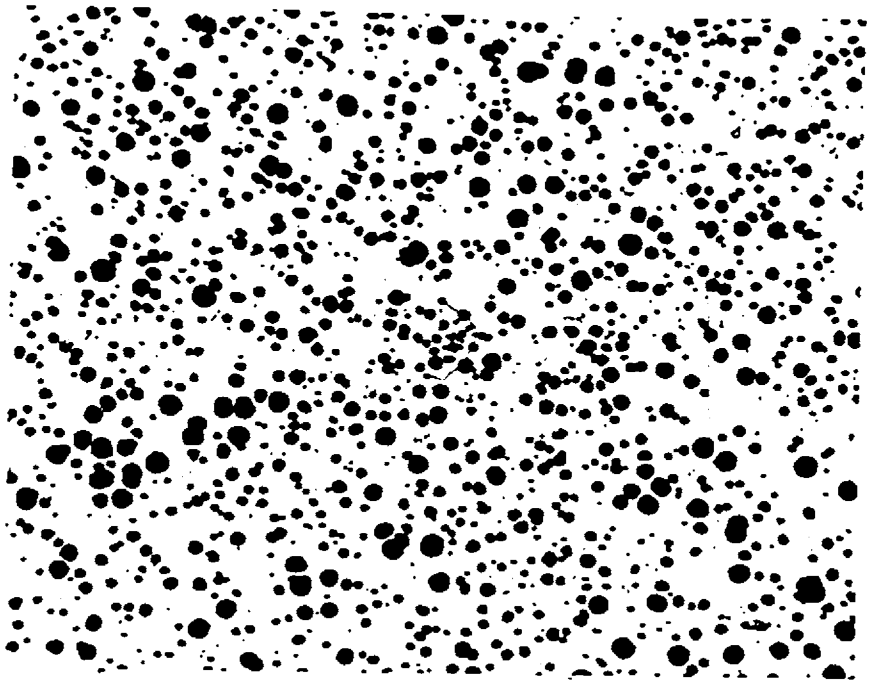

Figure 15(c) Unetched microstructure of ingot 29, (50x).

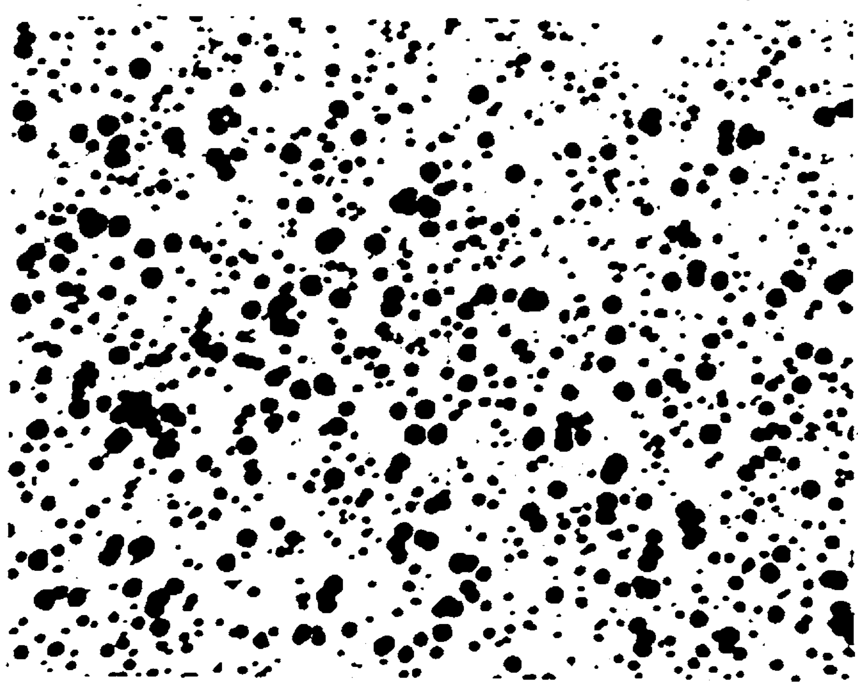

Figure 15(d) Unetched microstructure of ingot 34, (50x).

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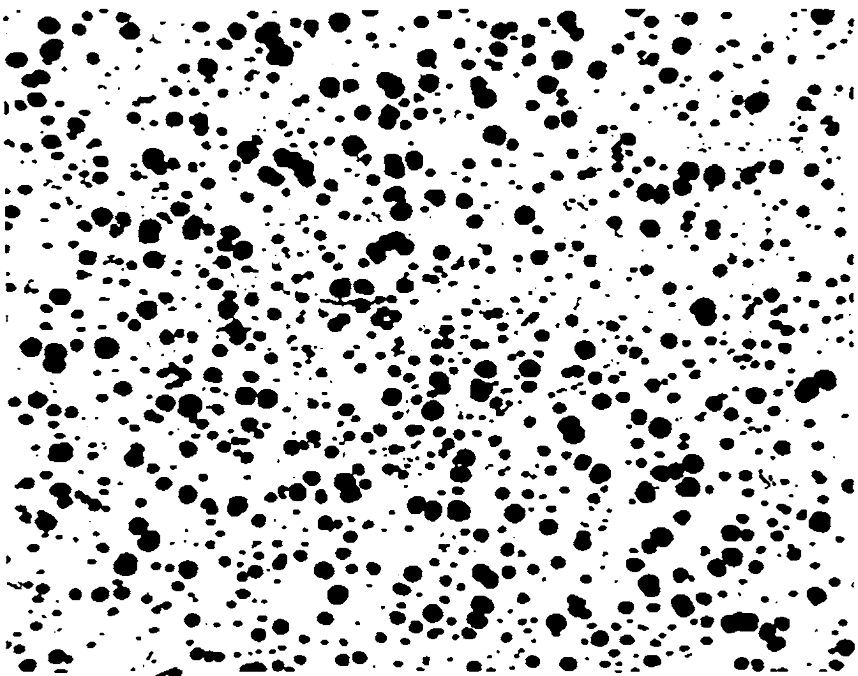

Figure 15(e) Unetched microstructure of ingot 28, (50x).

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7.4 Effect of High Carbon Content

The strong tendency toward carbon macrosegregation is clearly evident from the micrographs of the ingots listed in Table 8, and shown in Figure 16. This is particularly so for ingot 11 which has the lowest $(R_n+1)_{max}$, $(SC_n)_{max}$, and $(SC_n/X_n)_{max}$ values. The variation in metal chemistry, particularly silicon content, in this group appears to have less influence on nodule distribution and carbon macrosegregation than in previous cases. The very high carbon contents (and equivalents) greatly increase the nodule count, but also decrease nodule size considerably. A severe carbon flotation would occur if agglomeration of the tiny nodules into irregular chunks of graphite were to take place during an extended solidification period.

7.5 Importance of Solidification Parameters and Carbon Equivalent in Predicting Carbon Macrosegregation

From the above data it is evident that the solidification parameters $(R_n+1)_{max}$, $(SC_n)_{max}$, and $(SC_n/X_n)_{max}$ generally decrease as the carbon equivalent increases. It is also evident that the effects of various processing variables are less pronounced for high carbon equivalent irons. The duration of proeutectic graphite precipitation must necessarily increase with carbon equivalent, which continues until the eutectic composition is reached. Time is of the essence here, and if the cooling rate is slow, carbon macrosegregation will be pronounced. Also, a relatively slow rate for the eutectic solidification stage will also enhance the macrosegregation process. The generation of numerous precipitation sites

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Table 8

Ingot Solidification Parameters

(Carbon equivalent: 4.92-5.02%)

Ingot	C%	Si%	C.E.%	$(X_n)_{max}$	$(R_n+1)_{max}$	$(SC_n)_{max}$	$(SC_n/X_n)_{max}$
37	4.19	2.34	4.97	-32	0.5207	18.8059	-0.5877
16	4.25	2.31	5.02	-28	0.4156	13.5715	-0.4847
12	4.38	1.86	5.00	-30	0.2700	9.5960	-0.4093
26	4.14	2.52	4.98	-40	0.1799	8.2432	-0.2061
11	4.25	2.01	4.92	-30	0.1089	3.6691	-0.2129

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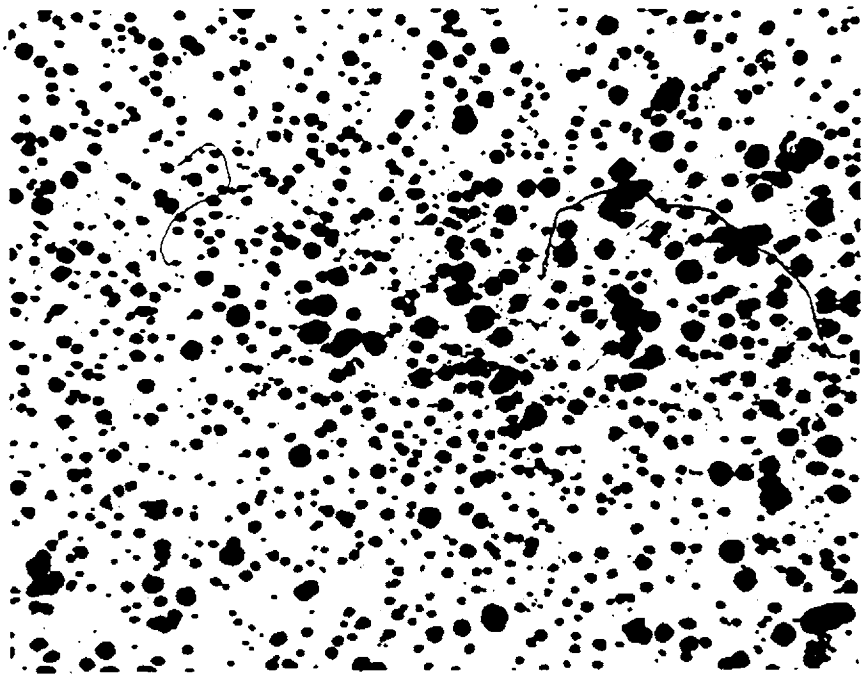

Figure 16(a) Unetched microstructure of ingot 37, (50x).

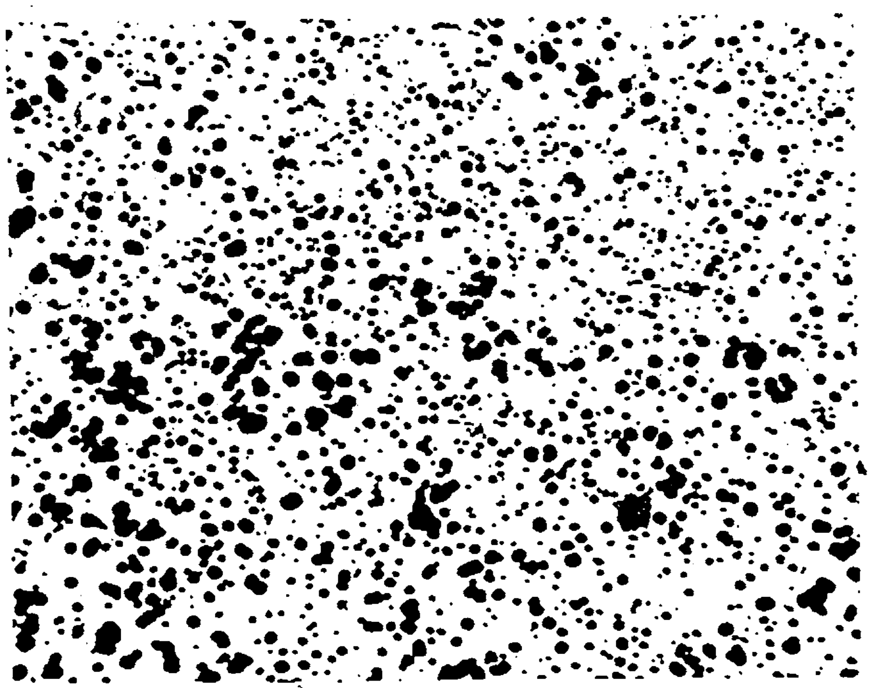

Figure 16(b) Unetched microstructure of ingot 16, (50x).

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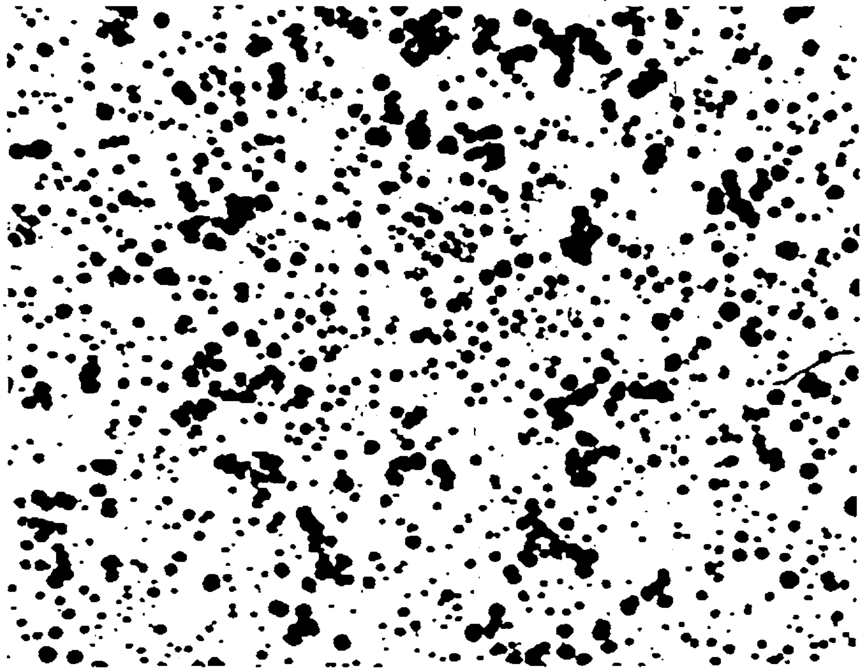

Figure 16(c) Unetched microstructure of ingot 12, (50x).

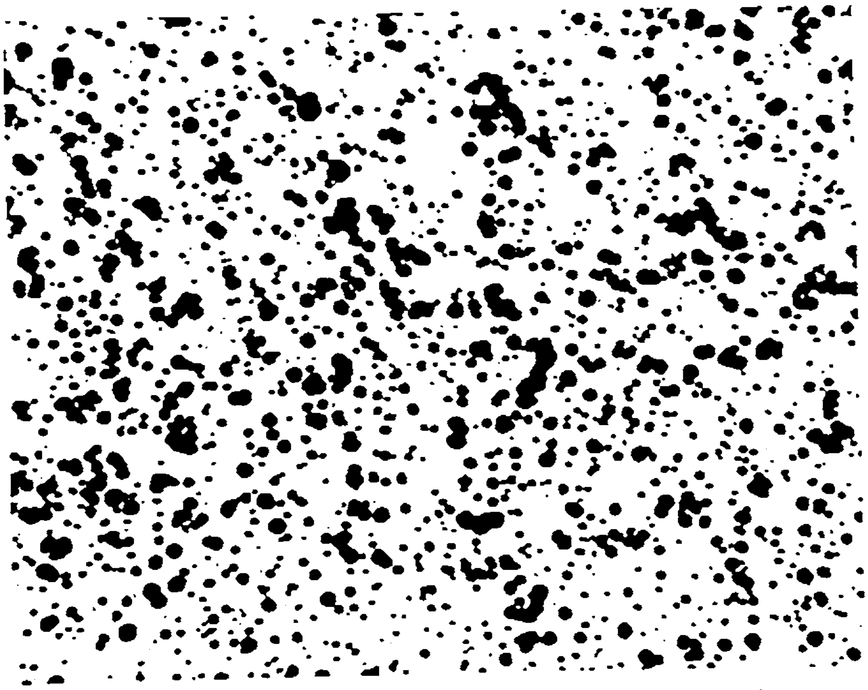

Figure 16(d) Unetched microstructure of ingot 26, (50x).

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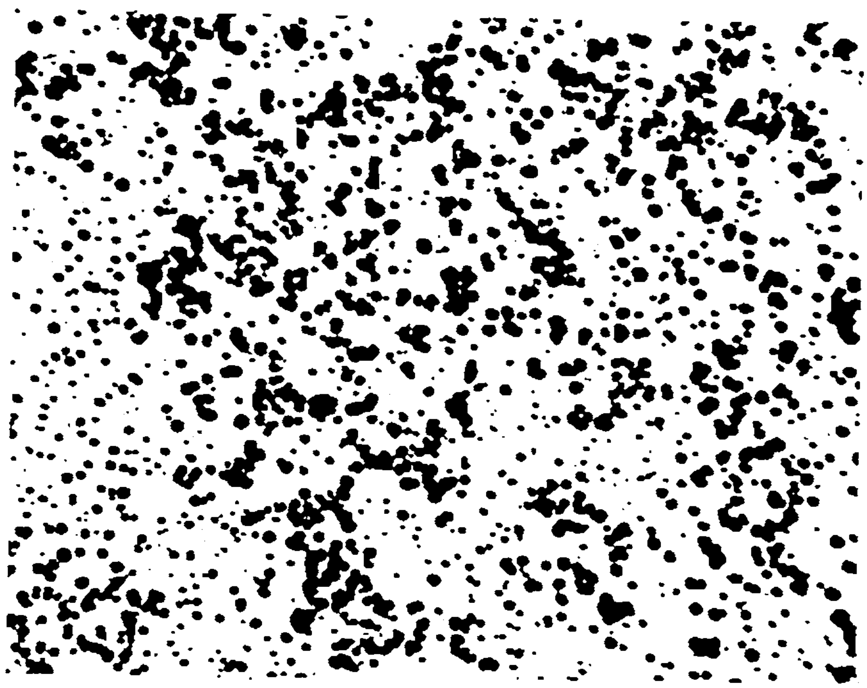

Figure 16(e) Unetched microstructure of ingot 11, (50x).

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during the proeutectic graphite precipitation stage appears to favor a gradual rate for the subsequent eutectic solidification stage, which is evident from lower values of solidification parameters obtained in irons having higher carbon equivalent levels. This could be attributed to a lesser tendency to supercooling prior to eutectic solidification, since the proeutectic graphite nodules serve as existing nuclei for eutectic graphite nodule formation. Without any substantial supercooling of the eutectic liquid, there would be no (initially) accelerated eutectic solidification rate. The degree of carbon macrosegregation in ingots having different carbon equivalents, but similar or close solidification parameters, are generally higher as the carbon equivalent increases.

It is evident that both carbon equivalent levels (and/or carbon and silicon contents) and solidification parameter values are necessary for correctly interpreting the microstructures and predicting the tendency for carbon flotation. The solidification parameters are affected by all the processing variables, including metal chemistry, e.g., ingots 39 and 35 have close values for $(R_n+1)_{max}$ and $(SC_n/X_n)_{max}$, and although there are similarities in the carbon morphologies, the higher macrosegregation tendency in ingot 35 can be attributed to its higher carbon equivalent. Similar conclusions can be drawn by comparing ingots 38 and 35, or ingots 27 and 36. In both these cases, the higher carbon equivalents of ingots 25 and 36 result in more pronounced carbon

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macrosegregation tendencies. On the other hand, ingot 38 does show greater macrosegregation tendency than ingots 18 and 30. Since carbon equivalent for ingot 38 is lower than for both ingots 18 and 30, the higher incidence of carbon macrosegregation in ingot 38 can be attributed to its lower solidification parameters. The smaller solidification parameters are primarily the result of the lower solidification rates resulting from processing variables other than metal chemistry. Similar conclusions can be deducted by comparing ingot 37 with ingots 36, 35, 25, 27, and 38. The tendency toward carbon macrosegregation in ingot 37 is less, although its carbon equivalent exceeds that of the other ingots.

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CHAPTER 8

SUMMARY

The carbon macrosegregation phenomenon, particularly in hypereutectic nodular cast irons, has an adverse effect on surface quality of castings. The extent of carbon macrosegregation and carbon flotation is dependent on metal chemistry, but it is also significantly affected by other processing variables. These processing variables (e.g., inoculation procedure, pouring temperature, solidification rate) directly affect the solidification mechanism, and thus indirectly carbon macrosegregation, and as such must be closely controlled if the desired casting structure is to be achieved. The solidification parameters (R_n+1), $(C_o+C_e)_{n+1}$, SC_n, SC_n/X_n and their respective maximum values, in addition to metal chemistry, constitute a comprehensive set of indicators of the thermal history during the solidification process, and as such their interpretation can greatly facilitate prediction and control of carbon macrosegregation and flotation in commercial nodular cast irons.

The method for identification and control of carbon macrosegregation in commercial nodular cast irons developed in this study utilizes both the chemical and thermal aspects of metal testing practice, which are summarized in the following conclusions:

1) A thermal analysis method is developed, which in conjunction with metal chemistry monitoring, is

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capable of qualitatively predicting from cooling curves the tendency to carbon macrosegregation in commercial nodular cast irons, and provides a rapid quality control procedure in nodular iron production.

2) The thermal history of the solidification process, initially obtained as a cooling curve, is analyzed using a specially developed mathematical and computational procedure, to give sets of distinctive numerical values of solidification parameters. The essential role of the mathematical procedure is to characterize and amplify the significant features of the cooling curve, which otherwise are not easily discernible from the original cooling curve itself.

3) The absolute time and temperature data obtained from cooling curves are transformed to relative values by using as a reference the maximum undercooling point, so that the values of all solidification parameters thus obtained become relative.

4) The solidification parameter values are unique for every single segment of the cooling curve and can be correlated with carbon macrosegregation tendencies.

5) The solidification parameters essentially represent relative solidification rates and relative amounts solidified for any point in time. The

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relative nature of the solidification parameters removes the need for absolute calibration of the measuring instruments, and accordingly reduces the influence of recurring errors in the interpretation of the cooling curve segments.

6) In general, the degree of carbon macrosegregation increases with carbon equivalent and decreasing values of the solidification parameters (R_n+1), SC_n, and SC_n/X_n.

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APPENDIX A

A.1 Development of the Curve Fitting Equations

A.1.1 Introductory Concepts

The value of a function $Y_n = f(X_n)$ in a sufficiently close neighbourhood of X_n, can be expressed by the Taylor series expansion of $f(X_n)$ [20], i.e.,

$$f(X_1) = f(X_0) + (X_1-X_0)*f'(X_0) + [(X_1-X_0)^2/2!]*f''(X_0) +$$
$$+ [(X_1-X_0)^3/3!]*f'''(X_0) + \ldots +$$
$$+ [(X_1-X_0)^n/n!]*f^{(n)}(X_0) + \ldots$$

where the primes denote the differentiation orders.

If the function in the neighbourhood of $X_n = X_0$ is approximated by only the first three members of the series, a rearrangement of terms gives:

$$[(X_1-X_0)/2]*f''(X_0) + f'(X_0) - (Y_1-Y_0)/(X_1-X_0) = Q(X_0) \quad \text{A1}$$

where $Q(X_0)$ is the residual of the series and represents the error generated by truncation. If the first three terms of the series are assumed to give sufficient accuracy, and letting:

$$(Y_1-Y_0)/(X_1-X_0) = A, \text{ Eq A1 becomes,}$$

$$[(X_1-X_0)/2]*f''(X_0) + f'(X_0) - A = 0 \quad \text{A2}$$

By arbitrarily assigning a positive unit value to (X_1-X_0), Eq. A2 becomes (for the forward difference mode):

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$$(1/2)*f''(X_0) + f'(X_0) - A = 0 \qquad \text{A2a}$$

If arbitrarily $(X_1-X_0) = -1$, Eq. A2 then expresses the backward difference mode given by:

$$(1/2)*f''(X_0) - f'(X_0) + A = 0 \qquad \text{A2b}$$

In the following the variable Y (or Y_n) will be taken to represent temperature and X (or X_n) time relative to the maximum undercooling point on the cooling curve.

A.1.2 Homogeneous Differential Equations

a) General Solution

i) Forward Difference Mode

Eq. A2a can be written as $d^2Y/dX^2 + 2*dY/dX - 2*A = 0$. Multiplying the third member by Y/Y, and redefining A/y = Z, gives:

$$d^2Y/dX^2 + 2*dY/dX - 2*Z*Y = 0 \qquad \text{A3}$$

If Z is considered to be constant in the close neighbourhood of X, Eq. A3 becomes a first degree, second order differential equation, the general solution of which is:

$$Y = C_1*\exp(M_1*X) + C_2*\exp(M_2*X) \qquad \text{A4}$$

where $M_{1,2}$ are the roots of the auxiliary quadratic equation $M^2 + 2*M - 2*Z = 0$, and $C_{1,2}$ are the integration constants. The roots are:

$$M_{1,2} = -1 \pm (1+2*Z)^{1/2} \qquad \text{A5}$$

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ii) Backward Difference Mode

Eq. A2b may be written as $d^2Y/dX^2 - 2*dY/dX + 2*A = 0$. Applying the above mathematical treatment gives:

$$d^2Y/dX^2 - 2*dY/dX + 2*Z*Y = 0 \qquad A6$$

the general solution of which is,

$$Y = C_1*\exp(M_1*X) + C_2*\exp(M_2*X) \qquad A7$$

The roots of auxiliary quadratic equation $M^2 - 2*M + 2*Z = 0$ are:

$$M_{1,2} = +1 +- (1-2*Z)^{1/2} \qquad A8$$

The roots $M_{1,2}$ in Eq. A4 and Eq. A7 are not the same, and therefore the integration constants $C_{1,2}$ in these equations are different also.

If two close points on the curve are considered, the integration constants can be calculated for either the forward or backward difference mode. The values of the roots can be determined, for the expression for $Z = (dY/dX)/Y$ ($Z=$ const.) gives upon integration $\ln(Y)/X = Z + C$.

b) Hyperbolic Solution

Eqs. A4 and A7 can also be expressed as:

$$Y = \exp(-+X) * [C_1*\exp(+R*X) + C_2*\exp(-R*X)] \qquad A9$$

where $R = (1+-2*Z)^{1/2}$, and where the double sign denotes respectively the forward and backward difference modes.

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Since,

$$\exp(+R*X) = \cosh(R*X) + \sinh(R*X), \text{ and}$$

$$\exp(-R*X) = \cosh(R*X) - \sinh(R*X),$$

Eq. A9 becomes:

$$Y = \exp(-+X) * \left[(C_1+C_2)*\cosh(R*X) + (C_1-C_2)*\sinh(R*X)\right] \qquad \text{A9a}$$

Eq. A9a can be simplified by reducing it to the form:

$$Y = \exp(-+X) * C*\cosh(A+R*X) \qquad \text{A10}$$

according to the following:

$$C*\cosh(A+R*X) = \left[C*\cosh(A)\right]*\cosh(R*X) + \left[C*\sinh(A)\right]*\sinh(R*X) \qquad \text{A11}$$

The comparison with Eqs. A9a and A10 gives $C_1+C_2 = C*\cosh(A)$ and $C_1-C_2 = C*\sinh(A)$. On squaring and subtracting these two expressions, $C^2*\left[\cosh^2(A) - \sinh^2(A)\right] = (C_1+C_2)^2 - (C_1-C_2)^2$, and since $\cosh^2(A) - \sinh^2(A) = 1$, it follows that:

$$C = 2*(C_1*C_2)^{1/2} \qquad \text{A12}$$

In order to determine A, the relations to be considered are:

$$\left[C*\sinh(A)\right]/\left[C*\cosh(A)\right] = \left[\exp(A)-\exp(-A)\right]/\left[\exp(A)+\exp(-A)\right]$$

and,

$$\left[C*\sinh(A)\right]/\left[C*\cosh(A)\right] = (C_1-C_2)/(C_1+C_2).$$

On subtraction and reduction of terms:

$$\exp(2*A) = (C_1/C_2),$$

or,

$$A = (1/2)*\ln(C_1/C_2) \qquad \text{A13}$$

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Introduction of Eqs. A12 and A13 into Eq. A10 gives the simplified form of Eq. A9a, viz.

$$Y = 2*(C_1*C_2)^{1/2} * \exp(-+X) * \cosh\left[(1/2)*\ln(C_1/C_2) + R*X\right] \qquad A14$$

Redefining $K_1 = 2*(C_1*C_2)^{1/2}$ and $K_2 = (1/2*\ln(C_1/C_2)$, Eq. A14 becomes:

$$Y = K_1*\exp(-+X) * \cosh(K_2 + R*X) \qquad A14a$$

If several points on a curve are considered, each of which require different values for the constants, Eq. A14a for any point can be expressed as:

$$Y_n = K_{2n+1} * \exp(-+X_n) * \cosh(K_{2n+2} + R_n*X_n) \qquad A15$$

where n is the subscript of the point considered, K_{2n+1} and K_{2n+2} are the odd and even subscripted constants respectively, and $R_n = (1+-2*Z_n)^{1/2}$ is the exponential coefficient.

c) Simplified Forms of Hyperbolic Solutions

For sufficiently large values of X_n (e.g., $X_n > 5$), and depending on the magnitude of R_n and K_{2n+2}, the cosh function in Eq. A15 may be reduced to an exponential function, while still leaving sufficient accuracy for the purpose of this investigation. This is evident from the exponential form of the cosh function, in which relatively small members associated with negative exponential factors may be neglected.

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i) Forward Difference Mode*

The exponential form of Eq. A15 for the forward difference mode becomes:

$$Y_n = K_{2n+1}/2*\{\exp[K_{2n+2}+(R_n-1)*X_n] + \exp-[K_{2n+2}+(R_n+1)*X_n]\} \quad \text{A16}$$

For $X_n > 0$ and $|K_{2n+2}| << (R_n+-1)*X_n$ Eq. A16 becomes:

1) for $R_n > 1$, the second exponential member may be neglected to give:

$$Y_n = K_{2n+1}/2*\exp[K_{2n+2}+(R_n-1)*X_n] \quad \text{A16a}$$

2) for $R_n = 1$, the second exponential member may be neglected, and since the variable part of the first member is zero,

$$Y_n = K_{2n+1}/2*\exp(K_{2n+2}) \quad \text{A16b}$$

3) for $R_n = 0$,

$$Y_n = K_{2n+1}*\exp(-X_n)*\cosh(K_{2n+2}) \quad \text{A16c}$$

4) for $0 < R_n < 1$, depending on the magnitude of R_n (whether closer to 0 or 1), any of Eqs. A16a, A16b or A16c can be used;

5) for $R_n = -1$, the first exponential member can be omitted, and since the variable part of the second member is zero,

$$Y_n = K_{2n+1}/2*\exp-(K_{2n+2}) \quad \text{A16d}$$

* The forward difference mode is applied for the cooling curve segment in $X_n > 0$ region.

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6) for $R_n < -1$, the first member becomes negligible, and,

$$Y_n = K_{2n+1}/2*\exp-[K_{2n+2}+(R_n+1)*X_n] \qquad \text{A16e}$$

7) for $0 > R_n > -1$, depending on the magnitude of R_n (whether closer to 0 or -1), any of Eqs. A16c, A16d, or A16e can be applied.

ii) Backward Difference Mode*

For the backward difference mode, the exponential form of Eq. A15 is:

$$Y_n = K_{2n+1}/2*\{\exp[K_{2n+2}+(R_n+1)*X_n] + \exp-[K_{2n+2}+(R -1)*X_n]\} \qquad \text{A17}$$

Under the assumption that $X_n < 0$, i.e., for negative times, and $|K_{2n+2}| << (R_n+-1)*X_n$, Eq. A17 becomes:

1) for $R_n > 1$, the first exponential member may be neglected to give:

$$Y_n = K_{2n+1}/2*\exp-[K_{2n+2}+(R_n-1)*X_n] \qquad \text{A17a}$$

2) for $R_n = 1$, the first member is negligible and the variable part of the second member is zero, giving:

$$Y_n = K_{2n+1}/2*\exp-(K_{2n+2}) \qquad \text{A17b}$$

3) for $R_n = 0$,

$$Y_n = K_{2n+1}*\exp(+X_n)*\cosh(K_{2n+2}) \qquad \text{A17c}$$

---

* The backward differentiation mode is applied on cooling curve segments for which $X_n < 0$.

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4) for $0 < R_n < 1$, depending on the magnitude of R_n any of Eqs. A17a, A17b, or A17c can be used;

5) for $R_n = -1$, the second member can be neglected, and since the variable part of the first member equals zero,

$$Y_n = K_{2n+1}/2*\exp(K_{2n+2}) \qquad \text{A17d}$$

6) for $R_n < -1$, the second member is negligible, and,

$$Y_n = K_{2n+1}/2*\exp[K_{2n+2}+(R_n+1)*X_n] \qquad \text{A17e}$$

7) for $0 > R_n > -1$, depending on the magnitude of R_n, any of Eqs. A17c, A17d, or A17e can be used.

By taking logarithms of Eqs. A16a through A17e, equations of straight lines are obtained, the intercepts being $\ln(K_{2n+1}/2) +- K_{2n+2}$, and the slopes $+-(R_n+1)$ respectively. These logarithmic expressions are the fundamental equations required for the curve fitting process, and from which the values of the odd and even subscripted constants are selected to satisfy all the points considered. A single functional relation between all the points of the cooling curve (or segments) can be established by an appropriate selection of the constants.

d) <u>Trigonometric Solution</u>

If in either Eq. A5 or Eq. A8 the member under the square root is negative, the roots of auxiliary quadratic equation are conjugate imaginary, i.e., $M_{1,2} = -+1+-R*i$, where $R = |(1+-2*Z)|^{1/2}$, where the double sign in front of 1 and under the square root denotes the forward and backward

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differentiation modes. For this case the general solution of Eqs. A3 and A6 can be expressed as:

$$Y = \exp(-+X) * [C_1*\exp(+R*i*X) + C_2*\exp(-R*i*X)] \quad A18$$

The mathematical operations used in obtaining the hyperbolic solutions can also be applied to Eq. A18, resulting in the trigonometric solution given by:

$$Y_n = K_{2n+1} * \exp(-+X_n) * \cos(K_{2n+2}+R_n*X_n) \quad A19$$

where $K_{2n+1} = 2*(C_{2n+1}*C_{2n+2})^{1/2}$ and $K_{2n+2} = (i/2)*\ln(C_{2n+1}/C_{2n+2})$ are the odd and even subscripted constants respectively.

Physically, the cooling curves cannot include imaginary solutions (which describe oscillating systems) so that no further consideration is given to trigonometric solutions of the basic equations.

A.1.3 Nonhomogeneous Differential Equations and Their Solutions

It was noted earlier that only the first three terms of the Taylor series representations of the function are used in the derivation of the basic equations. The accuracy of the function can be further improved by including higher derivatives besides those considered in Eq. A2. The resulting linear differential equations would thus be of the third, fourth, and the higher order, with the respective cubic, quadratic, and higher power auxiliary equations. Solutions of these are not readily available, although possible. An equivalent but more tractable approach is the nonhomogeneous

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differential representation for function approximation. The appropriate form of nonhomogeneous differential equation considered for both differentiation modes is:

$$d^2Y/dX^2 +- 2*dY/dX -+ 2*Z*Y = f(X) \qquad A20$$

where f(X), being a function of independent variable X, and compensating for the error Q(X) in Eq. A1, is a further approximation of the function describing the curve. Assuming that the form of f(X) is consistent with the form of the complementary function, the general solution of nonhomogeneous differential equation A20, being the sum of the complementary and particular solutions, is (21):

$$Y = [C_1*\exp(M_1*X) + C_2*\exp(M_2*X)] +$$

$$+ [C_3*\exp(N_1*X) + C_4*\exp(N_2*X)] \qquad A21$$

where C_1 to C_4 are integration constants, and M_1, M_2 and N_1, N_2 are the roots of the auxiliary quadratic equations for each particular solution. By considering still further approximations of Eq. A20, additional members may be added to Eq. 21. Each member in square brackets can be developed in hyperbolic or trigonometric forms as already described.

For the purpose of this investigation general solutions of homogeneous differential equations (representing the first approximation of the function only) give satisfactory results, and therefore solutions for the nonhomogeneous differential equation case will not be considered further.

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A.2 Curve Fitting Method

A.2.1 Application of Simplified Hyperbolic Solutions of Homogeneous Differential Equations

For each point on the curve in its logarithmic form shown in Figure A1, one of Eqs. A16a through A17e in their logarithmic form can be applied. The straight lines (tangents) obtained, e.g., for the forward difference mode and $R_n > 0$, are shown schematically in Figure A1, the general form of which is $\ln(Y_n) = \ln(K_{2n+1}/2) + k_{2n+2} + (R_n-1)*X_n$. The straight line equations for the four points considered are:

$$\ln(Y_0) = \ln(K_1/2) + K_2 + (R_0-1)*X_0^* \qquad \text{A22a}$$

$$\ln(Y_1) = \ln(K_3/2) + K_4 + (R_1-1)*X_1 \qquad \text{A22b}$$

$$\ln(Y_2) = \ln(K_5/2) + K_6 + (R_2-1)*X_2 \qquad \text{A22c}$$

$$\ln(Y_3) = \ln(K_7/2) + K_8 + (R_3-1)*X_3 \qquad \text{A22d}$$

If an appropriate relation is to be established among the points, values of the constants will have to be appropriately adjusted and included into an equation capable of satisfying all four points considered. The general form of such an equation is:

$$\ln(Y_n) = [\ln(k_1/2)+k_2] \mp [\ln(k_3/2)+k_4] \mp [\ln(k_5/2)+k_6] \mp \mp \ldots \mp [\ln(k_{2m-1}/2) + k_{2m}] + (R_n-1)*X_n \qquad \text{A22}$$

---

* X_0 is not necessarily at the point of origin.

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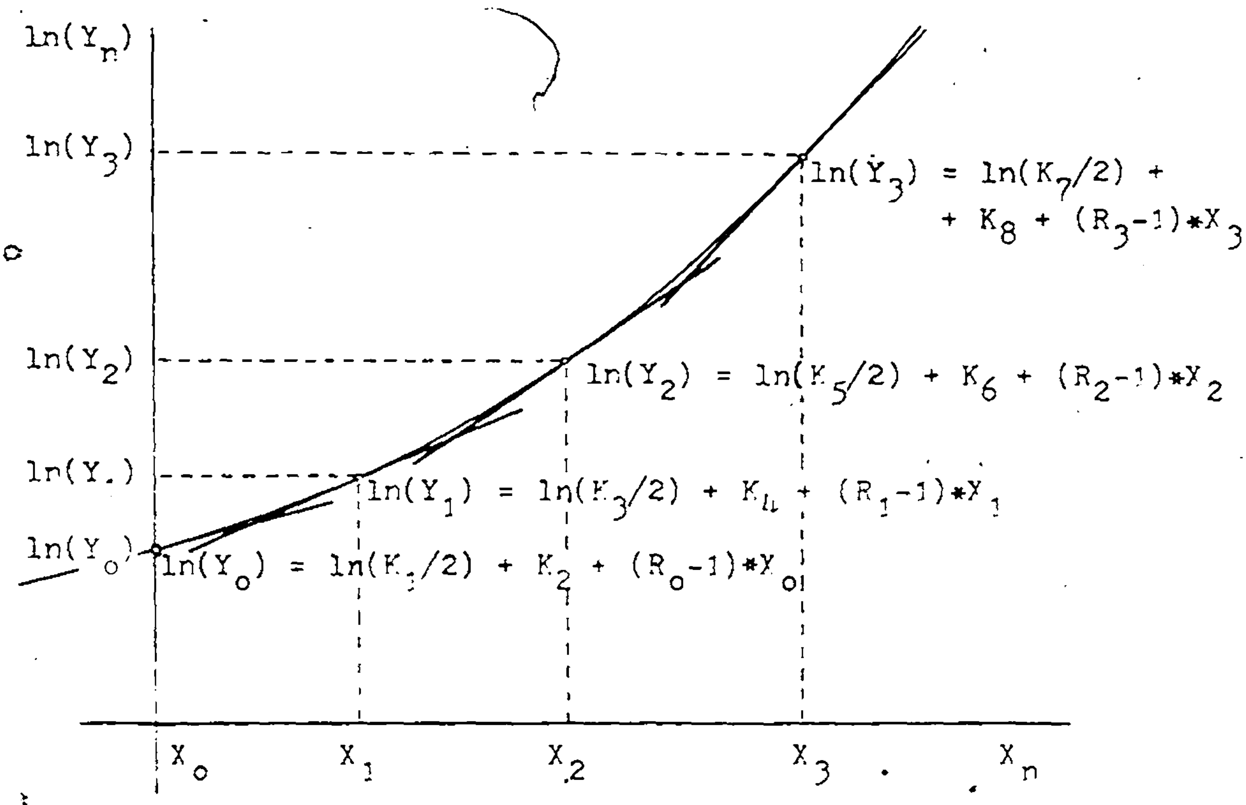

Figure A1 Schematic representation of simplified hyperbolic solutions (logarithmic form) of homogeneous differential equations as straight lines (tangents) at four points considered on a curve segment.

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where m is the total number of points considered (1 to m), and n is the subscript (0 to m-1) for each point.

The development of A22 can be illustrated from Figure A2. The ordinate at X_1 can be expressed as:

$$\ln(Y_1) = \ln(Y_{01}) + \left[\ln(Y_1) - \ln(Y_{01})\right] \qquad \text{A23}$$

where $\ln(Y_{01})$, denoting the ordinate of the straight line represented by Eq. A22a at X_1, is given by:

$$\ln(Y_{01}) = \ln(K_1/2) + K_2 + (R_0-1)*X_1 \qquad \text{A24}$$

Substituting Eqs. A22a and A24 into Eq. A23 gives:

$$\ln(Y_1) = \left[\ln(K_1/2)+K_2+(R_0-1)*X_1\right] +$$

$$+ \left[\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_2)*X_1\right] \qquad \text{A23a}$$

At X_2 the ordinate can be expressed as:

$$\ln(Y_2) = \ln(Y_{12}) + \left[\ln(Y_2) - \ln(Y_{12})\right] \qquad \text{A25}$$

where $\ln(Y_{12})$ denotes the ordinate of the straight line represented by Eq. A22b at X_2. It is evident from Fig. A2 that:

$$\ln(Y_{12}) = \ln(Y_{02}) + \left[\ln(Y_{12}) - \ln(Y_{02})\right],$$

which if substituted into Eq. A25 gives:

$$\ln(Y_2) = \ln(Y_{02})+\left[\ln(Y_{12})-\ln(Y_{02})\right] + \left[\ln(Y_2)-\ln(Y_{12})\right] \qquad \text{A25a}$$

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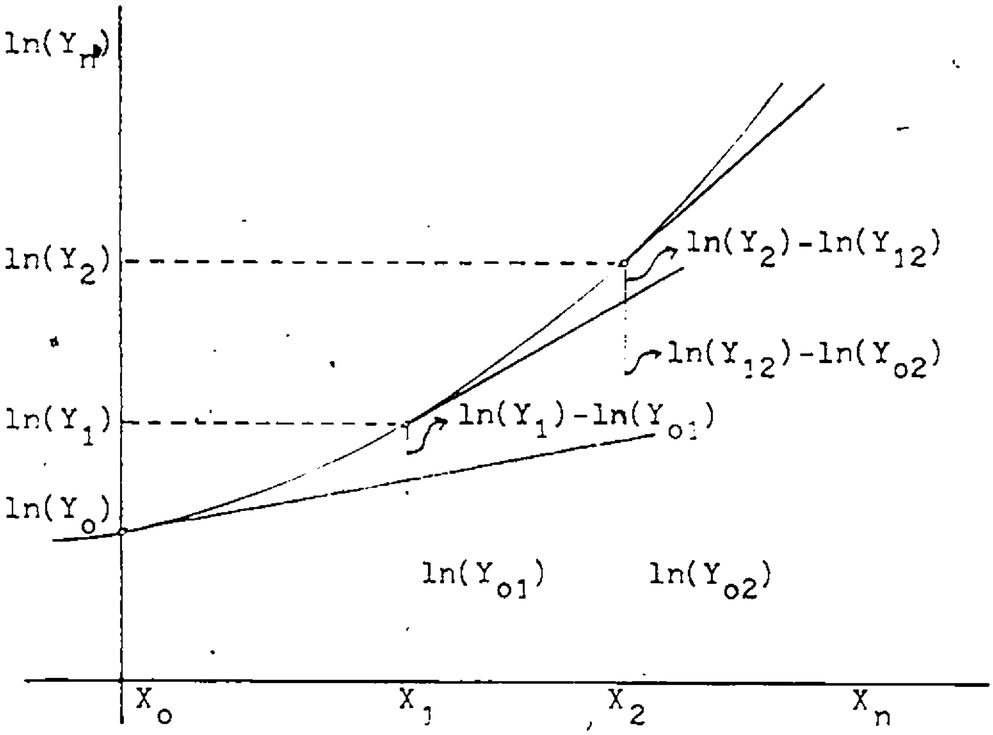

Figure A2 Schematic representation of ordinates at each abscissa as partial intercepts by tangents (log. form of simplified hyperboli solutions) drawn to the right hand side of each point considered.

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Since,

$$\ln(Y_{02}) = \ln(K_1/2) + K_2 + (R_0-1)*X_2$$

$$\ln(Y_{12}) = \ln(K_3/2) + K_4 + (R_1-1)*X_2 ,$$

substitution of these and Eq. A22c into Eq. A25a gives the expression for the ordinate at X_2:

$$\begin{aligned}\ln(Y_2) = & \left[\ln(K_1/2)+K_2+(R_0-1)*X_2\right] + \\ & + \left[\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_2\right] + \\ & + \left[\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_2\right]\end{aligned} \qquad \text{A25b}$$

Similarily, the ordinate at X_3 is expressed as:

$$\begin{aligned}\ln(Y_3) = & \left[\ln(K_1/2)+K_2+(R_0-1)*X_3\right] + \\ & + \left[\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_3\right] + \\ & + \left[\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_3\right] + \\ & + \left[\ln(K_7/K_5)+(K_8-K_6)+(R_3-R_2)*X_3\right]\end{aligned} \qquad \text{A26}$$

This process is continued until all the points considered are accounted for.

The arrangement of Eqs. A22a, A23a, A25b and A26 in ascending order according to their subscripts results in a triangular set of equations, from which is evident that only Eq. A26 conforms with Eq. A22. If establishment of appropriate relations for the entire curve is sought, the remainder of the equations in the triangular set must conform as well. This in turn will result in a square set of equations each having all

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the features of Eq. A22. Explanation of this process is aided by Figure A3.

The composite expression for the ordinate at X_0 is:

$$\ln(Y_0) = \ln(Y_{20}) + [\ln(Y_{10})-\ln(Y_{20})] + [\ln(Y_0)-\ln(Y_{10})] \quad \text{A27}$$

Since the expressions for partial intercepts at X_0 are:

$$\ln(Y_{10}) = [\ln(K_3/2)+K_4+(R_1-1)*X_0] \quad \text{and}$$

$$\ln(Y_{20}) = [\ln(K_5/2)+K_6+(R_2-1)*X_0],$$

the differences in Eq. A27 are:

$$\ln(Y_{10})-\ln(Y_{20}) = -[\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_0] \quad \text{and}$$

$$\ln(Y_0) -\ln(Y_{10}) = -[\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_0] .$$

Eq. A27 thus becomes:

$$\ln(Y_0) = [\ln(K_5/2)+K_6+(R_2-1)*X_0] -$$

$$- [\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_0] -$$

$$- [\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_0] \quad \text{A27a}$$

The composite expression for the ordinate at X_1 is:

$$\ln(Y_1) = \ln(Y_{21}) + [\ln(Y_{21})-\ln(Y_{01})] + [\ln(Y_1)-\ln(Y_{21})] \quad \text{A28}$$

Since the expression for the partial intercept $\ln(Y_{21})$ at X_1 is:

$$\ln(Y_{21}) = \ln(K_5/2) + K_6 + (R_2-R_1)*X_1 ,$$

the differences in Eq. A28 are:

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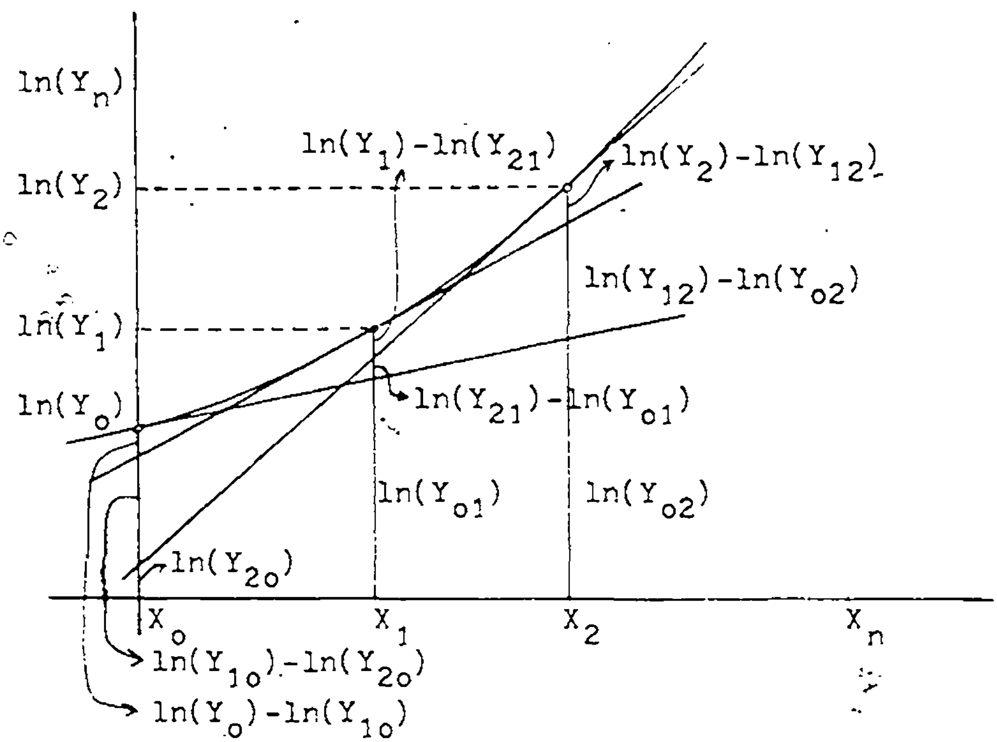

Figure A3 Schematic representation of partial intercepts on the ordinates generated by tangents drawn on both sides of each point considered.

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$$\ln(Y_{21})-\ln(Y_{01}) = +[\ln(K_5/K_1) + (K_6-K_2)+(R_2-R_0)*X_1]$$

and,

$$\ln(Y_1)-\ln(Y_{21}) = -[\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_1].$$

The composite expression for the ordinate at X_1 becomes:

$$\ln(Y_1) = [\ln(K_1/2)+K_2+(R_0-1)*X_1]$$

$$+ [\ln(K_5/K_1)+(K_6-K_2)+(R_2-R_0)*X_1]-$$

$$- [\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_1] \qquad \text{A28a}$$

Further, the composite expression for the ordinate at X_2 is:

$$\ln(Y_2) = \ln(Y_{02})+[\ln(Y_{12})-\ln(Y_{02})]+[\ln(Y_2)-\ln(Y_{12})] \qquad \text{A29}$$

and since the expression for the partial intercept $\ln(Y_{02})$ is:

$$\ln(Y_{02}) = \ln(K_1/2)+K_2+(R_0-1)*X_2$$

the differences in Eq. A29 are:

$$\ln(Y_{12})-\ln(Y_{02}) = [\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_2],$$

and,

$$\ln(Y_2)-\ln(Y_{12}) = [\ln(K_5/K_3)+(K_6-K_4)+(R_2-R_1)*X_2].$$

The composite expression for the ordinate at X_2 is thus:

$$\ln(Y_2) = [\ln(K_1/2)+K_2+(R_0-1)*X_2]+$$

$$+ [\ln(K_3/K_1)+(K_4-K_2)+(R_1-R_0)*X_2]+$$

$$+ [\ln(K_5/K_3)+(K_6-K_4)+R_2-R_1)*X_2] \qquad \text{A29a}$$

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Similarily, the composite expression for the ordinate at X_3 and other points can be obtained.

By adding Eqs. A22a and A27a, and rearranging terms, the final composite expression for the ordinate at X_0 is:

$$\ln(Y_0) = (1/2)*[\ln(K_5*K_1/4) + (K_6+K_2) + (R_2-R_0-2)*X_0] - $$
$$- (1/2)*[\ln(K_3/K_1) + (K_4-K_2) + (R_1-R_0)*X_0] - $$
$$- (1/2)*[\ln(K_5/K_3) + (K_6-K_4) + (R_2-R_1)*X_0] \qquad \text{A27b}$$

By adding Eqs. A22b and A28a, the final composite expression for the ordinate at X_1 is:

$$\ln(Y_1) = (1/2)[\ln(K_5*K_1/4) + (K_6+K_2) + (R_2-R_0-2)*X_1] + $$
$$+ (1/2)*[\ln(K_3/K_1) + (K_4-K_2) + (R_1-R_0)*X_1] - $$
$$- (1/2)*[\ln(K_5/K_3) + (K_6-K_4) + (R_2-R_1)*X_1] \qquad \text{A28b}$$

Similarily, the final composite expression for the ordinate at X_2 is given by:

$$\ln(Y_2) = (1/2)*[\ln(K_5*K_1/4) + (K_6+K_2) + (R_2-R_0-2)*X_2] + $$
$$+ (1/2)*[\ln(K_3/K_1) + (K_4-K_2) + (R_1-R_0)*X_2] + $$
$$+ (1/2)*[\ln(K_5/K_3) + (K_6-K_4) + (R_2-R_1)*X_2] \qquad \text{A29b}$$

Note the sign change from negative to positive in front of square brackets successively on moving from $n = 0$ to $n = 3$.

Generally, the final composite expression for the ordinate at X_n for m number of points considered on a curve

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segment is:

$$\ln(Y_n) = (1/2)*[\ln(K_{2m-1}*K_1/4) + (K_{2m}+K_2) + (R_n-R_0-2)*X_n] -+$$

$$-+ (1/2)*[\ln(K_3/K_1) + (K_4-K_2) + (R_1-R_0)*X_n] -+$$

$$-+ (1/2)*[\ln(K_5/K_3) + (K_6-K_4) + (R_2-R_1)*X_n] -+$$

$$-+ (1/2)*[\ln(K_{2m-1}/K_{2m-3}) + (K_{2m}-K_{2m+2}) + (R_n-R_{n-1})*X_n] \qquad \text{A30}$$

Eq. A30 is identical to Eq. A22, since all the constants in Eq. A30 cancel out except those having the subscripts pertinent to the original equation of the tangent at the point considered, and that all the variable members cancel out as well, except those having the subscript applicable to the point considered.

If equations A30 for each point considered are arranged in ascending order according to their subscripts, the square set of equations is obtained. Double signs in front of the members in square brackets are indicative of the progressive sign change toward the bottom right hand corner of the set. By redefining the constants, and reducing the variable parts (which are the members having exponential coefficients) into their shortest form, the square set of equations can be expressed as:

$$\ln(Y_0) = [c_o+c_e]_1-[c_o+c_e]_2- \dots -[c_o+C_e]_m + (R_o-1)*X_o \qquad 1$$

$$\ln(Y_1) = [c_o+c_e]_1+[c_o+c_e]_2- \dots -[c_o+c_e]_m + (R_1-1)*X_1 \qquad 2$$

$$\ln(Y_2) = [c_o+c_e]_1+[c_o+C_e]_2+ \dots -[c_o+c_e]_m + (R_2-1)*X_2 \qquad 3$$

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$$\ln(Y_n) = [c_o+c_e]_1+[c_o+c_e]_2+ \dots +[c_o+c_e]_m + (R_n-1)*X_n \qquad m$$

where c_o and c_e are the odd and even subscripted constants respectively, or:

$$[c_o+c_e]_1 = [\ln((K_{2m-1}*K_1)^{1/2}/2)+(K_{2m}+K_2)/2] = [\ln(k_1/2)+k_2]$$

$$[c_1+c_e]_2 = [\ln((K_3/K_1)^{1/2})+(K_4-K_2)/2] = [\ln(k_3/2)+k_4]$$

$$[c_o+c_e]_3 = [\ln((K_5/K_3)^{1/2})+(K_6-K_4)/2] = [\ln(k_5/2)+k_6]$$

$$[c_o+c_e]_m = [\ln((K_{2m-1}/K_{2m-3})^{1/2})+(K_{2m}-K_{2m-2})/2] =$$

$$= [\ln(k_{2m-1}/2) + k_{2m}] .$$

It is evident from these equations that they are composed of as many unit members (in square brackets) as there are points in consideration. Each unit member in Eq. A30 represents the mean value of the function between two adjacent points, except the first one which gives the mean value between the two extreme points.

A.2.2 Square Matrix and Computation of Constants

If the variable member in each line of the square set is transferred to the left hand side, and all the constants are left on the right hand side, the square matrix obtained consists of m number of rows and twice as many columns, i.e.,

$$L_0 = [c_{o1}+c_{e1}-c_{o2}-c_{e2}-c_{o3}-c_{e3}- \dots -c_{om}-c_{em}] \qquad 1$$

$$L_1 = [c_{o1}+c_{e1}+c_{o2}+c_{e2}-c_{o3}-c_{e3}- \dots -c_{om}-c_{em}] \qquad 2$$

$$L_2 = [c_{o1}+c_{e1}+c_{o2}+c_{e2}+c_{o3}+c_{e3}- \dots -c_{om}-c_{em}] \qquad 3$$

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$$L_n = [c_{o1}+c_{e1}+c_{o2}+c_{e2}+c_{o3}+c_{e3}+ \cdots -c_{om}-c_{em}] \quad m$$

where, $L_n = \ln(Y_n)-(R_n-1)*X_n$, and $c_{o1},\ldots,c_{om}$ and $c_{e1},\ldots,c_{em}$ are the odd and even subscripted constants respectively.

In order to calculate the values of all the constants, an initial value of either the odd or even subscripted constants in each point considered is arbitrarily set, and the initial values of the remaining constants are calculated from Eqs. A22a through A22d (or Eq. A30). For example, for n = 0, Eq. A30 is reduced to Eq. A22a, for n = 1 to Eq. A22b, and so forth, and for n = n to $\ln(Y_n) = \ln(K_{2n+1}/2)+(R_n-1)*X_n$. The initial values of both the odd and even subscripted constants thus obtained are introduced into the square matrix, from which new values of the constants are computed. Since there are twice as many constants in each line of the square matrix than there are equations available, and since all their coefficients are one, the final value of each constant is obtained by an iterative procedure capable of making each constant converge to a definite value. This iterative procedure is continued until the values finally obtained give a sufficiently accurate representation of the cooling curve. Thus the final equation satisfying every point considered on the cooling curve (or within the segment) is given by:

$$\ln(Y_n) = [C_o+C_e]_1 -+ [C_o+C_e]_2 -+ [C_o+C_e]_3 -+ \cdots -+ -+ [C_o+C_e]_m + (R_n-1)*X_n \quad \text{A31}$$

where the odd and even subscripted constants C_o and C_e

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respectively are referred to as the constant solidification parameters, and possess definite values characterizing significant features of the cooling curve.

The entire iterative process, as part of the computer program designed for computation of the constants, is given in Appendix B.

An identical curve fitting procedure as used above for the forward difference mode and $R_n > 0$ can also be developed for any R_n value for either the forward or backward difference modes. For the backward difference mode the even subscripted constants in Eq. A31 already include the negative sign peculiar to the differentiation mode adopted in developing the basic functional relation for each point.

A.3 Exponential Parameter R

Throughout foregoing discussion the exponential coefficient (parameter) R or R_n has been considered to be constant in the close neighbourhood of the (X_n, Y_n) point. For infinitesimal distances the expression for R (c.f. Eq. A9) becomes a differential equation, i.e.,

$$R = \left[1 +- 2*(dX/dY)/Y\right]^{1/2} \qquad \text{A32}$$

since Z = A/y may be replaced by (dY/dX)/Y. Rearrangement of terms gives:

$$(R^2-1)dX = +-2*dY/Y,$$

can be integrated to give:

$$(R^2-1)*X + C_x = +-2*\ln(Y) + C_y .$$

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If the integration constants C_x and C_y are arbitrarily set to zero, the equation for R becomes:

$$R = \left[1 +- 2*\ln(Y)/X \right]^{1/2} \qquad A33$$

or,

$$Y = \exp +- \left[(R^2-1)/2 \right]*X \qquad A33a$$

Since R is the function of two variables (c.f. Eq. A33), namely R = F(X,Y), the implicit differentiation (for constant R) gives:

$$dY/dX = -(\partial F/\partial X)/(\partial F/\partial Y) \qquad A34$$

Moreover, R may also be considered as a function of variables A and Y, namely R = f(A,Y), both of which are functions of X. The total differential of R is then:

$$dR/dX = (\partial f/\partial A)*(dA/dX) + (\partial f/\partial Y)*(dY/dX)$$

Since, dA/dX = (d/dX)(dY/dX),

$$dR/dX = (\partial f/\partial A)*(d^2Y/dX^2) + (\partial f/\partial Y)(*dY/dX) \qquad A35$$

The second part of the first member on the right hand side of Eq. A35 is the second derivative of the function describing R. By substituting Eq. A34 into the second member on the right hand side of Eq. A35:

$$dR/dX = (\partial f/\partial A)*(d^2Y/dX^2) = (\partial f/\partial Y)*(\partial F/\partial X)/(\partial F/\partial Y) \qquad A35a$$

However, in the vicinity of the point considered R is not generally constant, and thus $(\partial f/\partial Y) = (\partial F/\partial Y)$. By further assuming that $(\partial f/\partial A) \approx (\partial F/\partial X)$, Eq. A35a can be simplified

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to give:

$$dR/dX = (\partial R/\partial X)*(d^2Y/dX^2-1) \quad \text{A36}$$

From Eq. A33, for R ≠ const., it follows that:

$$\partial F/\partial X = -+[\ln(Y)/X^2]*[1+-2*\ln(Y)/X]^{-1/2} \quad \text{A33a}$$

and,

$$\partial F/\partial Y = +-[1/(X*Y)]* 1+[2*\ln(Y)/X]^{-1/2} . \quad \text{A33b}$$

which on substitution into Eq. A34 gives:

$$dY/dX = +-Y*\ln(Y)/X \quad \text{A34a}$$

where the double sign denotes the forward and backward difference mode. Integration of Eq. A34a gives the implicit form of the function for R ≠ const., viz.,

$$+-\ln[\ln(Y)] = X^2/2 + C \quad \text{A37}$$

which in its explicit form is:

$$Y = +- \exp[\exp(X^2/2 + C)] \quad \text{A37a}$$

(Note the difference for the explicit form of the function for R = const. given by Eq. A33a).

Differentiation of Eq. A34a gives the second derivative of the function, i.e.,

$$d^2Y/dX^2 = Y*\ln^2(Y)/X^2,$$

which upon substitution into Eq. A36, together with Eq. A33a gives:

$$dR/dX = -+[\ln(Y)/X^2]*[1\pm-2*\ln(Y)/X]^{-1/2} * [Y*\ln^2(Y)/X^2-1]$$

A36a

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Rearrangement of terms and redefinition of functions gives:

$$dR/dX = -+A*(B-X^2)*X^{-7/2}*(X+-2*A)^{-1/2} \qquad A36b$$

where A = ln(Y), and B = Y*ln^2(Y).

Separation of variables and integration of Eq. A36b gives the expression for R, i.e.,

$$R = -+A*\int(B-X^2)*X^{-7/2}*(X+-2*A)^{-1/2}dX \qquad A38$$

Integration by parts of Eq. A38 is done by setting,

$$R = -+A*\left[U*V - \int(VdU)\right] \qquad A39$$

where,

$$U = B-X^2,$$

and,

$$dV = X^{-7/2}*(X+-2*A)^{-1/2}dX .$$

From the latter,

$$V = \int X^{-7/2}*(X+-2*A)^{-1/2}dX$$

Substitution for $(X+-2*A)^{1/2}$ = G gives,

$$X = G^2 -+ 2*A,$$

and,

$$dX = 2*GdG ,$$

so that the expression for V becomes:

$$V = 2*\int(G^2-+2*A)^{-7/2}dG$$

which integrated gives (21,26):

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$$V = -+G/5*A*(G^2-+2*A)^{5/2} + 2*G/15*A^2*(G^2-+2*A)^{3/2} -+$$
$$-+ 2*G/15*A^3*(G^2-+2*A)^{1/2}$$

Substituting for G gives:

$$V = -+(X+-2*A)^{1/2}/5*A*X^{5/2} + 2*(X+-2*A)^{1/2}/15*A^2*X^{3/2} -+$$
$$-+ 2*(X+-2*A)^{1/2}/15*A^3*X^{1/2}$$

Since $U = B-X^2$,

$$U*V = \left[(X+-2*A)^{1/2}/5*A\right] * \left[-+B/X^{5/2} + 2*B/3*A*X^{3/2} -+\right.$$
$$\left.-+ 2*B/3*A^2*X^{1/2} +-1/X^{1/2} - 2*X^{1/2}/3*A -+ 2*X^{3/2}/3*A^2\right]$$

Since $dU = -2*XdX$,

$$V*dU = \left[2*(X+-2*A)^{1/2}/5*A\right] * \left[+-1/X^{3/2} - 2/3*A*X^{1/2} +-\right.$$
$$\left.+-2*X^{1/2}/3*A^2\right] dX$$

from which,

$$\int\left[VdU\right] = +-(2/5*A)*\int\left[(X+-2*A)^{1/2}/X^{3/2}\right]dX - \quad (=AA)$$
$$-(4/15*A^2)*\int\left[(X+-2*A)^{1/2}/X^{1/2}\right]dX +- \quad (=BB)$$
$$+-(4/15*A^3)*\int\left[(X+-2*A)*X^{1/2}\right]dX \quad (=CC)$$

A41

Separate integration of AA, BB, and CC using the identical substitution for $(X+-2*A)^{1/2} = G$ gives (21,26):

$$AA = -+4*(X+-2*A)^{1/2}/5*A*X^{1/2} +-4*\ln\left[(+-2*A)^{1/2}+X^{1/2}\right]/5*A$$

$$BB = -4*(X+-2*A)^{1/2}*X^{1/2}/15*A^2 -+8*\ln\left[(X+-2*A)^{1/2}+X^{1/2}\right]/15*A$$

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$$CC = +-2*(X+-2*A)^{1/2}*X^{3/2}/15*A^3+2*(X+-2*A)^{1/2}*X^{1/2}/15*A-+$$
$$-+4*\ln\left[(X+-2*A)^{1/2}+X^{1/2}\right]/15*A$$

which on substitution into Eq. A41 gives:

$$\int\left[V*dU\right] = \left[(X+-2*A)^{1/2}/5*A\right]*\left[-+4/X^{1/2} +- 2*X^{1/2}/3*A +- +- 2*X^{3/2}/3*A^2\right] \qquad \text{A41a}$$

Introduction of Eqs. A40 and A41a into Eq. A39 gives:

$$R = \left[(X+-2*A)/X\right]^{1/2}*\left[2*B/5*X^2-+2*B/15*A*X+2*B/15*X-1\right]$$

Since A = ln(Y) and B = $Y*\ln^2(Y)$, the final expression for R for either the forward or backward difference mode is given by:

$$R = \left[1+-2*\ln(Y)/X\right]^{1/2}* *\left[Y*\ln^2(Y)/5*X^2-+2*Y*\ln(Y)/15*X+2*Y/15-1\right]+C_n \qquad \text{A42}$$

Eq. A42 is the expression for R (≠ constant) used in this investigation. The first member in square brackets is identical to Eq. A33, i.e., to the expression for R = constant. The second member is a power series for ln(Y)/X, the highest power being 2, since the original expression for R was derived from the auxiliary quadratic equation of the first degree, second order differential equation (c.f., Eqs. A5, A8, and A9). In this form the second member may be considered a correction factor resulting from the variation in R.

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APPENDIX B

COMPUTER PROGRAM FOR

CALCULATION OF CONSTANTS

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```
$JOB    WATFIV  XXXXXXXXXX   NAME-SPIRO BUJ
C NODULAR IRON SOLIDIFICATION CURVES
      REAL XP(18),YP(18),X(18),Y(18),R(85),XX(35),YY(35)
      COMMON /AREA1/XL(85),YL(85)/AREA2/C(L,TO)/AREA3/TI(85),GY(85),
     XTIGY(85)/AREA4/XINIT/AREA5/A(18)/AREA6/MF/AREA7/XZERY
      READ,M,TEMP,(XP(I),I=1,M),(YP(I),I=1,M)
C XP(I) AND YP(I) ARE PRELIMINARY VALUES OF COORDINATES FOR EACH
C POINT IN CONSIDERATION ON THE CURVE.
C M IS THE NUMBER OF POINTS IN CONSIDERATION (COORDINATES XP(I),
C YP(I)) ARBITRARILY SELECTED AT RANDOM FROM THE GRAPH.
C TEMP IS THE MAXIMUM RECORDED TEMPERATURE (PEAK TEMPERATURE).
      XINIT=46.
C XINIT IS THE INITIAL VALUE OF XX(I) - TIME IN SEC., I.E. XX(1),
C ARBITRARILY SELECTED AFTER INTERPOLATIONS BETWEEN TWO ADJACENT
C POINTS HAVE BEEN COMPUTED BY SUBPROGRAM XANDY.
C X(I) AND Y(I) ARE VALUES OF XP(I) AND YP(I) NORMALIZED BY THE
C TIME-TEMPERATURE CORRECTION FACTOR (TTFACT). XX(I) AND YY(I) ARE
C RESPECTIVE RENAMED VALUES OF X(I) AND Y(I) TOGETHER WITH ADDITIO-
C NAL INTERPOLATED VALUES FOR XX(I) AND YY(I) BETWEEN TWO ADJACENT
C POINTS.
      XZERY=-70.
C THE VALUE OF YP(I) READ FROM THE GRAPH IMMEDIATELY AFTER THE XZERY
C POINT (XP(I)=XZERY) SHOULD READ ZERO.
      PRINT 70
 70   FORMAT(//' ','NODULAR IRON SOLIDIFICATION CURVE # 3'///
     X' ','XP(I) - PRELIMINARY VALUES FOR TIMES (IN SEC.) RELATIVE'
     X/' ','TO THE LOWEST UNDERCOOLING POINT READ AT RANDOM FROM'/
     X' ','THE GRAPH')
      PRINT 81,(XP(I),I=1,M)
 81   FORMAT(' ',10(F7.2,2X)/' ',10(F7.2,2X))
      PRINT 82
 82   FORMAT(/' ','YP(I) - PRELIMINARY VALUES FOR TEMPERATURES (IN '
     X/' ','DEG. FAHR.) RELATIVE TO THE LOWEST UNDERCOOLING POINT'/
     X' ','READ AT RANDOM FROM THE GRAPH')
      PRINT 83,(YP(I),I=1,M)
 83   FORMAT(' ',10(F7.2,2X)/' ',10(F7.2,2X))
      PRINT 20,TEMP
C TEMP IS THE MAXIMUM RECORDED TEMPERATURE OF LIQUID METAL AFTER
C METAL HAS BEEN POURED INTO RECORDING CUP EQUIPED WITH CHR. AL.
C THERMOCOUPLE
 20   FORMAT(//' ','PEAK TEMPERATURE RECORDED    : ',F8.2,' DEG. F')
      TTFACT=2200./TEMP
      PRINT 30,TTFACT
 30   FORMAT(' ','TEMP-TIME CORRECTION FACTOR :',F8.4)
      PRINT 111
 111  FORMAT(//' ','METAL CHEMISTRY :'//' ','C      3.65  X'/' ',
     X'SI    2.75  X'/' ','MN    .68  X'/' ','CR    .10  X'/' ',
     X'CU    .14  X'/' ','AL    .016 X'/' ','MG    .042 X'/' ',
     X'S     .007  X'///)
      DO 40 I=1,M
      X(I)=TTFACT*XP(I)
 40   Y(I)=TTFACT*YP(I)
      N=M*2
      CALL XANDY(M,N,X,Y,XX,YY)
C SUBPROGRAM XANDY CALCULATES THE AVERAGE VALUE FOR X(I) BETWEEN TWO
C ADJACENT X(I) VALUES,AND FINDS THE INTERPOLATED VALUE FOR Y(I)
C BETWEEN TWO ADJACENT Y(I) VELUES.
      ML=N-1
      NL=2*ML
      PRINT 69
 69   FORMAT(' ','XX(I) - XP(I) VALUES NORMALIZED BY THE TIME-'/
     X' ','TEMPERATURE CORRECTION FACTOR, AND CORRESPONDING AVERAGE'
     X/' ','VALUES BETWEEN TWO ADJACENT POINTS')
      PRINT 84,(XX(I),I=1,ML)
 84   FORMAT(4(' ',10(F9.4,2X)/)/)
      PRINT 85
 85   FORMAT(/' ','YY(I) - YP(I) VALUES NORMALIZED BY THE TIME-'/
     X' ','TEMPERATURE CORRECTION FACTOR, AND CORRESPONDING INTER-'
     X/' ','POLATED VALUES BETWEEN TWO ADJACENT POINTS')
      PRINT 86,(YY(I),I=1,ML)
 86   FORMAT(4(' ',10(F9.4,2X)/))
      PRINT 73,(A(I),I=1,M)
 73   FORMAT(//' ','A(I)',4X,9(F10.5,3X)/' ',8X,9(F10.5,3X)///)
C A(I) IS THE VALUE OF N-LOGARITHM OF Y(I) DEVIDED BY X(I). IN THIS
C PARTICULAT CASE THE VALUE OF A(I) AT X(I)=0 EQUALS ONE, AND AT
C Y(I)=0 THE VALUE OF A(I) IS ASSUMED TO BE ZERO.
      MF=78
C MF IS THE FINAL NUMBER OF POINTS CONSIDERED FOR CALCULATION OF ALL
C RELEVANT CONSTANTS AND EXPONENTIAL COEFFICIENTS R(I).
      CALL LINUP (ML,NL,XX,YY)
```

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```
C SUBPROGRAM LINUP LINES UP ALL THE VALUES OF XX(I) IN DESCENDING
C ORDER STARTING WITH INITIAL VALUE XINIT. AND CALCULATES CORRESPON-
C DING VALUES FOR YY(I).
          NF=2*MF
          CALL REXPO(MF,XL,YL,R)
C SUBPROGRAM REXPO CALCULATES VALUES FOR EXPONENTIAL COEFFICIENT
C R(I) FOR EACH POINT IN CONSIDERATION. THE EXPONENTIAL COEFFICIENT
C R(I) IS A TIME-TEMPERATURE DEPENDENT FACTOR WORKED OUT FOR EACH
C PARTICULAR POINT. AND IS THUS CHARACTERISTIC FOR EACH POINT AND
C ALSO DIFFERENT FROM ONE CURVE TO THE OTHER.
          CALL ALLEN(MF,NF,XL,YL)
C SUBPROGRAM ALLEN TOGETHER WITH SUBPROGRAM LODEB CALCULATE ALL
C RELEVANT CONSTANTS (E.G. C(ODD),C(EVEN)) AND THEIR SUMS. WHICH IN
C TURN MUST SATISFY THE BASIC EQUATION LN(Y(I))=C(ODD)+C(EVEN)*
C (R(I)+1)*X(I) FOR ANY POINT ON THE CURVE.
          PRINT 71
 71       FORMAT(//' ',5X,'X(I)',9X,'Y(I)',9X,'R(I)',9X,'C(ODD)',6X,
         X'C(EVEN)',4X,'SUM(C(ODD))',3X,'SUM(C(EVEN))',6X,'SUM(C(I))')
          DO 66 I=1,MF
          PRINT 72,XL(I),YL(I),R(I),C(I*2-1),C(I*2),TI(I),GY(I),TIGY(I)
 72       FORMAT(' ',F9.4,5X,F8.4,5X,F8.4,5X,F10.4,5X,F10.4,5X,F10.4,
         X5X,F10.4,5X,F10.4)
 66       CONTINUE
          STOP
          END

          SUBROUTINE LINUP (M,N,X,Y)
          COMMON /AREA1/XL(85),YL(85)/AREA4/XINIT/AREA6/MF/AREA7/XZERY
          REAL X(M),Y(M),DB(35)
          P=0.
          DO 14 I=1,MF
          XL(I)=XINIT-P
 14       P=P+2.
          DO 203 I=1,M
          IF(X(I).EQ.0.)GO TO 201
          IF(Y(I))200,201,202
 200      DB(I)=-ALOG(ABS(Y(I)))/X(I)
          GO TO 203
 201      DB(I)=0.
          GO TO 203
 202      DB(I)=ALOG(Y(I))/X(I)
 203      CONTINUE
          L=1
          DO 12 I=1,MF
          IF(XL(I).LT.X(L+1))L=L+1
          IF(XL(I).LT.X(L+1))L=L+1
          IF(L.EQ.(N-1))GO TO 13
          IF((ABS(Y(L+1)).LE.1.).AND.(X(L+1).LT.XZERY))GO TO 144
          IF((ABS(Y(L)).LT.1.).AND.(X(L).LT.XZERY))GO TO 144
          IF((DB(L).EQ.0.).OR.(DB(L+1).EQ.0.).AND.(X(L).LT.0.))GO TO 144
          OTT=(DB(L+1)*(X(L)-XL(I))+DB(L)*(XL(I)-X(L+1)))*XL(I)/
         X(X(L)-X(L+1))
          GO TO 145
 144      YL(I)=(Y(L+1)*(X(L)-XL(I))+Y(L)*(XL(I)-X(L+1)))/(X(L)-X(L+1))
          GO TO 12
 145      IF((OTT.LT.0.).AND.(XL(I).GT.XZERY))GO TO 313
          IF(OTT.LT.0.)GO TO 18
 313      YL(I)=EXP(OTT)
          GO TO 12
 18       YL(I)=-(EXP(ABS(OTT)))
          GO TO 12
 12       CONTINUE
 13       RETURN
          END

          SUBROUTINE XANDY (M,N,X,Y,XX,YY)
          COMMON/AREA5/A(18)/AREA7/XZERY
          REAL X(M),Y(M),XX(35),YY(35),FACT2(17)
          DO 40 I=1,M
          XX(I*2-1)=X(I)
          IF(Y(I))66,55,56
 66       YY(I*2-1)=-ALOG(ABS(Y(I)))
          GO TO 14
 55       YY(I*2-1)=0.
          GO TO 14
 56       YY(I*2-1)=ALOG(Y(I))
 14       IF(X(I).EQ.0.)GO TO 41
          A(I)=YY(2*I-1)/X(I)
          GO TO 40
 41       A(I)=1.
```

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```
      40  CCNTINUE
          K=M-1
          DO 24 I=1,K
          IF((X(I+1).EQ.0.).OR.(X(I).EQ.0.))GO TO 130
          IF((YY(2*I-1).EQ.0.).OR.(YY(2*I+1).EQ.0.))GO TO 140
          XXM=(X(I)+X(I+1))/2.
          GC TO 132
     130  YYM=(YY(I*2-1)+YY(I*2+1))/2.
          XXM=(X(I)+X(I+1))/2.
          GO TO 141
     132  AA1=A(I)/A(I+1)
          AA2=A(I+1)/A(I)
          FACT1=(AA1+1.)/2.
          FACT2(I)=(AA1+AA2)/4.+0.5
          IF((X(I).LT.0.).OR.(I.EQ.1))GC TO 131
          AAA=(A(I)+A(I+1))/2.
          IF(FACT2(I).GT.FACT2(I-1))FACT2(I)=1./FACT2(I)
          YYM=FACT2(I)*XXM*AAA
          GC TO 141
     131  YYM=FACT1*XXM*A(I+1)
          GO TO 141
     140  XXM=(X(I)+X(I+1))/2.
          YEX=(Y(I)+Y(I+1))/2.
          GO TO 44
     141  IF((YYM.LT.0.).AND.(XXM.GT.XZERY))GO TO 31
          IF(YYM)33,31,31
      33  YEX=-(EXP(ABS(YYM)))
          GO TO 44
      31  YEX=EXP(YYM)
      44  XX(I*2)=XXM
          YY(I*2)=YEX
      24  CCNTINUE
          L=M*2-1
          DC 25 I=1,L,2
          IF((YY(I).LT.0.).AND.(XX(I).GT.XZERY))GO TO 20
          IF((ABS(YY(I)).LE..05).AND.(XX(I).LT.XZERY))GO TO 21
          IF(YY(I))19,21,20
      20  YY(I)=EXP(YY(I))
          GC TO 25
      21  YY(I)=0.0
          GC TO 25
      19  YY(I)=-(EXP(ABS(YY(I))))
      25  CCNTINUE
          RETURN
          END

          SUBROUTINE ALLEN(M,N,X,Y)
          CCMMON/AREA2/C(170)/AREA3/TI(85),GY(85),TIGY(85)
          REAL X(M),Y(M),BL(85),H(170)
          CALL LODEB(M,N,X,Y,BL)
          DO 37 I=1,N
      37  H(I)=-1.
          DC 38 I=1,M
          TIG=0.
          GGY=0.
          H(I)=1.
          DO 39 J=1,M
          TIG=TIG+H(J)*C(J*2-1)
      39  GGY=GGY+H(J)*C(J*2)
          TI(I)=TIG
          GY(I)=GGY
      38  TIGY(I)=TI(I)+GY(I)
          RETURN
          END

          SUBROUTINE LODEB (M,N,X,Y,BL)
          CCMMCN/AREA2/C(170)
          REAL X(M),Y(M),EQ(170),BL(M),C(170),H(170),ZR(85),LOV,HH(85),
         XCC(85)
          DC 77 K=2,N,2
          IF(ABS(X(K/2)).LE.0.1)GO TO 78
          IF(ABS(Y(K/2)).LE.0.1)GO TO 76
          IF(Y(K/2))900,902,901
     900  YC=-ALOG(ABS(Y(K/2)))
          GO TO 966
     901  YC=ALOG(Y(K/2))
          GC TO 966
     902  YC=0.
     966  C(K)=YC/X(K/2)
          GC TO 77
```

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```
76    C(K)=0.
      GO TO 77
78    C(K)=1.
77    CONTINUE
      DO 55 I=4,N,2
55    C(I)=(C(I)-C(I-2))/2.
      C(2)=(C(N)+C(2))/2.
      CALL ZEREX (M,N,X,Y,EQ,ZR)
      DO 8 I=1,M
8     O(2*I-1)=ALOG(2.)+EQ(I)
      C(1)=0.5*(O(1)+O(N-1))-ALOG(2.)
      J=M-1
      DO 4 I=1,J
4     C(2*I+1)=0.5*(O(2*I+1)-O(2*I-1))
      J=0
3     DO 1 I=1,N
1     H(I)=1.
      DO 2 I=1,N
      K=I+J
      IF(I+J.GT.N)K=I+J-N
      F=1.
      IF(I.GT.M)GO TO 88
      LOV=0.
      H(I)=-1.
      DO 35 L=1,M
35    LOV=LOV+H(L)*(C(L*2-1)+C(L*2))
      IF(K.GT.I*2)F=-1.
      C(K)=C(K)+(F*(EQ(I)+LOV))/(2.**(J+1))
      GO TO 2
88    DEN=0.
      H(I)=-1.
      DO 36 L=1,M
36    DEN=DEN+H(L+M)*(C(L*2-1)+C(L*2))
      IF(K.GT.(I-M)*2)F=-1.
      C(K)=C(K)+(F*(EQ(I)+DEN))/(2.**(J+1))
2     CONTINUE
      J=J+1
      IF(J.EQ.N)GO TO 44
      GO TO 3
44    DO 11 I=1,M
11    CC(I)=(C(2*I-1)+C(2*I))*2.
      HH(1)=(EQ(1)+EQ(M))/CC(1)
      DO 333 I=2,M
333   HH(I)=(EQ(I)-EQ(I-1))/CC(I)
      DO 222 I=1,M
      C(2*I-1)=HH(I)*C(2*I-1)
222   C(2*I)=HH(I)*C(2*I)
      DO 37 I=1,N
37    H(I)=-1.
      DO 38 I=1,M
      LOV=0.
      H(I)=1.
      DO 39 J=1,M
39    LOV=LOV+H(J)*(C(J*2-1)+C(J*2))
      BL(I)=LOV
38    CONTINUE
      RETURN
      END

      SUBROUTINE ZEREX (M,N,X,Y,EQ,ZR)
      COMMON/AREA7/XZERY
      REAL X(M),Y(M),R(85),EQ(N),ZR(M)
      CALL REXPO (M,X,Y,R)
      DO 77 I=1,M
      IF(ABS(X(I)).LE.0.1)X(I)=0.
      IF((ABS(Y(I)).LT.0.1).AND.(X(I).LT.XZERY))Y(I)=0.
      IF(X(I))1,3,3
1     IF(ABS(X(I)).LE.10.)GO TO 4
      GO TO 2
4     Z=ALOG(Y(I))
      EQ(I)=Z-X(I)-ALOG(COSH(R(I)*X(I)))
      ZR(I)=-(EQ(I)-Z)
      GO TO 77
2     IF(Y(I))66,8,55
66    Z=-ALOG(ABS(Y(I)))
      GO TO 7
8     Z=0.
      GO TO 7
55    Z=ALOG(Y(I))
7     EQ(I)=Z-(R(I)+1.)*X(I)+ALOG(2.)
```

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```
      ZR(I)=-(EQ(I)-Z)
      GO TO 77
    3 IF(Y(I))44,45,46
   44 Z=-ALOG(ABS(Y(I)))
      GO TO 47
   45 Z=0.
      GO TO 47
   46 Z=ALOG(Y(I))
   47 IF(R(I)*X(I).GT.170.)GO TO 444
      EQ(I)=Z+X(I)-ALOG(COSH(R(I)*X(I)))
      GO TO 445
  444 EQ(I)=Z+X(I)*(1.-R(I))+ALOG(2.)
  445 ZR(I)=-(EQ(I)-Z)
   77 EQ(I+M)=EQ(I)
      RETURN
      END

      SUBROUTINE REXPO (M,X,Y,R)
      COMMON/AREA7/XZERY
      REAL X(M),Y(M),R(M)
      DO 6 I=1,M
      IF(ABS(X(I)).LE.0.1)GO TO 11
      IF((ABS(Y(I)).LT.0.1).AND.(X(I).LT.XZERY))Y(I)=0.
      IF (Y(I))66,8,55
   66 Q=-ALOG(ABS(Y(I)))
      GO TO 9
    8 A=0.
      GO TO 99
   55 Q=ALOG(Y(I))
      GO TO 9
   11 A=-1.
      IF(ABS(X(I)).LE.0.1)X(I)=0.
      GO TO 99
    9 A=Q/X(I)
   99 IF(X(I))1,1,2
    1 R(I)=(SQRT(1.-2.*A))*((Y(I)*A**2)/5.+2.*Y(I)*A/15.+
     X2.*Y(I)/15.-1.)
      GO TO 6
    2 R(I)=(SQRT(1.+2.*A))*((Y(I)*A**2)/5.-2.*Y(I)*A/15.+
     X2.*Y(I)/15.-1.)
    6 CONTINUE
      RETURN
      END

  $ENTRY
```

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APPENDIX C

Metal Chemistry, Cooling Curve Data, and Solidification Parameters for Ingots

List of Symbols

X(I) - time (sec.) relative to the maximum undercooling point spaced evenly along the curve (corresponding to the symbol X_n);

Y(I) - temperature (°F) relative to the maximum undercooling temperature at X(I) (corresponding to the symbol Y_n);

R(I) - exponential parameter (corresponding to R_n) for each point considered (variable solidification parameter = R_n+-1);

C(ODD) - odd subscripted constant solidification parameter in expanded form (corresponding to the symbol C_o);

C(EVEN) - even subscripted constant solidification parameter in expanded form (corresponding to C_e);

SUM(C(I)) - sum of all odd and even subscripted constant solidification parameters (condensed form) for each point considered (corresponding to the symbol SC_n).

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Sample Ingot 1

Metal Chemistry - C 3.84 %, Si 2.32 %, C.E. 4.61 %,
Mn 0.77 %, Cr 0.14 %, Cu 0.12 %,
Al o.020 %, Mg 0.046 %, S 0.009 %.

X(I)	Y(I)	A(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	28.4573	4.0524	-627.4551	-0.1343	-44.4895
14.0000	24.4285	2.1340	16.4155	-3.1608	-11.9793
12.0000	15.4279	0.9031	8.1171	0.1725	4.5996
10.0000	9.1704	0.0502	3.6223	0.1291	12.1021
8.0000	5.3289	-0.4662	-2.7097	-0.0196	6.6434
6.0000	3.2911	-0.7356	-1.6119	0.0291	3.4778
4.0000	2.2279	-0.8811	-1.0339	0.2831	1.9763
2.0000	1.3019	-0.9497	-0.8502	0.3835	1.0429
0.0000	1.0000	-1.3856	-4.1531	3.6354	0.0074
-2.0000	1.6435	-0.9971	-1.7679	2.3565	1.1845
-4.0000	2.4439	-0.8691	-0.0721	0.0352	2.1165
-6.0000	3.7812	-0.6853	1.7153	-0.8145	3.9180
-8.0000	4.9503	-0.5115	0.9483	0.1962	6.2071
-10.0000	5.8807	-0.3700	1.0880	0.1942	8.7714
-12.0000	6.3780	-0.2866	1.3590	-0.1878	11.1139
-14.0000	6.3153	-0.2775	0.5757	0.1961	12.6577
-16.0000	6.2869	-0.2678	0.7298	0.0695	14.2544
-18.0000	6.9933	-0.1676	1.4729	0.2141	17.6295
-20.0000	7.5627	-0.0549	1.6580	0.0406	21.0258
-22.0000	7.9700	-0.0255	1.4175	0.1771	24.2150
-24.0000	8.1658	0.0065	1.6006	-0.2298	26.9569
-26.0000	8.1401	0.0091	1.4713	-0.4332	29.0332
-28.0000	7.8952	-0.0176	8.3382	-7.7171	30.2756
-30.0000	7.4506	-0.0707	0.0496	0.1065	30.5881
-32.0000	7.3779	-0.0763	3.2963	-2.4617	32.2573
-34.0000	7.3626	-0.0749	0.8556	0.0907	34.1498
-36.0000	7.2384	-0.0880	0.4299	0.2507	35.5108
-38.0000	7.0108	-0.1149	0.2798	0.1054	36.2815
-40.0000	6.6897	-0.1543	0.0051	0.0700	36.4314
-42.0000	6.2886	-0.2042	-0.1289	-0.1055	35.9625
-44.0000	5.8239	-0.2626	-0.4502	-0.0776	34.9070
-46.0000	5.3126	-0.3271	-0.3089	-0.4826	33.3238
-48.0000	4.7528	-0.3982	-0.7561	-0.3329	31.1455
-50.0000	4.1509	-0.4746	-0.6897	-0.6856	28.3947
-52.0000	3.5677	-0.5485	-4.6414	3.1702	25.4523
-54.0000	3.0176	-0.6179	-1.6159	0.1090	22.4387
-56.0000	2.5118	-0.6814	-1.2999	-0.1881	19.4626
-58.0000	1.9524	-0.7511	-1.4975	-0.3324	15.8030
-60.0000	1.3992	-0.8202	-1.8606	-0.1334	11.8148
-62.0000	1.0000	-0.8667	-1.6458	0.2220	8.9670
-64.0000	0.2627	-0.9439	-3.0441	0.0388	2.9565
-66.0000	-0.3557	-1.0630	-2.4979	-0.1911	-2.4214
-68.0000	-1.0000	-0.8607	-5.9770	0.1172	-9.7008

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-70.0000	-1.4233	-1.1847	-11.5774	0.4026	-12.5828
-72.0000	-1.7911	-1.2307	-4.3504	2.3956	-16.4925
-74.0000	-2.2818	-1.2930	-4.1955	1.5374	-21.8087
-76.0000	-2.9425	-1.3780	-3.3594	-0.2910	-29.1098
-78.0000	-3.8413	-1.4948	-4.4893	-0.5741	-39.2368
-80.0000	-4.8459	-1.6262	-5.6372	-0.2307	-50.9729
-82.0000	-5.6928	-1.7376	-5.3022	0.0280	-61.5211
-84.0000	-6.7275	-1.8740	-6.0600	-0.4914	-74.6238
-86.0000	-7.9976	-2.0418	-7.5779	-0.5986	-90.9770
-88.0000	-9.5541	-2.2492	-10.4737	0.2201	-111.4840
-90.0000	-11.5054	-2.5065	-12.3931	-0.5268	-137.3236
-92.0000	-13.6453	-2.7904	-14.9507	0.2954	-166.6338
-94.0000	-15.3952	-3.0230	-13.0434	0.2609	-192.1985
-96.0000	-17.4167	-3.2918	-15.2196	0.2322	-222.1734
-98.0000	-19.7572	-3.6032	-18.4142	0.8040	-257.3936
-100.0000	-22.4733	-3.9646	-21.5747	0.8368	-298.8694
-102.0000	-25.2347	-4.3521	-22.5919	-0.1977	-344.4485
-104.0000	-28.6185	-4.7827	-25.0601	-0.7417	-396.0522
-106.0000	-32.3346	-5.2775	-28.0609	-2.0096	-456.1934
-108.0000	-36.6126	-5.8473	-35.8616	0.7545	-526.4077
-110.0000	-41.5469	-6.5046	-42.1657	1.1261	-608.5269
-112.0000	-47.2487	-7.2641	-48.9327	0.8282	-704.7361
-114.0000	-52.1172	-7.9129	-41.0256	-2.2682	-791.3235
-116.0000	-56.9290	-8.5542	-45.7000	1.5458	-879.6321
-118.0000	-62.2257	-9.2602	-47.4183	-1.8321	-978.1328
-120.0000	-68.0597	-10.0378	-53.2757	-1.6854	-1088.0540
-122.0000	-74.4893	-10.8948	-62.2693	0.9094	-1210.7750

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Sample Ingot 2

Metal Chemistry - C 3.54 %, Si 3.02 %, C.E. 4.57 %,
Mn 0.66 %, Cr 0.12 %, Cu 0.08 %,
Al 0.020 %, Mg 0.055 %, S 0.009 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
50.0000	65.7134	7.6934	-667.2764	0.1524	-329.7844
48.0000	55.2933	6.3155	39.8572	-0.1801	-250.4305
46.0000	46.7073	5.1559	31.9863	-0.0833	-186.6249
44.0000	39.3946	4.1796	25.5751	-0.0255	-135.5257
42.0000	33.2685	3.3749	20.0564	-0.0632	-95.5391
40.0000	28.2353	2.7029	15.8746	-0.1398	-64.0694
38.0000	26.2213	2.4188	6.9107	0.1498	-49.9483
36.0000	25.2786	2.3034	3.2540	0.2256	-42.9890
34.0000	24.5474	2.1893	2.0032	0.2241	-36.5343
32.0000	23.6247	2.0627	3.1604	0.0355	-30.1425
30.0000	21.2555	1.7571	5.5233	0.0721	-18.9516
28.0000	18.1827	1.3320	6.3263	0.3017	-5.6956
26.0000	15.4010	0.9589	5.6485	-0.5481	4.5053
24.0000	12.5840	0.6344	4.2051	-0.4386	12.0381
22.0000	10.2106	0.2776	3.7463	-0.3019	13.9265
20.0000	6.5750	-0.2117	-1.2957	1.0070	18.3490
18.0000	4.5264	-0.4763	-3.4293	0.0735	11.6374
16.0000	3.3656	-0.6240	-2.1512	0.2979	7.9306
14.0000	2.7914	-0.6983	-1.5968	0.6070	5.9509
12.0000	2.4205	-0.7481	-0.4522	-0.2194	4.6078
10.0000	2.0965	-0.7917	-0.3915	-0.1504	3.5240
8.0000	1.8131	-0.8298	-0.3229	-0.1107	2.6569
6.0000	1.4191	-0.8674	-0.7026	0.2971	1.8455
4.0000	1.1683	-0.8824	-0.0494	-0.2107	1.3256
2.0000	1.0397	-0.8806	-0.0508	-0.1375	0.9487
0.0000	1.0000	-1.3856	0.0091	-0.4799	0.0072
-2.0000	1.0000	-0.8667	3.7767	-3.3122	0.9366
-4.0000	1.1258	-0.8799	0.0934	0.0921	1.3076
-6.0000	1.2037	-0.8699	-5.7555	5.9350	1.6662
-8.0000	1.2745	-0.8599	0.1034	0.0953	2.0637
-10.0000	1.3468	-0.8498	0.1093	0.1092	2.5006
-12.0000	1.4200	-0.8395	0.1987	0.0398	2.9776
-14.0000	1.4966	-0.8288	0.1491	0.1121	3.4999
-16.0000	1.5751	-0.8180	0.0025	0.2511	4.0673
-18.0000	1.6551	-0.8069	0.1653	0.1410	4.6797
-20.0000	1.7363	-0.7957	0.8964	-0.5671	5.3381
-22.0000	1.8186	-0.7843	-9.7721	10.1245	6.0429
-24.0000	1.7912	-0.7852	-0.9514	1.1496	6.4395
-26.0000	1.7106	-0.7924	0.0607	0.0376	6.6361
-28.0000	1.5472	-0.8092	-0.0485	-0.0294	6.4804
-30.0000	1.1522	-0.8511	-0.5059	-0.0795	5.3095
-32.0000	0.7571	-0.8903	-0.7109	0.0221	3.9321
-34.0000	0.2621	-0.9214	-0.9939	0.2065	2.3576

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-36.0000	0.0000	-1.0000	-0.5180	-0.3105	0.7008
-38.0000	-0.7661	-1.1091	-1.6354	-0.3050	-3.1799
-40.0000	-1.4732	-1.1867	-1.7168	-0.2704	-7.1545
-42.0000	-2.0571	-1.2570	-1.8425	0.0134	-10.8124
-44.0000	-2.6945	-1.3365	-1.9711	-0.1701	-15.0948
-46.0000	-3.5958	-1.4499	-2.6797	-0.4093	-21.2724
-48.0000	-4.0460	-1.5099	-2.1435	0.1946	-25.1702
-50.0000	-4.5900	-1.5810	-3.3470	0.9958	-29.8725
-52.0000	-5.2356	-1.6657	-3.4763	0.6282	-35.5685
-54.0000	-6.0045	-1.7668	-2.9419	-0.5220	-42.4965
-56.0000	-6.9240	-1.8879	-4.2524	0.0219	-50.9573
-58.0000	-8.0277	-2.0336	-4.7725	-0.4152	-61.3329
-60.0000	-9.3580	-2.2096	-5.9481	-0.4400	-74.1091
-62.0000	-10.9682	-2.4229	-8.8503	0.9511	-89.9072
-64.0000	-12.9256	-2.6823	-10.3929	0.5839	-109.5253
-66.0000	-14.2063	-2.8007	-8.0231	0.4033	-124.7647
-68.0000	-15.5495	-3.0317	-7.4140	-0.3032	-140.1991
-70.0000	-16.5539	-3.2188	-8.2030	-0.4208	-157.4467
-72.0000	-18.4909	-3.4237	-9.3463	-0.2898	-176.7139
-74.0000	-20.1740	-3.6479	-10.5209	-0.2450	-198.2504
-76.0000	-22.0176	-3.8936	-12.2597	0.2322	-222.3053
-78.0000	-24.0376	-4.1629	-13.1171	-0.3191	-249.177[illegible]
-80.0000	-26.2515	-4.4579	-16.3564	1.3479	-279.194[illegible]
-82.0000	-28.7156	-4.7963	-17.8313	0.8647	-313.1274
-84.0000	-32.5154	-5.2922	-24.2770	-0.8232	-363.3276
-86.0000	-36.8924	-5.8752	-29.4943	0.0730	-422.1702
-88.0000	-41.9432	-6.5479	-33.9866	-0.5531	-491.2493
-90.0000	-47.7819	-7.3257	-42.8559	2.2429	-572.4753
-92.0000	-54.4777	-8.2177	-46.5871	-0.3368	-667.3230
-94.0000	-61.0540	-9.0940	-50.3405	1.3786	-764.2468
-96.0000	-68.5031	-10.0867	-57.2352	1.4361	-875.8452
-98.0000	-76.9458	-11.2123	-62.1099	-1.1915	-1004.4460

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Sample Ingot 3

Metal Chemistry - C 3.65 %, Si 2.75 %, C.E. 4.57 %,
Mn 0.68 %, Cr 0.10 %, Cu 0.14 %,
Al 0.016 %, Mg 0.042 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
46.0000	72.8003	8.6359	-621.4849	-0.2776	-346.2673
44.0000	55.9875	6.9243	45.5132	-0.3204	-255.8746
42.0000	49.4622	5.5184	35.4367	-0.0841	-195.1697
40.0000	42.9625	4.6495	21.8704	-0.0447	-141.5182
38.0000	39.0866	4.1303	13.6524	-0.1843	-114.5821
36.0000	35.3793	3.6333	12.1431	-0.1183	-90.5324
34.0000	32.7056	3.4071	6.1444	0.3116	-77.6204
32.0000	32.0047	3.1769	5.5596	0.5047	-65.4921
30.0000	30.2312	2.9367	5.2481	0.5030	-53.9899
28.0000	29.4484	2.8291	3.1618	0.2819	-47.1027
26.0000	28.4646	2.6924	3.5715	0.0034	-37.9530
24.0000	27.1573	2.5132	4.5161	-0.6960	-32.3143
22.0000	24.1856	2.1113	7.3664	-1.4905	-20.5026
20.0000	20.9193	1.6694	7.0632	-1.6051	-9.6467
18.0000	18.0335	1.2774	4.3242	-0.2006	-1.3996
16.0000	14.6475	0.8180	3.4670	0.3915	6.2974
14.0000	10.5908	0.2739	3.8072	-0.3220	13.2679
12.0000	7.6338	-0.1282	-0.2511	0.2923	13.1502
10.0000	5.4663	-0.4206	-2.3227	-0.1561	8.1927
8.0000	3.5640	-0.6359	-2.1035	0.4896	4.9652
6.0000	2.7412	-0.7865	-0.6822	-0.3054	2.9990
4.0000	1.6758	-0.8971	-0.6574	-0.0236	1.6290
2.0000	1.1378	-0.9108	0.0391	-0.3617	0.9829
0.0000	1.0000	-1.3956	-0.1289	-0.3586	0.0032
-2.0000	1.4000	-0.9674	0.3654	0.1717	1.0823
-4.0000	1.8000	-0.8959	0.2298	0.0316	1.7053
-6.0000	2.2000	-0.8289	-0.0359	0.4414	2.5163
-8.0000	2.7313	-0.7527	0.2346	0.3494	3.6840
-10.0000	3.5290	-0.6463	-0.1564	1.0638	5.4990
-12.0000	4.5687	-0.5075	2.3324	-1.0165	8.1308
-14.0000	5.9060	-0.3285	1.9566	-0.0331	11.8779
-16.0000	7.0356	-0.1733	1.4001	0.6007	15.8794
-18.0000	8.2179	-0.0111	2.1335	0.2307	20.6076
-20.0000	9.4119	0.1526	4.9753	-2.2919	25.9944
-22.0000	10.5693	0.3113	9.0459	-6.0905	31.9074
-24.0000	11.6379	0.4581	2.4716	0.6491	39.1488
-26.0000	12.5646	0.5959	5.8139	-2.6560	44.4644
-28.0000	13.3010	0.6882	3.5035	-0.4560	50.5595
-30.0000	13.8062	0.7597	2.4150	0.3645	56.1153
-32.0000	14.0514	0.7966	2.0117	0.3461	60.8341
-34.0000	14.0223	0.7969	1.9822	-0.1320	64.4347
-36.0000	13.7207	0.7608	1.7322	-0.5949	66.7093
-38.0000	13.1639	0.6909	0.4437	-0.0335	67.5298

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-40.0000	12.9590	0.6668	1.0995	0.1036	69.9360
-42.0000	12.8582	0.6563	2.2534	-0.8119	72.8191
-44.0000	12.5942	0.6240	-0.7955	1.7309	74.6898
-46.0000	12.1770	0.5713	0.1319	0.2631	75.4799
-48.0000	11.6222	0.5003	-0.0970	-0.0595	75.1668
-50.0000	10.9501	0.4136	-0.5969	-0.1058	73.7756
-52.0000	10.1841	0.3145	-1.3002	0.1003	71.3759
-54.0000	9.2500	0.2063	-23.5063	21.8568	68.0770
-56.0000	8.4738	0.0925	0.3099	-2.3356	64.0198
-58.0000	7.5809	-0.0234	12.1746	-14.5009	59.3673
-60.0000	6.6949	-0.1385	-2.1712	-0.3653	54.2941
-62.0000	5.7637	-0.2593	-2.6385	-0.3211	48.3747
-64.0000	4.7123	-0.3956	-4.4080	0.6870	43.9327
-66.0000	3.7911	-0.5145	-2.7136	-0.7144	34.0770
-68.0000	2.9941	-0.6168	-2.3095	-0.8007	27.8566
-70.0000	2.0547	-0.7363	-5.2081	1.2208	19.8820
-72.0000	1.1153	-0.8529	-5.6761	1.4392	11.4080
-74.0000	0.1759	-0.9528	-4.0565	-0.4188	2.4573
-76.0000	-1.4449	-1.1878	-6.9521	-1.2465	-13.9397
-78.0000	-3.0520	-1.3925	-7.3445	-1.2013	-31.0307
-80.0000	-4.4591	-1.5757	-7.0432	-0.8649	-46.8472
-82.0000	-5.5722	-1.7218	-7.4594	0.7823	-60.2012
-84.0000	-7.0264	-1.9133	-12.9998	4.1161	-77.9632
-86.0000	-8.9407	-2.1662	-13.0747	1.1663	-101.7846
-88.0000	-11.4799	-2.5024	-16.2578	0.1740	-133.9525
-90.0000	-14.8741	-2.9526	-22.8199	0.9297	-177.7327
-92.0000	-19.0439	-3.5064	-25.1371	-2.3634	-232.8338
-94.0000	-22.2188	-3.9287	-21.2613	-1.1687	-277.6936
-96.0000	-26.0225	-4.4348	-27.9260	0.6259	-332.2939
-98.0000	-30.5946	-5.0433	-24.7527	1.4191	-393.9612
-100.0000	-36.1083	-5.7773	-37.8083	-3.0197	-460.6169
-102.0000	-42.7755	-6.6657	-52.7643	3.5974	-560.9509
-104.0000	-46.4513	-7.4213	-42.1987	-2.8243	-670.9973
-106.0000	-54.9206	-8.2832	-50.8566	-1.3057	-775.3219
-108.0000	-62.3724	-9.2761	-61.8741	0.9116	-897.2471

STATEMENTS EXECUTED= 2203966 .

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 8008 BYT BYTES

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Sample Ingot 4

Metal Chemistry - C 3.92 %, Si 2.53 %, C.E. 4.76 %,
Mn o.76 %, Cr 0.14 %, Cu 0.13 %,
Al 0.022 %, Mg 0.034 %, S 0.008 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	52.2955	5.9099	-709.0703	-0.1344	-103.3366
20.0000	37.2255	3.8752	25.1237	-0.0463	-53.1820
18.0000	22.4283	1.9991	19.4871	0.0399	-14.1291
16.0000	14.3017	0.7722	10.3929	0.1850	7.0078
14.0000	8.8109	0.0398	4.3349	0.1797	10.0370
12.0000	5.5788	-0.3854	-2.7941	-0.3365	9.7958
10.0000	3.7910	-0.6172	-1.8461	-0.1205	5.8627
8.0000	2.8706	-0.7394	-1.1053	0.0948	3.8416
6.0000	2.1863	-0.8298	-1.0163	0.3480	2.5052
4.0000	1.5070	-0.8963	-0.5471	0.0575	1.5263
2.0000	1.1080	-0.9022	-0.2230	-0.0534	0.9734
0.0000	1.0000	-1.3856	-1.0723	0.5901	0.0088
-2.0000	1.2098	-0.9294	-0.1022	0.0026	1.0096
-4.0000	1.4196	-0.8945	0.1195	0.1126	1.4738
-6.0000	1.6294	-0.8608	-0.7414	1.0173	2.0257
-8.0000	1.8743	-0.8254	0.2224	0.1283	2.7272
-10.0000	2.2097	-0.7314	0.3932	0.0938	3.6809
-12.0000	2.6120	-0.7294	1.2301	-0.6097	4.9217
-14.0000	3.0564	-0.6643	0.6329	0.1710	6.5316
-16.0000	3.4918	-0.6092	0.8445	-0.0077	8.2049
-18.0000	3.8549	-0.5578	0.8735	0.0291	10.0099
-20.0000	4.2018	-0.5086	1.0953	-0.1179	11.9648
-22.0000	4.5220	-0.4630	0.6867	0.3434	14.0249
-24.0000	4.8049	-0.4223	0.7623	0.2932	16.1359
-26.0000	5.0408	-0.3879	0.9329	0.1102	18.2338
-28.0000	5.2213	-0.3609	1.0359	-0.0308	20.2502
-30.0000	5.4209	-0.3317	1.4491	-0.3543	22.4399
-32.0000	5.7038	-0.2922	5.9354	-4.5091	25.0921
-34.0000	5.9553	-0.2569	-3.2241	4.5543	27.7529
-36.0000	6.1699	-0.2264	1.7007	-0.3918	30.3703
-38.0000	6.2432	-0.2015	1.2784	-0.0176	32.8918
-40.0000	6.4710	-0.1826	1.0892	0.0969	35.2638
-42.0000	6.5507	-0.1702	0.6919	0.3929	37.4334
-44.0000	6.5803	-0.1644	0.8569	0.1022	39.3515
-46.0000	6.5591	-0.1654	1.1688	-0.3576	40.9740
-48.0000	6.5067	-0.1706	-0.2119	0.9175	42.3654
-50.0000	6.4094	-0.1919	-0.5531	1.0952	43.4696
-52.0000	6.2668	-0.1990	0.2901	0.0686	44.1872
-54.0000	6.0818	-0.2219	0.0536	0.1148	44.5240
-56.0000	5.8586	-0.2499	0.0635	-0.0375	44.4757
-58.0000	5.6016	-0.2323	-0.7463	0.5325	44.0483
-60.0000	5.3162	-0.3196	0.1312	-0.5274	43.2560
-62.0000	5.0279	-0.3579	-0.3849	-0.1320	42.1222

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-64.0000	4.6824	-0.3995	-0.6362	-0.0859	40.6782
-66.0000	4.2457	-0.4426	-0.6782	-0.1505	38.9009
-68.0000	4.0032	-0.4864	-0.8399	-0.1345	37.0121
-70.0000	3.6603	-0.5303	-1.0159	-0.0514	34.8773
-72.0000	3.3220	-0.5736	-1.5100	0.3730	32.6037
-74.0000	2.7512	-0.6468	-2.2449	-0.1296	27.8546
-76.0000	2.2208	-0.7143	-2.1416	-0.1806	23.2106
-78.0000	1.7700	-0.7713	-2.0957	0.0465	19.1124
-80.0000	1.2937	-0.8307	-2.5165	0.2116	14.5025
-82.0000	0.7805	-0.8929	-3.0469	0.4139	9.2363
-84.0000	0.2673	-0.9485	-5.3348	2.5699	3.7065
-86.0000	-0.2915	-1.0531	-3.9919	0.8229	-2.6313
-88.0000	-0.8999	-1.1212	-3.5463	-0.0660	-9.8558
-90.0000	-1.5083	-1.1965	-3.3360	-0.4337	-17.3952
-92.0000	-2.0554	-1.2642	-3.2950	-0.2612	-24.5077
-94.0000	-2.5417	-1.3299	-3.8694	0.5493	-31.1491
-96.0000	-3.1693	-1.4105	-3.9245	-0.4302	-39.8573
-98.0000	-3.9248	-1.5092	-5.4879	0.1311	-50.5705
-100.0000	-4.4619	-1.5799	-4.1332	0.0295	-58.7778
-102.0000	-5.0931	-1.6030	-5.1441	0.2587	-63.5488
-104.0000	-5.8368	-1.7511	-4.9576	-0.8772	-80.2195
-106.0000	-6.7161	-1.8773	-6.2613	-0.7293	-94.1999
-108.0000	-7.7590	-2.0154	-8.2569	-0.1457	-111.0052
-110.0000	-8.9999	-2.1798	-10.1592	0.0265	-131.2703
-112.0000	-10.4912	-2.3763	-12.6250	0.3666	-155.7369
-114.0000	-12.2554	-2.6113	-16.3441	1.4646	-185.5457
-116.0000	-14.0703	-2.8529	-16.8380	1.1711	-216.8796
-118.0000	-15.6601	-3.0644	-14.5321	0.1510	-245.6419
-120.0000	-17.4659	-3.3046	-16.4070	-0.1255	-278.7005
-122.0000	-19.5205	-3.5780	-18.8382	-0.1999	-316.7327
-124.0000	-21.6625	-3.8897	-22.4499	-1.5113	-360.7029
-126.0000	-24.5365	-4.2457	-25.3912	0.0078	-411.4500
-128.0000	-27.5950	-4.6529	-29.6369	0.2691	-470.1853
-130.0000	-31.1686	-5.1288	-35.6115	0.9646	-539.4792
-132.0000	-35.2903	-5.6778	-40.6354	0.2125	-620.3247
-134.0000	-40.0437	-6.3109	-47.0711	-0.0927	-714.6526
-136.0000	-45.5356	-7.0425	-56.2491	1.1225	-824.9060
-138.0000	-51.8926	-7.8496	-63.1210	-1.4284	-954.0046
-140.0000	-59.5712	-8.9127	-76.8690	-1.7177	-1111.1590
-142.0000	-68.5516	-10.1094	-93.5571	0.6104	-1297.0533

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Sample Ingot 5

Metal Chemistry - C 3.55 %, Si 2.45 %, C.E. 4.37 %,
Mn 0.67 %, Cr 0.13 %, Cu 0.14 %,
Al 0.018 %, Mg 0.036 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
58.0000	112.2390	13.9193	-829.9624	-0.3241	-743.8979
56.0000	98.2072	12.0458	65.4790	-0.1699	-613.2791
54.0000	85.6478	10.3822	55.7791	0.1161	-501.4879
52.0000	74.9107	8.9084	47.5468	0.0855	-406.2234
50.0000	66.2496	8.0317	29.8254	-0.0464	-346.0033
48.0000	65.6152	7.6787	15.7781	-0.2932	-315.6936
46.0000	63.0066	7.3299	14.9384	-0.2365	-286.2998
44.0000	60.1491	6.9459	14.4419	0.2905	-250.8252
42.0000	59.1803	6.8148	7.9875	0.7039	-239.4421
40.0000	57.9261	6.6455	8.6018	0.5977	-221.3627
38.0000	57.2705	6.5561	7.0061	0.3315	-206.3067
36.0000	55.7495	6.3512	8.9285	0.3033	-187.9231
34.0000	50.8885	5.6997	16.3440	0.0358	-155.1636
32.0000	45.8969	5.0395	16.4373	-1.0916	-124.4521
30.0000	40.6729	4.3298	16.4992	-2.0187	-95.4912
28.0000	35.5824	3.6466	13.4362	-0.6576	-69.3340
26.0000	30.8392	3.0093	10.6342	0.2255	-48.1147
24.0000	26.1624	2.3805	9.8288	-0.3562	-29.1697
22.0000	21.8179	1.7958	7.4537	0.2591	-13.7201
20.0000	17.5596	1.2757	5.7270	0.1720	-1.9282
18.0000	14.6756	0.8325	4.3707	-0.2069	6.3994
16.0000	11.7685	0.4383	4.5299	-1.6536	12.1499
14.0000	8.3447	-0.0595	1.6821	0.1356	15.7852
12.0000	5.1874	-0.4232	-4.2584	0.9389	9.1460
10.0000	3.5954	-0.6390	1.7469	-3.5261	5.5872
8.0000	2.6456	-0.7604	-0.2567	-0.7425	3.5884
6.0000	2.0603	-0.8392	-0.2370	-0.3617	2.3911
4.0000	1.5459	-0.8968	9.8565	-10.2796	1.5452
2.0000	1.1153	-0.9043	-0.1521	-0.1348	0.9717
0.0000	1.0000	-1.3856	-0.3183	-0.1051	0.0049
-2.0000	1.2796	-0.9640	0.0686	0.4044	1.0710
-4.0000	1.7552	-0.8964	0.1354	0.1575	1.6768
-6.0000	2.1339	-0.8321	-0.0307	0.4224	2.4602
-8.0000	2.5953	-0.7655	0.2993	0.2348	3.5283
-10.0000	3.2958	-0.6702	0.7540	0.0793	5.1931
-12.0000	4.2292	-0.5476	295.8530	-294.6046	7.5752
-14.0000	5.4144	-0.3893	0.5290	1.1548	10.9426
-16.0000	6.5125	-0.2394	2.8557	-0.9535	14.7471
-18.0000	7.4757	-0.1061	1.0272	1.0016	18.3044
-20.0000	8.3956	0.0218	1.8600	0.3716	23.2678
-22.0000	9.2380	0.1383	1.9072	0.5434	27.9690
-24.0000	9.9449	0.2372	2.4325	-0.0706	32.6931
-26.0000	10.4792	0.3133	3.3108	-1.0612	37.1924

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-28.0000	10.8087	0.3616	2.5041	-0.4963	41.2078
-30.0000	10.9124	0.3800	1.5451	0.0975	44.4937
-32.0000	10.7829	0.3675	0.8917	0.2924	46.8418
-34.0000	10.8296	0.3774	1.3033	0.2339	49.9158
-36.0000	10.8195	0.3795	2.2599	-0.3443	52.7468
-38.0000	10.6414	0.3593	0.0378	0.9487	54.7197
-40.0000	10.3033	0.3177	0.2232	0.2893	55.7444
-42.0000	9.8209	0.2570	0.0114	0.0066	55.7800
-44.0000	9.2155	0.1799	-0.2815	-0.1899	54.8374
-46.0000	8.5120	0.0898	-0.5578	-0.0429	52.9761
-48.0000	7.7417	-0.0093	0.3479	-1.0856	50.3008
-50.0000	6.9308	-0.1128	-0.2262	-1.4469	46.9504
-52.0000	6.1083	-0.2197	6.5301	-8.4611	43.3896
-54.0000	4.9869	-0.3644	-2.7094	-0.5179	36.6340
-56.0000	3.8743	-0.5073	-4.5111	1.0180	29.6477
-58.0000	2.9436	-0.6260	-2.6460	-0.4395	23.4766
-60.0000	1.8681	-0.7613	-3.7572	-0.1559	15.6504
-62.0000	0.7870	-0.8912	-4.9689	0.7481	7.2097
-64.0000	-0.4534	-1.0727	-8.1756	2.3905	-3.1616
-66.0000	-2.1201	-1.2712	-6.9769	-0.4172	-17.9495
-68.0000	-3.7867	-1.4551	-7.0027	-0.8308	-33.6162
-70.0000	-5.1527	-1.6633	-5.5201	-1.3556	-47.3077
-72.0000	-6.6912	-1.8654	-6.6670	-1.4012	-63.5042
-74.0000	-8.7946	-2.1413	-10.1233	-1.0914	-85.9334
-76.0000	-10.3535	-2.3491	-10.0749	0.9579	-104.1074
-78.0000	-12.2705	-2.6033	-14.3196	2.0744	-126.6580
-80.0000	-14.6226	-2.9155	-16.6557	2.4744	-155.2204
-82.0000	-17.5250	-3.3009	-19.4671	1.0619	-190.8305
-84.0000	-21.1192	-3.7785	-25.1579	2.7307	-235.7449
-86.0000	-25.5922	-4.3734	-26.3509	-2.1015	-292.6494
-88.0000	-31.1856	-5.1176	-34.1438	-2.0719	-365.0306
-90.0000	-35.6098	-5.7067	-30.5313	-0.1636	-426.4707
-92.0000	-39.5070	-6.2259	-29.9019	1.2580	-483.7578
-94.0000	-43.8774	-6.8093	-30.5597	-2.3970	-549.0532
-96.0000	-48.7829	-7.4619	-39.7879	2.5508	-623.5273
-98.0000	-54.2949	-8.1964	-39.7398	-2.7601	-738.5396
-100.0000	-60.4937	-9.0225	-47.7457	-0.3082	-635.6475
-102.0000	-67.4723	-9.9525	-56.5432	1.0366	-916.6606

STATEMENTS EXECUTED= 245142

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Sample Ingot 6

Metal Chemistry - C 3.67 %, Si 2.52 %, C.E. 4.51 %,
Mn 0.65 %, Cr 0.14 %, Cu 0.14 %,
Al 0.020 %, Mg 0.033 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
40.0000	106.4487	13.4025	-741.8264	0.1300	-490.7112
38.0000	89.9277	10.9255	59.4046	-0.0323	-371.9666
36.0000	74.2171	8.5214	47.6596	0.0426	-275.5623
34.0000	66.9413	7.0442	37.9937	-0.0583	-200.6918
32.0000	49.7924	5.5513	29.9385	-0.1096	-141.0339
30.0000	35.5142	3.6410	32.8590	0.1789	-74.9582
28.0000	24.8400	2.2147	22.0674	0.3617	-30.1000
26.0000	17.8075	1.2766	12.9372	0.3073	-3.6112
24.0000	12.1613	0.5266	9.0151	0.0708	14.5605
22.0000	8.6082	0.0568	4.6699	-0.1879	23.5248
20.0000	8.4675	0.0305	-0.7282	-0.0505	21.9674
18.0000	8.0473	-0.0330	-0.7732	-0.2479	19.9255
16.0000	7.8333	-0.0718	-1.0177	-0.1375	17.5151
14.0000	7.3212	-0.1508	-1.4389	-0.0356	14.5661
12.0000	5.8471	-0.3524	-2.5493	0.3848	10.2374
10.0000	4.3908	-0.5486	-1.9471	0.1755	6.6941
8.0000	3.2872	-0.6975	-1.2749	0.0833	4.3110
6.0000	2.4538	-0.8102	-1.1021	0.3154	2.7375
4.0000	1.8258	-0.8953	-0.3758	-0.1324	1.7210
2.0000	1.1387	-0.9243	-0.3970	0.0369	1.0010
0.0000	1.0000	-1.3856	0.2723	-0.7688	0.0081
-2.0000	1.1910	-0.9248	0.3739	0.1230	1.0019
-4.0000	1.3919	-0.8934	0.1457	0.0786	1.4503
-6.0000	1.5900	-0.8623	-0.3665	0.6369	1.9911
-8.0000	1.8499	-0.8272	0.0905	0.2632	2.6983
-10.0000	2.1488	-0.7870	-0.1247	0.5736	3.5963
-12.0000	2.3796	-0.7522	-29.6700	30.1424	4.5406
-14.0000	2.5492	-0.7246	0.2485	0.2270	5.4917
-16.0000	2.6724	-0.7031	0.2307	0.1900	6.4331
-18.0000	2.7417	-0.6888	0.3932	0.0452	7.3098
-20.0000	2.7526	-0.6823	0.2671	0.1116	8.0069
-22.0000	2.7402	-0.6794	0.5252	-0.1776	8.7621
-24.0000	2.7383	-0.6759	0.3130	0.0482	9.4848
-26.0000	2.6947	-0.6781	-0.1172	0.4054	10.0611
-28.0000	2.6112	-0.6855	0.0794	0.1228	10.4056
-30.0000	2.4917	-0.6977	0.0595	0.0483	10.6610
-32.0000	2.3413	-0.7141	0.0097	0.0004	10.7012
-34.0000	2.0115	-0.7521	-0.4571	0.0197	9.8262
-36.0000	1.4254	-0.8197	-1.4449	0.3039	7.5440
-38.0000	1.0000	-0.8667	-1.1128	0.2242	5.7667
-40.0000	0.3526	-0.9266	-1.1977	-0.3886	2.5943
-42.0000	-0.1739	-1.0640	-1.0810	-0.3356	-0.2387
-44.0000	-0.6377	-1.0952	-1.1805	-0.2193	-3.0383

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-46.0000	-1.1015	-1.1448	-1.5840	0.0756	-6.0550
-48.0000	-1.5652	-1.1993	-1.4561	-0.1438	-9.3149
-50.0000	-1.9008	-1.2405	-2.4915	1.0755	-11.9674
-52.0000	-2.3080	-1.2915	7.9210	-9.5846	-15.2946
-54.0000	-2.8389	-1.3590	-2.6528	0.4356	-19.7291
-56.0000	-3.4108	-1.4326	-2.4014	-0.1101	-24.7522
-58.0000	-3.9112	-1.4977	-2.4257	0.0374	-29.5287
-60.0000	-4.5139	-1.5764	-3.0299	0.0992	-35.3902
-62.0000	-5.2431	-1.6720	-3.4282	-0.1856	-42.6175
-64.0000	-6.1293	-1.7884	-4.9036	0.4258	-51.5731
-66.0000	-7.2114	-1.9311	-5.7226	0.1468	-62.7246
-68.0000	-8.5392	-2.1064	-6.6590	-0.3186	-76.6800
-70.0000	-10.1766	-2.3230	-7.9995	-0.7765	-94.2323
-72.0000	-12.2061	-2.5919	-10.5434	-0.5505	-116.4199
-74.0000	-14.1237	-2.8465	-11.3916	0.3078	-138.5873
-76.0000	-15.9470	-3.0889	-12.0920	0.9742	-160.6228
-78.0000	-18.0529	-3.3689	-13.6325	0.5593	-186.9689
-80.0000	-20.4958	-3.6932	-15.2937	-0.1104	-217.7770
-82.0000	-23.3188	-4.0696	-19.6393	1.4522	-254.1510
-84.0000	-26.6070	-4.5072	-19.7961	-1.7203	-297.1836
-86.0000	-30.7514	-5.0589	-26.8357	-0.4651	-351.7849
-88.0000	-35.5752	-5.7543	-34.8737	0.1379	-421.2563
-90.0000	-42.2341	-6.5877	-44.3716	2.0341	-505.9316
-92.0000	-49.7568	-7.5895	-51.5490	-0.2049	-609.4392
-94.0000	-58.8250	-8.7974	-64.2699	0.8278	-736.3235
-96.0000	-67.7188	-9.9823	-66.0355	1.2914	-865.8118
-98.0000	-76.0478	-11.0922	-62.4535	-0.9736	-992.6660

STATEMENTS EXECUTED= 1619036

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 9008 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.66 SEC,EXECUTION TIME= 167.19 SEC, 11.15.3 WATFIV - MAR 198

C$EOF

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Sample Ingot 7

Metal Chemistry - C 3.77 %, Si 2.64 %, C.E. 4.65 %,
Mn 0.61 %, Cr 0.14 %, Cu 0.13 %,
Al 0.020 %, Mg 0.032 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	72.2491	8.6577	-655.5886	-0.2320	-148.1703
18.0000	52.9478	6.0236	31.3641	-0.1559	-85.7539
16.0000	35.9890	3.7120	23.3245	-0.0013	-39.1075
14.0000	22.4009	1.8560	15.2621	0.2050	-8.1734
12.0000	14.0418	0.7155	7.3093	0.1562	6.7579
10.0000	8.0225	-0.0994	2.5746	-0.1227	11.6617
8.0000	4.7619	-0.5239	-2.8018	-0.0330	5.9920
6.0000	3.0042	-0.7630	-1.6893	0.3050	3.2233
4.0000	2.0765	-0.8979	-1.2433	0.5716	1.8798
2.0000	1.2769	-0.9445	-0.7623	0.3394	1.0339
0.0000	1.0000	-1.3856	-1.4403	0.9274	0.0080
-2.0000	1.4409	-0.9737	-0.0327	0.5781	1.0990
-4.0000	1.9424	-0.8925	0.1612	0.1866	1.7946
-6.0000	2.7140	-0.7889	0.9116	-0.2257	2.9665
-8.0000	3.6491	-0.6593	0.6592	0.2182	4.7215
-10.0000	4.7216	-0.5099	1.3798	-0.1631	7.1548
-12.0000	5.9504	-0.3397	1.7105	-0.0835	10.4090
-14.0000	7.3038	-0.1530	1.8415	0.2252	14.5482
-16.0000	8.5792	0.0239	1.9807	0.3615	19.2324
-18.0000	9.6040	0.1677	2.3923	-0.0173	23.9823
-20.0000	10.3853	0.2790	1.8982	0.4209	28.6207
-22.0000	10.8481	0.3476	1.7038	0.3523	32.7328
-24.0000	11.0000	0.3747	1.6655	0.0142	36.0921
-26.0000	11.8378	0.4906	3.0509	-0.1327	41.9285
-28.0000	12.4940	0.5823	3.0251	-0.2243	47.5298
-30.0000	12.9326	0.6449	4.6744	-2.1357	52.6074
-32.0000	13.1266	0.6752	4.9710	-2.8341	56.8815
-34.0000	13.0710	0.6716	2.6786	-1.0656	60.1075
-36.0000	12.7630	0.6348	1.0525	-0.0567	62.0992
-38.0000	12.2222	0.5669	0.1355	0.1381	62.7466
-40.0000	12.3229	0.5844	1.7349	0.1868	66.5698
-42.0000	12.6269	0.6258	2.9617	-0.4961	71.5211
-44.0000	12.8028	0.6515	6.8534	-4.0560	75.9158
-46.0000	12.8556	0.6607	2.0133	-0.1469	79.6487
-48.0000	12.7835	0.6534	1.3832	0.0981	82.6113
-50.0000	12.5854	0.6297	-0.3628	1.4163	84.7180
-52.0000	12.2781	0.5904	1.2372	-0.6412	85.9099
-54.0000	11.8587	0.5367	0.0770	0.0407	86.1375
-56.0000	11.3427	0.4702	-0.3087	-0.0397	85.4607
-58.0000	10.7443	0.3927	-0.5979	-0.2069	83.9514
-60.0000	10.0791	0.3063	-0.8990	-0.3328	81.3877
-62.0000	9.3635	0.2132	-1.3645	-0.2523	78.1543
-64.0000	8.6146	0.1156	-1.8584	-0.0913	74.2547

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-66.0000	7.8772	0.0196	-2.4515	0.3531	70.0580
-68.0000	7.2874	-0.0571	-1.5096	-0.1166	66.8055
-70.0000	6.6861	-0.1353	-1.6056	-0.2304	63.1335
-72.0000	6.0841	-0.2135	-1.8899	-0.1104	59.1329
-74.0000	5.4907	-0.2906	-2.2603	0.1424	54.8969
-76.0000	4.9144	-0.3655	-5.1269	2.9377	50.5187
-78.0000	4.3625	-0.4370	6.2383	-8.4547	46.0857
-80.0000	3.8407	-0.5046	-2.4683	0.2656	41.6800
-82.0000	3.3525	-0.5675	-1.7233	-0.4292	37.3750
-84.0000	2.8123	-0.6373	-2.1275	-0.4573	32.2052
-86.0000	2.0304	-0.7375	-4.9392	0.8294	23.9856
-88.0000	1.4221	-0.8144	-2.7875	-0.5114	17.3879
-90.0000	0.7078	-0.9018	-4.0148	-0.0814	9.1956
-92.0000	0.0000	-1.0000	-3.8152	-0.4321	0.7016
-94.0000	-1.2770	-1.1714	-8.1486	-0.0415	-15.6785
-96.0000	-2.6022	-1.3369	-7.7522	-0.7094	-32.6018
-98.0000	-3.7440	-1.4856	-7.7272	-0.0771	-48.2103
-100.0000	-4.8625	-1.6324	-8.0798	0.1258	-64.1191
-102.0000	-6.2747	-1.8316	-10.9925	0.0639	-85.9754
-104.0000	-7.7105	-2.0082	-10.9940	0.8743	-106.1948
-106.0000	-9.1461	-2.1983	-13.2582	2.0873	-128.5364
-108.0000	-10.9029	-2.4313	-14.2219	0.3555	-156.2692
-110.0000	-12.0619	-2.7179	-17.3061	0.0227	-190.8356
-112.0000	-15.7262	-3.0718	-20.0343	-1.5972	-234.0986
-114.0000	-18.6743	-3.4638	-23.4672	-1.0312	-283.0952
-116.0000	-22.0941	-3.9187	-29.5085	0.5762	-343.9597
-118.0000	-26.2457	-4.4711	-36.5761	0.9764	-412.1592
-120.0000	-31.3031	-5.1444	-45.0350	1.0816	-500.0659
-122.0000	-37.4861	-5.9676	-51.6946	-2.7591	-608.9736
-124.0000	-44.1703	-6.8579	-62.2397	1.9932	-729.4663
-126.0000	-50.6719	-7.7241	-57.5629	-2.9320	-859.4561
-128.0000	-58.2713	-8.7366	-69.3494	-2.2453	-993.6455
-130.0000	-67.1728	-9.9227	-86.0949	1.1909	-1163.4530

STATEMENTS EXECUTED= 204643C

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 8008 BYS BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

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Sample Ingot 8

Metal Chemistry - C 3.72 %, Si 2.48 %, C.E. 4.55 %,
Mn 0.66 %, Cr 0.12 %, Cu 0.13 %,
Al 0.020 %, Mg 0.036 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
40.0000	104.4465	12.8665	-794.2253	0.0222	-409.3079
38.0000	82.0501	10.0073	56.2225	-0.1468	-337.1560
36.0000	66.0601	7.2298	48.9969	[illegible]	-237.2793
34.0000	45.0026	5.4559	45.3136	-0.0769	-146.9050
32.0000	35.4900	3.6413	33.4312	-0.1032	-30.2499
30.0000	26.5555	2.3864	21.1345	0.1761	-37.6290
28.0000	22.1047	1.8515	8.4125	0.3797	-23.3430
26.0000	18.6651	1.4165	6.2351	0.3917	-7.1992
24.0000	16.2275	1.0588	4.4393	0.1940	2.2765
22.0000	15.7373	0.9895	0.8553	-0.0520	3.0893
20.0000	14.6061	0.8584	-2.4224	-1.1539	0.2279
18.0000	14.2258	0.7725	-4.5940	5.1960	7.4514
16.0000	12.8921	0.5860	-4.1594	5.3744	9.3829
14.0000	10.0410	0.1992	2.4714	-0.3040	14.2103
12.0000	7.6923	-0.1219	-0.7595	0.2641	13.2257
10.0000	5.7513	-0.2822	-2.6246	0.3289	8.0342
8.0000	4.1625	-0.6027	-1.8213	0.1573	5.3053
6.0000	2.9257	-0.7702	-1.5020	0.4259	3.1537
4.0000	1.8760	-0.8942	-1.8473	1.1469	1.7539
2.0000	1.1703	-0.9195	-0.2179	-0.1612	0.9943
0.0000	1.0000	-1.3856	-0.9656	0.4724	0.0034
-2.0000	1.2486	-0.9384	0.3943	0.1233	1.0237
-4.0000	1.4571	-0.8962	0.1269	0.1212	1.5198
-6.0000	1.7457	-0.8557	0.2037	0.0987	2.1246
-8.0000	2.0910	-0.8090	0.6503	-0.2289	2.9674
-10.0000	2.5051	-0.7533	-0.0716	0.6312	4.0864
-12.0000	2.9569	-0.6973	-0.0507	0.6316	5.5509
-14.0000	3.4087	-0.6288	1.5696	-1.0741	7.1239
-16.0000	3.7985	-0.5720	1.9482	-1.0764	[illegible]
-18.0000	4.1627	-0.5206	0.4353	0.5359	10.7558
-20.0000	4.4861	-0.4732	0.6743	0.3121	12.7283
-22.0000	4.7544	-0.4341	1.1545	-0.1533	14.7105
-24.0000	4.9552	-0.4034	13.3722	-12.4181	15.6157
-26.0000	5.0787	-0.3831	-1.8469	2.7291	13.3052
-28.0000	5.1190	-0.3738	-0.9274	-0.1770	19.0059
-30.0000	5.0741	-0.3759	0.5044	0.0354	21.0462
-32.0000	5.0786	-0.3722	0.7752	-0.0905	22.4154
-34.0000	5.0226	-0.3764	0.1390	0.3516	23.5164
-36.0000	4.9039	-0.3952	[illegible]	[illegible]	[illegible]
-38.0000	4.7241	-0.4101	0.2730	-0.0766	24.0710
-40.0000	4.4912	-0.4380	0.0170	-0.0105	24.6939
-42.0000	4.2136	-0.4719	0.2488	-0.4294	24.3230
-44.0000	[illegible]	-0.5310	[illegible]	-0.3015	[illegible]

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-46.0000	2.1091	-0.6098	-1.0740	-0.3612	19.7046
-48.0000	2.5210	-0.6517	-1.0559	-0.3790	15.9085
-50.0000	2.0148	-0.7453	-1.1624	-0.2229	14.1390
-52.0000	1.4287	-0.5162	-1.5843	0.1198	10.6291
-54.0000	1.0000	-0.5667	-3.6745	2.3209	7.9013
-56.0000	0.2566	-0.9412	-3.8445	1.2111	2.6339
-58.0000	-0.5679	-1.0854	-6.6187	5.4579	-3.6879
-60.0000	-1.5780	-1.2028	-4.5391	0.4225	-11.9214
-62.0000	-2.5695	-1.3273	-4.0834	-0.2223	-23.0327
-64.0000	-3.3522	-1.4279	-3.4640	-0.2153	-27.6424
-66.0000	-4.4382	-1.5689	-5.0935	-0.1297	-38.0373
-68.0000	-5.4640	-1.7333	-5.3057	-0.2304	-45.6213
-70.0000	-6.2995	-1.8123	-4.3692	-0.2548	-58.0695
-72.0000	-7.3009	-1.9454	-6.4873	0.3438	-69.3563
-74.0000	-8.5000	-2.1047	-6.9226	0.0308	-83.1374
-76.0000	-9.9623	-2.2975	-7.7263	-0.7834	-103.2063
-78.0000	-11.7256	-2.5317	-9.5810	-0.4342	-121.2370
-80.0000	-13.6335	-2.8175	-12.3717	-0.6755	-147.3314
-82.0000	-16.0830	-3.1097	-14.3225	0.4517	-173.3727
-84.0000	-18.1400	-3.3833	-15.3073	1.0471	-202.3929
-86.0000	-20.5114	-3.6988	-16.5932	0.3323	-234.4147
-88.0000	-23.2510	-4.0634	-19.0118	0.2094	-272.0193
-90.0000	-26.4227	-4.4855	-22.1099	1.0450	-315.2695
-92.0000	-30.1024	-4.9754	-24.7030	-1.3327	-368.4404
-94.0000	-34.1130	-5.5095	-27.5943	-1.2452	-420.7222
-96.0000	-38.7155	-6.1225	-34.4917	0.4934	-494.7163
-98.0000	-44.0335	-6.8309	-40.3389	0.4412	-574.5120
-100.0000	-50.1900	-7.6510	-46.5530	-0.3313	-663.3145
-102.0000	-56.9570	-8.5526	-53.7791	1.0835	-773.7350
-104.0000	-63.1238	-9.3758	-50.0000	-0.4093	-874.5239
-106.0000	-70.0444	-10.2968	-57.1946	-0.0457	-989.0340
-108.0000	-77.7523	-11.3281	-64.5584	-0.4801	-1119.0820

STATEMENTS EXECUTED= 1570510

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 3003 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

[illegible]

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Sample Ingot 9

Metal Chemistry – C 3.77 %, Si 2.35 %, C.E. 4.55 %, Mn 0.65 %, Cr 0.12 %, Cu 0.12 %, Al 0.023 %, Mg 0.036 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	65.6412	7.7102	-709.1624	-0.3220	-142.7393
20.0000	42.5591	4.5847	37.8554	-0.1055	-67.2419
18.0000	27.7064	2.3759	21.3341	0.1159	-24.3422
16.0000	16.2548	1.3041	11.2334	0.2382	-1.2592
14.0000	11.5307	0.4339	5.9773	0.2029	11.1215
12.0000	7.6208	-0.1291	1.4827	-0.4037	13.1307
10.0000	5.0878	-0.4553	-2.8574	-0.0502	7.6545
8.0000	3.6658	-0.6571	-1.5134	0.0583	4.7443
6.0000	2.6529	-0.7940	-0.5441	-0.0720	2.9121
4.0000	1.6957	-0.8971	-0.5059	-0.1320	1.0362
2.0000	1.1401	-0.9114	-0.2341	-0.0904	0.9330
0.0000	1.0000	-1.3956	-0.0187	0.1004	0.0072
-2.0000	1.2086	-0.9510	1.6735	-1.1545	1.0452
-4.0000	1.6172	-0.8972	0.1495	0.1236	1.5715
-6.0000	1.9258	-0.8463	0.2904	0.0528	2.2730
-8.0000	2.3935	-0.7536	0.3112	-0.2981	3.3040
-10.0000	2.5752	-0.7058	0.5144	0.2000	4.7331
-12.0000	3.6574	-0.6091	0.9326	0.0501	6.6983
-14.0000	4.1886	-0.5374	0.9215	0.0322	9.0950
-16.0000	4.6142	-0.4740	2.3490	-1.3863	10.0311
-18.0000	4.9475	-0.4244	1.7529	0.2513	14.0591
-20.0000	5.1637	-0.3896	0.6764	0.2692	14.5504
-22.0000	5.2459	-0.3725	0.7212	0.0945	16.1615
-24.0000	5.1874	-0.3742	0.8365	-0.2340	17.3655
-26.0000	4.9921	-0.3939	-0.0145	0.3650	18.0005
-28.0000	4.6782	-0.4297	0.0393	0.0349	13.2128
-30.0000	4.5501	-0.4424	0.3566	0.0084	16.9427
-32.0000	4.5786	-0.4358	0.4689	0.1973	20.2751
-34.0000	4.5520	-0.4364	0.4630	0.0971	21.3773
-36.0000	4.4743	-0.4441	0.2965	0.1202	22.2173
-38.0000	4.3451	-0.4535	-0.0343	0.2722	22.7458
-40.0000	4.1699	-0.4790	0.0514	0.0592	22.9070
-42.0000	3.9547	-0.5049	-0.0634	0.0151	22.8775
-44.0000	3.6565	-0.5415	0.2259	-0.3753	22.1714
-46.0000	3.1531	-0.6042	-0.0122	-0.4406	20.0539
-48.0000	2.6705	-0.6642	-2.0976	0.4714	17.2716
-50.0000	2.2225	-0.7194	-1.9959	0.3477	15.5272
-52.0000	1.3235	-0.7684	1.5001	-2.5902	12.3403
-54.0000	1.1054	-0.8112	[illegible]	-0.3201	11.1328
-56.0000	1.1635	-0.8476	-0.7343	-0.2128	9.3346
-58.0000	1.0000	-0.8667	-0.3323	-0.1449	6.4345
-60.0000	0.4522	-0.9263	-1.2956	-0.1555	4.3323
-62.0000	0.0000	-1.0000	-1.8064	-0.0092	0.7312

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-64.0000	-0.6627	-1.0943	-3.0175	0.1836	-4.9522
-66.0000	-1.5494	-1.1909	-4.0294	0.0300	-12.9317
-68.0000	-2.3422	-1.2957	-4.1413	0.3428	-20.5247
-70.0000	-3.1827	-1.4077	-4.3755	0.6453	-23.9942
-72.0000	-3.6578	-1.4695	-3.4101	0.7068	-34.4007
-74.0000	-4.2285	-1.5441	-4.1372	0.8351	-41.0349
-76.0000	-4.9173	-1.6344	-3.8551	-0.1960	-49.1080
-78.0000	-5.7519	-1.7442	-4.5599	-0.4342	-59.0963
-80.0000	-6.7683	-1.8782	-5.3450	-0.2301	-71.4043
-82.0000	-7.5357	-1.9709	-5.7922	0.0947	-81.0592
-84.0000	-8.2706	-2.0772	-4.5087	-0.5312	-91.0975
-86.0000	-9.0962	-2.1369	-5.6284	-0.0064	-103.0073
-88.0000	-10.0250	-2.2101	-6.6307	0.0194	-116.2893
-90.0000	-11.0713	-2.4491	-6.7793	1.1625	-132.1201
-92.0000	-12.2534	-2.6061	-8.0562	-0.6050	-149.5636
-94.0000	-13.5655	-2.7837	-9.1311	-0.3234	-169.5726
-96.0000	-15.1027	-2.9849	-11.2558	-0.2386	-192.0012
-98.0000	-16.8154	-3.2132	-13.4053	0.1731	-219.0150
-100.0000	-18.7704	-3.4729	-16.1040	0.3574	-249.5035
-102.0000	-20.8217	-3.7458	-17.5241	1.0750	-282.4058
-104.0000	-22.8842	-4.0175	-16.7775	-0.1577	-316.2701
-106.0000	-25.1409	-4.2209	-18.5939	-0.5342	-354.5325
-108.0000	-27.6786	-4.6590	-21.5000	-0.1257	-397.7050
-110.0000	-30.5134	-5.0366	-24.0504	-0.4144	-440.7373
-112.0000	-33.6927	-5.4589	-25.7493	1.0144	-502.1041
-114.0000	-37.2299	-5.9312	-31.7615	0.3153	-565.0045
-116.0000	-41.4010	-6.4871	-36.6744	-0.5454	-634.5247
-118.0000	-46.7216	-7.1959	-44.9702	-2.0649	-734.2539
-120.0000	-52.8265	-8.0093	-57.1365	2.0702	-844.3747
-122.0000	-59.8446	-8.9444	-62.2522	-1.8502	-972.5033
-124.0000	-67.3522	-9.9449	-65.1230	-1.9077	-1112.0060
-126.0000	-75.9003	-11.0840	-82.1117	1.3389	-1274.2120

STATEMENTS EXECUTED= 157055

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 8008 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

[illegible]

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Sample Ingot 10

Metal Chemistry – C 3.65 %, Si 2.42 %, C.E. 4.46 %,
Mn 0.50 %, Cr 0.14 %, Cu 0.09 %,
Al 0.018 %, Mg 0.025 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
34.0000	50.2884	6.4351	-640.4148	0.0312	-180.0581
32.0000	34.5101	3.5107	52.1541	- .1741	-76.0983
30.0000	23.7818	2.0790	23.7940	0.0051	-28.5002
28.0000	16.5422	1.1153	14.4869	-0.0976	0.2785
26.0000	11.6667	0.4682	8.2420	0.1108	16.9841
24.0000	9.7787	0.2156	2.1924	0.2195	21.8081
22.0000	8.1779	0.0013	1.0053	0.1453	24.1093
20.0000	7.4683	-0.0978	-1.7291	0.0426	20.7362
18.0000	7.1154	-0.1521	-1.0168	-0.3903	17.9222
16.0000	6.8042	-0.2026	-1.0407	-0.2325	15.3760
14.0000	6.3189	-0.2771	-1.6443	0.2891	12.6659
12.0000	5.4078	-0.4063	-1.5819	0.0057	9.5135
10.0000	4.4717	-0.5392	-1.3998	0.0467	6.8074
8.0000	3.5822	-0.6665	-0.9816	-0.0991	4.0400
6.0000	2.6377	-0.7953	-1.2631	0.3900	2.8999
4.0000	1.9130	-0.8933	-0.7676	0.2060	1.7764
2.0000	1.1761	-0.9210	-1.6890	1.2992	0.9972
0.0000	1.0000	-1.3856	1.9212	-2.4154	0.0090
-2.0000	1.0000	-0.8667	0.0754	0.3891	0.9378
-4.0000	1.0000	-0.8667	0.1460	0.0023	1.2340
-6.0000	1.0000	-0.8667	0.0702	0.0636	1.5016
-8.0000	1.0000	-0.8667	0.0761	0.0573	1.7682
-10.0000	1.0000	-0.8667	-0.6682	0.8016	2.0349
-12.0000	1.0000	-0.8667	0.0979	0.0354	2.3017
-14.0000	1.0000	-0.8667	0.1015	0.0318	2.5682
-16.0000	1.0000	-0.8667	0.0684	0.0649	2.8350
-18.0000	1.0000	-0.8667	-0.0410	0.1743	3.1018
-20.0000	1.0000	-0.8667	0.1328	0.0006	3.3683
-22.0000	0.6464	-0.8938	0.1617	-0.3447	2.6023
-24.0000	0.3782	-0.9082	1.4351	-1.7702	1.9324
-26.0000	0.1004	-0.8939	0.2400	-0.6257	1.1612
-28.0000	-0.2284	-1.0819	-0.5492	-0.0884	-0.1139
-30.0000	-0.5861	-1.0958	-0.3587	-0.4032	-1.6379
-32.0000	-0.9428	-1.1276	-0.5555	-0.2551	-3.3250
-34.0000	-1.2411	-1.1591	-2.2876	1.4383	-4.9234
-36.0000	-1.5220	-1.1912	0.0706	-0.9094	-6.6008
-38.0000	-1.9066	-1.2371	-1.0932	-0.0825	-8.9521
-40.0000	-2.2558	-1.2924	-1.5306	0.0803	-11.6527
-42.0000	-2.6808	-1.3327	-0.9603	-0.2525	-14.2982
-44.0000	-3.0758	-1.3842	-1.2256	-0.2889	-17.3275
-46.0000	-3.5582	-1.4464	-1.6656	-0.2220	-21.1027
-48.0000	-4.1502	-1.5232	-2.3112	-0.0556	-25.8362

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-50.0000	-4.8807	-1.6185	-3.1818	0.1960	-31.8077
-52.0000	-5.7873	-1.7372	-4.4172	0.6269	-39.3884
-54.0000	-6.9189	-1.8859	-4.3957	-0.4[illegible]61	-49.0718
-56.0000	-8.3122	-2.0696	-6.2233	0.1033	-61.3118
-58.0000	-9.1204	-2.1770	-4.2596	0.0278	-69.7755
-60.0000	-10.0191	-2.2965	-5.2128	0.4039	-79.3933
-62.0000	-11.0194	-2.4296	-5.1762	-0.2921	-90.3296
-64.0000	-12.1340	-2.5778	-6.2696	0.0473	-102.7744
-66.0000	-13.3770	-2.7432	-6.9314	-0.1535	-116.9442
-68.0000	-14.7649	-2.9279	-8.6612	0.5887	-133.0894
-70.0000	-16.3161	-3.1344	-10.9599	1.7552	-151.4985
-72.0000	-18.0516	-3.3655	-10.2844	-0.2180	-172.5036
-74.0000	-19.9954	-3.6243	-11.4008	-0.5917	-196.4854
-76.0000	-22.1747	-3.9145	-13.2339	-0.4699	-223.8958
-78.0000	-24.3130	-4.2259	-15.6220	0.5104	-254.1189
-80.0000	-26.8585	-4.5385	-15.6284	-0.1447	-285.6650
-82.0000	-29.4421	-4.8828	-17.5618	-0.1386	-321.0662
-84.0000	-32.2893	-5.2622	-19.2238	-0.6415	-360.7966
-86.0000	-35.4285	-5.6805	-24.5270	2.2295	-405.3916
-88.0000	-38.8910	-6.1420	-24.4449	-0.5861	-455.4536
-90.0000	-42.7119	-6.6512	-27.9419	-0.1621	-511.0619
-92.0000	-46.9301	-7.2134	-30.9689	-0.5906	-574.7795
-94.0000	-51.8768	-7.8727	-39.1854	1.9375	-649.2754
-96.0000	-57.8979	-8.6750	-45.3738	-0.0661	-740.1555
-98.0000	-64.6874	-9.5798	-52.9452	0.8866	-844.2847
-100.0000	-72.3507	-10.6010	-60.3827	0.6845	-963.6812
-102.0000	-81.0090	-11.7549	-67.8052	-0.7009	-1100.6930

STATEMENTS EXECUTED= 1554174

CORE USAGE   OBJECT CODE= 18792 BYTES.ARRAY AREA=   8016 BYT86 BYTES

DIAGNOSTICS   NUMBER OF ERRORS=   0. NUMBER OF WARNINGS=   0

COMPILE TIME=   1.07 SEC.EXECUTION TIME= 165.02 SEC.   10.48.? WATFIV - MAR

C3ECF

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Sample Ingot 11

Metal Chemistry - C 4.25 %, Si 2.00 %, C.E. 4.91 %,
Mn 0.65 %, Cr 0.17 %, Cu 0.03 %,
Al 0.025 %, Mg 0.025 %, S 0.002 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	30.8981	3.0129	-624.1050	-0.1367	-28.0746
14.0000	20.8957	1.6505	11.5840	-0.2303	-5.3676
12.0000	14.3450	0.7564	5.6736	0.1535	6.2868
10.0000	5.2792	-0.0661	2.6312	0.1836	11.9165
8.0000	4.7014	-0.5408	-3.0348	0.0372	5.9214
6.0000	2.9050	-0.7721	-1.4371	0.0435	3.1341
4.0000	2.0161	-0.8901	-0.6071	-0.0399	1.8402
2.0000	1.3113	-0.9516	-0.3006	-0.0964	1.0461
0.0000	1.0000	-1.3856	-0.7700	0.2505	0.0070
-2.0000	1.0000	-0.8667	1.1259	-0.6614	0.9359
-4.0000	1.0000	-0.8667	0.0669	0.0813	1.2325
-6.0000	1.0000	-0.8667	0.1018	0.0320	1.4999
-8.0000	1.1061	-0.8650	0.1437	0.0465	1.8804
-10.0000	1.1238	-0.8618	0.0977	0.0618	2.1959
-12.0000	1.1435	-0.8586	0.0864	0.0793	2.5302
-14.0000	1.2194	-0.8515	1.3316	-1.1080	2.9776
-16.0000	1.2160	-0.8415	0.1588	0.1073	3.5099
-18.0000	1.4374	-0.8253	0.3804	-0.0587	4.1535
-20.0000	1.4617	-0.8239	-12.7277	12.9517	4.6017
-22.0000	1.4703	-0.8213	-0.0075	0.2149	5.0166
-24.0000	1.4703	-0.8199	0.0711	0.1249	5.4086
-26.0000	1.4618	-0.8196	0.1054	0.0757	5.7707
-28.0000	1.4084	-0.8244	0.0455	0.0496	5.9609
-30.0000	0.7418	-0.8911	-1.1700	0.0242	3.6691
-32.0000	0.0000	-1.0000	-1.1631	-0.3212	0.7007
-34.0000	-0.5704	-1.0924	-1.1734	-0.1173	-1.8808
-36.0000	-1.2133	-1.1564	-1.6471	0.0261	-5.1227
-38.0000	-1.7274	-1.2158	-1.1407	-0.3218	-8.0478
-40.0000	-2.3873	-1.2963	-1.7604	-0.2265	-12.0215
-42.0000	-2.9927	-1.3726	-2.1097	0.0989	-16.0432
-44.0000	-3.4228	-1.4280	-14.0398	12.3807	-19.3613
-46.0000	-3.9441	-1.4956	-1.9358	-0.1172	-23.4675
-48.0000	-4.5788	-1.5782	-2.1689	-0.3858	-28.5766
-50.0000	-5.3555	-1.6799	-2.9230	-0.2738	-34.9702
-52.0000	-6.3108	-1.8053	-3.9691	-0.0537	-43.0158
-54.0000	-7.4923	-1.9608	-5.1208	0.0298	-53.1977
-56.0000	-8.8610	-2.1415	-6.4612	0.3564	-65.4074

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-58.0000	-9.6222	-2.2429	-4.7965	0.6733	-73.6538
-60.0000	-10.4520	-2.3535	-4.7507	0.1501	-82.8548
-62.0000	-11.3569	-2.4740	-4.8201	-0.3120	-93.1159
-64.0000	-12.3440	-2.6055	-5.3243	-0.3996	-104.5668
-66.0000	-13.4210	-2.7490	-6.5169	0.1341	-117.3322
-68.0000	-14.5965	-2.9057	-6.7737	-0.3425	-131.5648
-70.0000	-15.8799	-3.0767	-7.6372	-0.2959	-147.4314
-72.0000	-17.2814	-3.2634	-8.4786	-0.3638	-165.1161
-74.0000	-18.8126	-3.4675	-11.5056	1.6504	-154.8264
-76.0000	-20.6291	-3.7094	-11.5242	-0.1844	-205.2439
-78.0000	-22.8727	-3.9817	-13.4549	0.0810	-234.9917
-80.0000	-24.9377	-4.2834	-15.3353	0.2364	-265.1895
-82.0000	-27.4498	-4.6151	-17.3580	0.3044	-299.2966
-84.0000	-30.2380	-4.9896	-18.8387	-0.4301	-337.8345
-86.0000	-33.3347	-5.4022	-20.9987	-0.7820	-381.3958
-88.0000	-37.2817	-5.9413	-28.6558	0.4765	-437.7544
-90.0000	-42.4154	-6.6118	-35.9072	0.7307	-508.1072
-92.0000	-48.2211	-7.3852	-41.7538	0.5018	-590.6111
-94.0000	-54.9288	-8.2788	-47.5870	-0.8637	-687.5127
-96.0000	-62.6924	-9.3132	-50.9566	-0.0383	-801.5027
-98.0000	-70.8615	-10.4017	-60.8760	-0.8367	-924.9295
-100.0000	-79.7276	-11.5823	-68.0170	-0.5202	-1062.0029
-102.0000	-89.8141	-12.9274	-79.3595	0.1632	-1220.3950

```
STATEMENTS EXECUTED= 1040492
CORE USAGE       OBJECT CODE=   18754 BYTES,ARRAY AREA=    8016 SYT6  BYTES
DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=      0
COMPILE TIME=    1.04 SEC,EXECUTION TIME=   109.81 SEC,    19.20.  WATFIV - MAR 19

        C$ECF
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Sample Ingot 12

Metal Chemistry - C4.38 %, Si 1.85 %, C.E. 5.01 %,
Mn 0.53 %, Cr 0.11 %, Cu 0.03 %,
Al 0.023 %, Mg 0.021 %, S 0.004 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
18.0000	64.3709	7.6027	-703.7009	-0.0196	-113.9841
16.0000	44.2055	4.8485	28.5521	-0.1036	-57.0872
14.0000	30.4290	2.9636	16.6420	0.2140	-23.3753
12.0000	20.7639	1.6369	9.5608	0.1723	-3.9094
10.0000	13.8075	0.6768	5.5000	-0.2664	6.5575
8.0000	7.1580	-0.2367	1.1547	-0.0573	8.7521
6.0000	3.6550	-0.6982	-2.4977	0.0252	3.8071
4.0000	2.3706	-0.8735	-0.8133	-0.0564	2.0677
2.0000	1.3366	-0.9564	-0.3863	-0.1199	1.0552
0.0000	1.0000	-1.3856	-0.8778	0.3533	0.0063
-2.0000	1.1575	-0.9162	-1.4290	1.9199	0.9880
-4.0000	1.3151	-0.8908	0.1009	0.1097	1.4093
-6.0000	1.4726	-0.8661	0.1819	0.0584	1.8899
-8.0000	1.6302	-0.8419	0.2566	0.0251	2.4529
-10.0000	1.8408	-0.8137	0.2507	0.1091	3.1723
-12.0000	2.0789	-0.7819	0.3897	0.0481	4.0480
-14.0000	2.3474	-0.7460	0.3896	0.1402	5.1076
-16.0000	2.6502	-0.7056	1.8000	-1.1619	6.3836
-18.0000	2.8787	-0.6731	0.4672	0.1612	7.6404
-20.0000	3.0975	-0.6418	0.7632	-0.0872	8.9927
-22.0000	3.1740	-0.6275	4.1412	-3.6169	10.0414
-24.0000	3.0504	-0.6386	0.0514	0.1716	10.4875
-26.0000	2.8618	-0.6580	-0.0455	0.0317	10.6420
-28.0000	2.6209	-0.6844	0.0619	-0.1326	10.5006
-30.0000	2.2216	-0.7300	0.3350	-0.7874	9.5960
-32.0000	1.8190	-0.7760	8.0205	-8.5857	8.4652
-34.0000	1.4429	-0.8153	-0.4127	-0.1959	7.2419
-36.0000	1.0000	-0.8667	-0.6690	-0.2026	5.4985
-38.0000	0.6505	-0.8991	-0.7606	0.0856	4.1486
-40.0000	0.2910	-0.9295	-1.8625	0.9233	2.2705
-42.0000	-0.1761	-1.0640	-1.1419	-0.1199	-0.2532
-44.0000	-0.8726	-1.1194	-1.6995	-0.3341	-4.4205
-46.0000	-1.5092	-1.1994	-2.1327	-0.1187	-8.9233
-48.0000	-2.1198	-1.2669	-2.9577	0.9882	-12.8621
-50.0000	-2.7902	-1.3513	-2.3925	-0.1222	-17.8913
-52.0000	-3.5947	-1.4544	-2.8569	-0.3010	-24.2072
-54.0000	-4.0362	-1.5120	-1.8894	-0.1751	-28.3420
-56.0000	-4.5544	-1.5798	-2.8293	0.3581	-33.2843
-58.0000	-5.1646	-1.6599	-3.0852	0.1203	-39.2138
-60.0000	-5.8855	-1.7547	-3.7695	0.1992	-46.3541
-62.0000	-6.7402	-1.8674	-4.7043	0.3890	-54.9846
-64.0000	-7.6903	-1.9929	-5.5887	0.6387	-64.8845
-66.0000	-8.2903	-2.0727	-4.1524	0.4578	-72.2141

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-68.0000	-8.9424	-2.1596	-3.8853	-0.1795	-80.3436
-70.0000	-9.6540	-2.2542	-4.1208	-0.3892	-89.3635
-72.0000	-10.4295	-2.3574	-4.9559	-0.0497	-99.3748
-74.0000	-11.2744	-2.4698	-5.4544	-0.1030	-110.4897
-76.0000	-12.1961	-2.5925	-6.0049	-0.1671	-122.8338
-78.0000	-13.2024	-2.7265	-6.4464	-0.4107	-136.5481
-80.0000	-14.2015	-2.8729	-8.1936	0.5730	-151.7890
-82.0000	-15.5028	-3.0325	-7.9150	-0.5573	-168.7335
-84.0000	-16.8456	-3.2116	-9.6235	0.0388	-187.9026
-86.0000	-18.4443	-3.4245	-11.7123	0.3024	-210.7225
-88.0000	-20.2165	-3.6605	-13.4125	0.5571	-236.4332
-90.0000	-22.1839	-3.9225	-15.2446	0.7497	-265.4226
-92.0000	-24.3689	-4.2135	-16.1758	-0.1798	-298.1340
-94.0000	-26.7987	-4.5372	-18.0454	-0.4275	-335.0796
-96.0000	-29.5076	-4.8980	-20.8791	-0.0268	-376.8911
-98.0000	-32.5260	-5.3001	-23.2996	-0.3506	-424.1914
-100.0000	-35.8924	-5.7456	-27.4168	0.6422	-477.7407
-102.0000	-39.6509	-6.2494	-30.6560	0.3180	-538.4165
-104.0000	-44.0305	-6.8329	-35.5577	-0.0874	-609.7068
-106.0000	-52.4449	-7.9536	-66.3243	1.0058	-740.3438
-108.0000	-62.7089	-9.3209	-80.2775	-0.5975	-902.0938
-110.0000	-74.1613	-10.8467	-91.7841	-0.5395	-1086.7400
-112.0000	-86.6815	-12.5150	-103.1666	-0.1842	-1293.4420

STATEMENTS EXECUTED= 1370041

CORE USAGE OBJECT CODE= 17848 BYTES,ARRAY AREA= 8008 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.90 SEC,EXECUTION TIME= 146.20 SEC, 12.07. WATFIV - MAR 1[illegible]

C$EOF

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Sample Ingot 13

Metal Chemistry - C 4.07 %, Si 2.28 %, C.E. 4.73 %,
Mn 0.64 %, Cr 0.32 %, Cu 0.11 %,
Al 0.019 %, Mg 0.022 %, S 0.005 %.

X(I)	Y(I)	P(I)	C(ODD)	C(EVEN)	SUM(C(I))
12.0000	35.4286	4.3320	-579.1343	-7.3513	-33.4501
10.0000	24.6373	2.2267	12.5222	-7.0546	-3.1637
8.0000	[illegible]	2.6236	6.3640	0.3771	3.4255
6.0000	7.2981	-0.2479	0.5133	0.1081	7.1714
4.0000	3.6078	-0.7452	-2.1603	0.1099	3.3325
2.0000	1.6240	-0.9932	-1.0109	0.0568	1.1065
0.0000	1.0000	-1.3956	-1.8838	1.3946	0.0350
-2.0000	1.3355	-1.0562	-1.5496	2.0735	1.1537
-4.0000	1.6709	-0.8972	-0.0599	0.3442	1.6222
-6.0000	2.0984	-0.8257	-0.1351	6.5305	[illegible]
-8.0000	2.6633	-0.7591	0.2952	0.1340	[illegible]
-10.0000	3.2715	-0.6744	0.5769	0.1907	5.1397
-12.0000	3.7554	-0.6025	0.8171	0.0037	6.7713
-14.0000	4.1727	-0.5298	0.7212	0.1677	9.0050
-16.0000	[illegible]	-0.4910	0.9126	0.3727	10.3415
-18.0000	4.5444	-0.4741	0.6114	0.3572	11.6737
-20.0000	4.2569	-0.5019	-0.1777	0.3226	12.1044
-22.0000	3.3054	-0.5513	-0.0344	-0.3375	11.4059
-24.0000	2.2467	-0.6149	-0.2630	-0.1247	[illegible]
-26.0000	2.5464	-0.6958	-0.6123	-0.1747	9.5428
-28.0000	1.8942	-0.7711	-0.6897	-0.2120	7.7304
-30.0000	1.2555	-0.8401	-1.0203	0.0116	5.7215
-32.0000	0.5591	-0.9044	-2.3754	1.1224	3.2159
-34.0000	-0.1286	-1.0758	-2.5769	5.3500	[illegible]
-36.0000	-1.2343	-1.1537	-2.3797	-0.1302	-5.22[illegible]
-38.0000	-2.1845	-1.2705	-2.0270	-0.5442	[illegible]
-40.0000	-2.4295	-1.4260	-2.3302	[illegible]	-17.5729
-42.0000	-3.8329	-1.4786	-3.1821	1.5949	-20.7472
-44.0000	-4.2527	-1.5335	-1.1863	-0.3521	-24.2237
-46.0000	-4.7342	-1.5965	-2.5175	0.4750	-28.2395
-48.0000	-5.2966	-1.6094	[illegible]	0.4579	-33.1213
-50.0000	-5.9214	-1.7545	-2.4372	1.0447	[illegible]
-52.0000	-6.6750	-1.8527	-2.1495	-0.1792	[illegible]
-54.0000	-7.5251	-1.9069	-2.5981	[illegible]	[illegible]
-56.0000	[illegible]	-2.1032	-4.3195	0.2590	[illegible]
-58.0000	-9.7219	-2.2507	-5.9912	0.1972	-74.4253
-60.0000	-11.0996	-2.4289	-6.9059	0.1034	[illegible]
-62.0000	-12.1486	-2.5652	-5.6555	0.2556	[illegible]
-64.0000	-12.8543	-2.6729	-5.5563	0.5152	[illegible]
-66.0000	-13.7711	-2.7662	-6.1511	0.7134	[illegible]
-68.0000	-14.5593	-2.9047	-5.3465	0.1947	-131.[illegible]
-70.0000	-15.8222	-3.0290	-5.6431	-0.3375	-144.[illegible]
-72.0000	-16.4940	-3.1291	-6.2221	-0.5412	-157.[illegible]

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-74.0000	-17.5121	-3.2951	-7.3341	0.1152	-172.0027
-76.0000	-18.5750	-3.4371	-7.3297	-0.3344	-137.4409
-78.0000	-19.7297	-3.5911	-8.3699	-0.1043	-204.3595
-80.0000	-21.0109	-3.7622	-9.3332	-0.0041	[illegible]
-82.0000	-22.3613	-3.9425	-10.7393	0.3372	[illegible]
-84.0000	-23.7828	-4.1331	-11.3040	0.4606	-265.5047
-86.0000	-25.2770	-4.3318	-12.0901	[illegible].3521	[illegible]
-88.0000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-90.0000	-29.0577	-4.8410	-16.6683	0.0256	[illegible].3534
-92.0000	-31.2456	-5.1412	-17.5297	-0.1585	[illegible].7251
-94.0000	-32.7753	-5.4046	-18.7346	-0.5427	-422.[illegible]
-96.0000	-34.3881	-5.8129	-20.2415	-0.4917	[illegible]
-98.0000	-35.0025	-6.1981	-22.2344	[illegible]	[illegible]
-100.0000	-41.3957	-6.6137	[illegible]	1.3514	[illegible]
-102.0000	-45.5754	-7.0622	-25.8815	[illegible].3323	[illegible]
-104.0000	-49.7282	-7.5300	[illegible]	[illegible]	[illegible]
-106.0000	-51.5874	-8.1430	-27.3241	[illegible]	[illegible]
-108.0000	-56.2657	-9.7426	-38.3302	-1.4335	[illegible].3098
-110.0000	-61.2612	-9.2930	-42.2052	[illegible]	[illegible]
-112.0000	-75.2327	-10.9949	-56.4835	0.2405	-1124.2071

STATEMENTS EXECUTED= 1201028

CORE USAGE OBJECT CODE= [illegible] BYTES,ARRAY AREA= [illegible] BYTES,[illegible]

DIAGNOSTICS NUMBER OF ERRORS= [illegible] NUMBER OF WARNINGS= [illegible]

COMPILE TIME= 0.67 SEC,EXECUTION TIME= 123.42 SEC, [illegible]

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Sample Ingot 14

Metal Chemistry - C 3.92 %, Si 2.33 %, C.E. 4 70 %,
Mn 0.66 %, Cr 0.19 %, Cu 0.13 %,
Al 0.019 %, Mg 0.016 %, S 0.005 %.

X(I)	Y(I)	P(I)	C(ODD)	C(EVEN)	SUM(C(I))
14.0000	47.9965	5.4363	-675.5437	0.0105	-57.5646
12.0000	32.4755	3.2941	17.1671	-0.2585	-23.3473
10.0000	20.0618	1.5603	10.5003	0.2225	-1.9027
8.0000	11.6545	0.3810	5.3525	-0.3467	5.1237
6.0000	6.6963	-0.3267	-0.7130	-0.0300	6.6226
4.0000	4.7559	-0.6209	-1.5275	0.1044	3.7764
2.0000	2.4155	-0.9960	-1.3014	0.1996	1.5727
0.0000	1.0000	-1.3856	-1.2132	0.4309	0.0079
-2.0000	1.3567	-0.9600	-1.6344	2.1628	1.0646
-4.0000	1.7123	-0.8969	-0.0885	0.3517	1.6511
-6.0000	2.1172	-0.8345	-0.3570	0.7535	2.4441
-8.0000	2.6883	-0.7568	0.4272	0.1686	3.6354
-10.0000	3.3945	-0.6610	0.6779	0.1607	5.3126
-12.0000	4.0384	-0.5695	1.0558	-0.0827	7.2556
-14.0000	4.5649	-0.4927	0.8481	0.1833	9.3212
-16.0000	5.0002	-0.4277	1.0322	0.0404	11.4663
-18.0000	5.3657	-0.3726	0.8952	0.2059	13.6746
-20.0000	5.6184	-0.3326	0.8315	0.2181	15.7740
-22.0000	5.7195	-0.3125	0.8602	0.0339	17.5623
-24.0000	5.6415	-0.3168	1.8463	-1.2158	18.8273
-26.0000	5.4050	-0.3415	0.0377	0.2992	19.5012
-28.0000	5.0215	-0.3550	0.0982	0.0395	19.5372
-30.0000	4.5510	-0.4423	-0.2158	-0.0797	18.9464
-32.0000	3.9996	-0.5090	-0.3055	0.2311	17.7976
-34.0000	3.3172	-0.5923	-3.0194	2.0009	15.7605
-36.0000	2.5348	-0.6875	-11.7275	10.2871	12.8799
-38.0000	1.8652	-0.7576	-1.0760	-0.2359	10.1560
-40.0000	1.1347	-0.8519	-1.3783	-0.3234	6.7528
-42.0000	0.3940	-0.9250	-1.9518	0.0342	2.9175
-44.0000	-0.3822	-1.0727	-2.8255	0.6010	-1.5375
-46.0000	-1.2020	-1.1503	-2.4343	-0.1324	-6.6738
-48.0000	-1.9342	-1.2465	-2.0070	-0.5581	-11.8008
-50.0000	-2.6475	-1.3333	-2.4937	-0.0754	-16.9391
-52.0000	-3.6484	-1.4512	-4.1731	0.3540	-24.5771

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-54.0000	-4.3401	-1.5125	-1.4725	-0.4225	-28.3677
-56.0000	-4.4911	-1.5716	-2.0233	-0.1979	-32.8103
-58.0000	-5.0118	-1.6400	-3.0692	0.4583	-38.0320
-60.0000	-5.6146	-1.7194	-3.2693	0.1916	-44.1875
-62.0000	-6.3142	-1.8117	-3.6655	0.0269	-51.4649
-64.0000	-7.1285	-1.9192	-4.4856	0.1712	-60.0934
-66.0000	-8.0790	-2.0449	-5.4877	0.3572	-70.3543
-68.0000	-9.0532	-2.1740	-6.0627	0.5712	-81.3372
-70.0000	-9.8070	-2.2743	-5.4386	0.7183	-90.7840
-72.0000	-10.6329	-2.3842	-4.9905	-0.2793	-101.3238
-74.0000	-11.5380	-2.5046	-5.3709	-0.5113	-113.0894
-76.0000	-12.5313	-2.6368	-6.4336	-0.1356	-125.2268
-78.0000	-13.6231	-2.7822	-7.2362	-0.1106	-140.9203
-80.0000	-14.8249	-2.9422	-7.9923	-0.2317	-157.3693
-82.0000	-16.1468	-3.1152	-5.6869	-0.5141	-175.7793
-84.0000	-17.6020	-3.3119	-10.5740	0.2740	-196.3704
-86.0000	-19.2052	-3.5255	-10.8487	-0.6579	-219.4438
-88.0000	-20.9729	-3.7609	-13.3368	0.4085	-245.3052
-90.0000	-22.9235	-4.0207	-15.1029	0.6060	-274.2937
-92.0000	-24.9490	-4.2906	-16.1797	0.7025	-305.2483
-94.0000	-26.8141	-4.5392	-15.9618	0.9497	-335.2725
-96.0000	-28.8212	-4.8068	-16.1910	-0.2272	-368.1089
-98.0000	-30.9815	-5.0947	-17.4933	-0.4604	-404.0161
-100.0000	-33.2967	-5.4047	-19.2967	-0.3325	-443.2747
-102.0000	-35.8098	-5.7384	-21.2579	-0.2011	-486.1926
-104.0000	-38.5044	-6.0976	-24.3595	0.9057	-533.1003
-106.0000	-41.4057	-6.4844	-26.1385	0.5554	-584.3667
-108.0000	-44.5296	-6.9008	-27.7675	-0.2415	-640.3848
-110.0000	-51.0520	-7.7697	-54.9044	1.1465	-747.9004
-112.0000	-59.7560	-8.9292	-70.8980	-0.8842	-891.4651
-114.0000	-70.1589	-10.3153	-86.1484	-0.8638	-1065.4990
-116.0000	-82.6936	-12.1136	-113.8407	-0.1582	-1293.4870

```
STATEMENTS EXECUTED= 1370124

CORE USAGE        OBJECT CODE=   13754 BYTES,ARRAY AREA=    5016 BYT  BYTES

DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=     0

COMPILE TIME=    1.05 SEC,EXECUTION TIME=   144.89 SEC.     19.45-WATFIV - MAR 19

        C$ECF
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Sample Ingot 15

Metal Chemistry - C 4.03 %, Si 2.23 %, C.E. 4.79 %,
Mn 0.43 %, Cr 0.14 %, Cu 0.06 %,
Al 0.021 %, Mg 0.016 %, S 0.004 %.

X(I)	Y(I)	F(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	43.8982	4.8058	-660.1643	0.0136	-50.4140
14.0000	26.8017	2.4691	15.9499	-0.7328	-10.5735
12.0000	16.7553	1.3062	7.7707	0.1998	-3.7251
10.0000	11.8476	0.4043	4.7292	0.1834	4.0710
8.0000	6.5645	-0.2617	-0.2565	0.0082	3.5344
6.0000	2.8210	-0.7812	-2.7671	0.0213	3.0436
4.0000	1.3812	-0.8423	-0.8840	0.0766	1.4328
2.0000	1.1490	-0.9140	-0.1756	-0.0400	6.4075
0.0000	1.0000	-1.2856	-0.8656	0.0781	2.0345
-2.0000	1.5575	-0.9858	-0.5539	1.1250	1.1324
-4.0000	2.2173	-0.8821	-0.0275	0.4207	1.4505
-6.0000	3.1092	-0.7455	0.5971	0.1214	3.2076
-8.0000	4.4015	-0.5750	0.8529	0.2225	5.5794
-10.0000	5.4795	-0.4190	1.3070	0.0795	9.2113
-12.0000	6.4206	-0.2813	1.3253	0.1617	11.1354
-14.0000	7.0812	-0.1412	1.3594	0.0744	14.1217
-16.0000	7.3509	-0.1333	1.1348	0.0362	15.5982
-18.0000	7.1822	-0.1436	0.6997	0.0629	13.2352
-20.0000	6.6352	-0.2073	-0.1077	[illegible]	13.4257
-22.0000	6.1974	-0.2523	-1.6477	1.4193	19.4738
-24.0000	6.0271	-0.2602	-1.2295	1.4734	20.2520
-26.0000	5.7984	-0.2915	0.0054	0.2396	24.8718
-28.0000	5.2563	-0.3436	0.0206	-0.0240	20.7549
-30.0000	4.7555	-0.4109	-0.4601	0.0537	17.4436
-32.0000	4.1755	-0.4875	-4.4305	0.7923	13.5215
-34.0000	3.3755	-0.5957	-7.7943	4.4531	15.0149
-36.0000	[illegible]	-0.6751	-1.7959	2.4505	13.2324
-38.0000	1.5550	-0.7565	-0.9983	-0.3599	12.6115
-40.0000	1.2143	-0.8429	-1.4236	-0.2937	7.1760
-42.0000	0.4735	-0.9199	-2.5471	0.7340	3.3044
-44.0000	-0.2479	-1.0643	-1.5151	-0.5277	-1.7333
-46.0000	-0.7352	-1.1261	-2.6265	0.4751	-5.0530
-48.0000	-1.6225	-1.2362	-2.7304	0.4075	-9.6014
-50.0000	-2.3097	-1.2911	-2.9434	0.4435	-14.6411
-52.0000	-2.8571	-1.3605	-2.3524	-0.1451	-19.0437
-54.0000	-3.4110	-1.4318	-2.3854	-0.2475	-23.5442
-56.0000	-4.1123	-1.5229	-2.3851	-0.1411	-29.5107
-58.0000	-4.8120	-1.6400	-4.5196	0.5210	-35.6040
-60.0000	-5.5430	-1.7102	-3.0229	0.2262	-40.6233
-62.0000	-6.0452	-1.7765	-2.3340	0.0240	-44.2134
-64.0000	-6.6243	-1.8505	-2.5136	0.3232	-55.6241
-66.0000	-7.2249	-1.9323	-4.2423	0.0127	-62.9754
-68.0000	-7.9276	-2.0260	-4.5713	0.7414	-71.1355

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-70.0000	-8.7104	-2.1299	-3.0757	[illegible].3672	-[illegible]0.5553
-72.0000	-9.5847	-2.2405	-4.3874	[illegible].4582	-91.3007
-74.0000	-10.5756	-2.3776	-5.6039	-[illegible].3416	-103.5973
-76.0000	-11.6553	-2.5251	-7.0945	[illegible].2255	-117.6704
-78.0000	-12.9253	-2.6916	-7.7234	-[illegible].3532	-133.0014
-80.0000	-14.0634	-2.8413	-7.6067	-[illegible].1172	-149.2499
-82.0000	-15.1359	-2.9846	-7.0240	-0.1234	-164.7556
-84.0000	-16.3027	-3.1397	-8.3948	-0.1394	-181.6241
-86.0000	-17.5624	-3.3075	-8.9895	-0.4051	-200.6135
-88.0000	-18.9265	-3.4893	-10.8293	0.4904	-221.2487
-90.0000	-20.4042	-3.6862	-11.9661	0.5795	-244.2779
-92.0000	-22.0054	-3.8996	-13.3272	[illegible].7563	-269.1515
-94.0000	-23.7412	-4.1309	-14.7591	0.4907	-296.7050
-96.0000	-25.6220	-4.3517	-14.3923	-0.3154	-327.1368
-98.0000	-27.7904	-4.6714	-16.3975	-[illegible].7137	-362.4172
-100.0000	-30.1824	-4.9894	-18.7796	-0.4331	-401.0433
-102.0000	-32.7937	-5.3272	-22.0815	[illegible].3101	-445.1872
-104.0000	-35.6505	-5.7179	-25.2899	1.1139	-493.5384
-106.0000	-38.7768	-6.1348	-27.4119	[illegible].5562	-547.2500
-108.0000	-42.2060	-6.5916	-29.9112	-[illegible].0396	-609.9335
-110.0000	-46.3628	-7.0723	-34.5334	1.2512	-672.2791
-112.0000	-55.1912	-8.3215	-72.8631	-1.1546	-823.3135
-114.0000	-67.3077	-9.9346	-98.1247	-1.2471	-1022.7572
-116.0000	-81.7787	-11.8636	-120.9389	[illegible].0296	-1263.0763

STATEMENTS EXECUTED= 1429727

CORE USAGE OBJECT CODE= 17[illegible] BYTES,ARRAY AREA= [illegible] BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= [illegible]

COMPILE TIME= 0.31 SEC,EXECUTION TIME= 149.24 SEC, 21.[illegible]

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Sample Ingot 16 %

Metal Chemistry – C 4.25 %, Si 2.30 %, C.E. 4.82 %,
Mn 0.59 %, Cr 0.14 %, Cu 0.09 %,
Al 0.023 %, Mg 0.014 %, S 0.004 %

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
18.0000	40.8521	4.3629	-641.9125	-0.1563	-30.1230
16.0000	31.3562	3.0756	12.6629	-0.1234	-29.0545
14.0000	23.1953	1.9648	0.4602	0.2405	[illegible]33
12.0000	17.4257	1.1759	5.3764	0.1735	1.[illegible]72
10.0000	12.6665	0.5199	3.5579	-0.2510	[illegible]
8.0000	7.5362	-0.1974	0.5351	-0.0394	[illegible]
6.0000	4.4573	-0.6035	-2.3310	0.0330	[illegible]
4.0000	2.7499	-0.8477	-1.2493	-0.0776	2.3142
2.0000	1.3700	-0.9624	0.4512	-0.1429	1.0638
0.0000	1.0000	-1.3956	-0.8617	0.2306	0.[illegible]
-2.0000	1.1513	-0.9145	2.0694	-1.5706	0.[illegible]
-4.0000	1.3022	-0.3902	0.1053	0.1022	1.[illegible]25
-6.0000	1.4551	-0.9695	0.2215	0.2131	1.6757
-8.0000	1.6402	-0.3412	0.2109	0.0427	2.4045
-10.0000	1.8440	-0.3134	0.2536	0.0753	2.[illegible]
-12.0000	2.0695	-0.7829	0.3268	0.0907	4.[illegible]
-14.0000	2.3309	-0.7478	-1.0537	1.3761	5.2776
-16.0000	2.6249	-0.7784	0.4371	0.1991	[illegible]
-18.0000	2.9541	-0.5943	0.6527	[illegible]352	7.[illegible]
-20.0000	3.3229	-0.6151	1.0350	-0.[illegible]72	[illegible]
-22.0000	3.7259	-0.5593	1.9452	-0.0344	11.7[illegible]
-24.0000	3.8315	-0.5474	-1.1934	1.3565	[illegible]
-26.0000	3.6737	-0.5583	0.1574	0.3770	[illegible]
-28.0000	3.4399	-0.5944	0.0204	0.0300	13.5715
-30.0000	3.1456	-0.6180	0.1305	-0.2535	[illegible]
-32.0000	2.8091	-0.6572	-0.1159	-0.2362	12.7[illegible]
-34.0000	2.4449	[illegible].5944	-0.3043	-0.1380	11.[illegible]143
-36.0000	2.0866	-0.7422	[illegible].3059	0.4554	10.7[illegible]
-38.0000	1.7102	-0.7593	-0.2947	-0.[illegible]34	[illegible]
-40.0000	1.2641	-0.2259	-2.7501	0.0641	[illegible]
-42.0000	1.0000	-0.3662	-0.0754	0.1372	[illegible]
-44.0000	0.7306	-0.4054	1.5747	-0.2377	4.[illegible]377
-46.0000	0.3922	-0.9271	-2.7831	-0.1537	[illegible]154
-48.0000	0.0000	-1.0000	-0.3332	-0.3747	[illegible]
-50.0000	-1.1963	-1.1552	-3.5400	-0.4179	-7.2359
-52.0000	-2.4676	-1.3122	-4.3956	-0.1623	-1[illegible].3521
-54.0000	-3.2364	-1.4299	-3.7156	[illegible]	-23.[illegible]
-56.0000	-3.8072	-1.4325	-2.0927	[illegible]965	-27.6577
-58.0000	-4.2614	-1.3455	-2.8263	0.[illegible]565	-32.[illegible]
-60.0000	-4.8455	-1.6198	-3.5507	0.5146	-33.7652
-62.0000	-5.5173	-1.7077	-3.3021	0.4930	-44.5324
-64.0000	-6.3095	-1.8120	-4.0420	-0.0707	-53.1133
-66.0000	-7.2511	-1.9352	-4.5032	-0.3791	[illegible]

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-68.0000	-8.3750	-2.0757	-5.6747	-0.9687	-74.5339
-70.0000	-9.1250	-2.1945	-4.3146	-0.1153	-34.4270
-72.0000	-10.0430	-2.3009	-5.3907	-0.2231	-95.8717
-74.0000	-11.0747	-2.4435	-6.2221	-0.2521	-106.2203
-76.0000	-12.2339	-2.5975	-8.4937	1.1450	-123.2162
-78.0000	-13.5291	-2.7711	-7.8732	-0.5426	-140.2477
-80.0000	-15.0138	-2.9604	-9.4735	-0.1793	-159.2511
-82.0000	-16.6591	-3.1874	-11.2949	0.1497	-181.4709
-84.0000	-18.5218	-3.4342	-13.1524	0.3754	[illegible]
-86.0000	-20.6210	-3.7133	-14.3758	0.4861	-235.0722
-88.0000	-22.9961	-4.0295	-16.4245	-0.3441	-259.2293
-90.0000	-25.6856	-4.3881	-18.5224	-0.7327	-307.4774
-92.0000	-28.7672	-4.7979	-21.5125	-0.7521	-352.2674
-94.0000	-32.9275	-5.3519	-30.0869	0.7501	-411.8074
-96.0000	-37.7591	-5.9493	-35.9681	0.4717	-452.8034
-98.0000	-43.4932	-6.7577	-41.4122	-0.3142	-567.3308
-100.0000	-50.3994	-7.6789	-52.3551	0.4036	-671.1357
-102.0000	-60.1592	-8.9842	-72.3379	-0.3304	-817.7544
-104.0000	-72.1154	-10.5817	-92.3344	-0.2227	-996.2571
-106.0000	-86.9467	-12.5476	-114.2336	0.3247	-1227.2032

STATEMENTS EXECUTED= 1201014

CORE USAGE OBJECT CODE= 17988 BYTES,ARRAY AREA= 4003 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.42 SEC,EXECUTION TIME= 128.74 SEC, 21.00, WATFIV - MAR

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Sample Ingot 17

Metal Chemistry - C 3.96 %, Si 2.17 %, C.E. 4.68 %,
Mn 0.47 %, Cr 0.09 %, Cu 0.04 %,
Al 0.022 %, Mg 0.021 %, S 0.005 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
12.0000	26.8987	3.9327	-794.4252	-0.0015	-30.5836
10.0000	25.7154	2.8325	8.2960	0.0108	-14.2599
8.0000	19.4271	1.5362	6.6233	0.2003	-0.6224
6.0000	11.1080	0.3252	3.8392	0.0317	7.1196
4.0000	5.3940	-0.5325	-1.5577	0.1188	4.2416
2.0000	2.1977	-1.0083	-1.5564	0.1625	1.4540
0.0000	1.0000	-1.3556	-3.2897	2.5665	0.0077
-2.0000	1.6940	-1.0011	1.8740	-1.2740	1.2075
-4.0000	2.3880	-0.8725	0.6405	-0.2041	2.0803
-6.0000	3.6029	-0.7941	2.6921	-1.8534	3.7574
-8.0000	5.4335	-0.4535	1.8161	-0.3127	6.7640
-10.0000	6.8758	-0.2454	1.5336	0.1684	10.1680
-12.0000	7.8747	-0.0974	1.4691	0.2444	13.5951
-14.0000	8.2911	-0.0270	1.4320	-0.0120	16.4370
-16.0000	8.1005	-0.0376	0.7262	0.1508	18.1910
-18.0000	8.1716	-0.0170	1.0916	0.0599	20.4942
-20.0000	7.7930	-0.0562	0.5044	0.0635	21.6297
-22.0000	7.1541	-0.1254	0.0623	0.0681	21.8906
-24.0000	7.4013	-0.0920	1.2403	0.0613	24.4939
-26.0000	7.4373	-0.0817	1.5521	-0.5075	26.5831
-28.0000	7.2896	-0.0958	-5.7341	6.4446	28.0042
-30.0000	6.5691	-0.1329	0.0357	0.2592	28.6539
-32.0000	6.4987	-0.1900	-0.0424	-0.0379	28.4935
-34.0000	5.9109	-0.2626	-0.5236	0.0520	27.5504
-36.0000	5.2440	-0.3456	-2.0393	1.2214	25.9141
-38.0000	4.5379	-0.4339	8.6236	-9.7183	23.7252
-40.0000	2.3683	-0.7055	-5.2460	0.0553	13.3438
-42.0000	1.4769	-0.8123	-1.7805	-0.4045	8.9735
-44.0000	1.2034	-0.8437	-0.4401	-0.1660	7.7614
-46.0000	1.0000	-0.8667	0.8695	-1.3330	6.8343
-48.0000	0.6564	-0.9037	-0.5400	-0.4252	4.9040
-50.0000	0.3829	-0.9296	-1.4070	0.5966	3.2630
-52.0000	0.1094	-0.9419	-1.2563	0.3790	1.5086
-54.0000	-0.3510	-1.0695	-2.2970	0.5261	-2.0333

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-56.0000	-1.0159	-1.1352	-2.1191	-0.3063	-6.8839
-58.0000	-1.6505	-1.2114	-2.3196	-0.2698	-12.0629
-60.0000	-2.2857	-1.2909	-2.2913	0.5332	-17.5758
-62.0000	-2.9206	-1.3720	-2.1963	0.2591	-23.4330
-64.0000	-3.4042	-1.4346	-2.5517	0.1004	-28.3354
-66.0000	-3.8942	-1.4984	-2.5877	-0.0209	-33.5528
-68.0000	-4.4808	-1.5751	-3.4437	0.2668	-39.9068
-70.0000	-5.1859	-1.6676	-4.3643	0.4781	-47.6793
-72.0000	-6.0371	-1.7796	-5.5039	0.7289	-57.2293
-74.0000	-6.7897	-1.8790	-4.8444	0.3250	-66.2620
-76.0000	-7.5931	-1.9553	-4.5319	-0.4424	-76.2105
-78.0000	-8.5184	-2.1079	-5.3258	-0.4967	-87.8554
-80.0000	-9.5868	-2.2495	-6.9277	0.0958	-101.5191
-82.0000	-10.8234	-2.4135	-7.6839	-0.3520	-117.5909
-84.0000	-11.9766	-2.5668	-7.8219	-0.0774	-133.3895
-86.0000	-13.0607	-2.7110	-7.7249	-0.0858	-149.0111
-88.0000	-14.2612	-2.8707	-8.3965	-0.3862	-166.5768
-90.0000	-15.5920	-3.0478	-9.9752	0.0909	-186.3454
-92.0000	-17.0689	-3.2443	-11.6433	0.5053	-208.6156
-94.0000	-18.7095	-3.4627	-13.0595	0.5043	-233.7258
-96.0000	-20.5342	-3.7057	-14.7953	0.6253	-262.0657
-98.0000	-22.6992	-3.9939	-17.7126	0.8329	-295.8250
-100.0000	-25.3656	-4.3489	-20.5126	-0.2582	-337.4226
-102.0000	-28.3990	-4.7525	-23.3298	-0.6752	-385.4324
-104.0000	-31.8553	-5.2131	-26.6916	-1.0539	-440.9233
-106.0000	-35.8000	-5.7385	-32.4395	0.3217	-505.1592
-108.0000	-40.3095	-6.3392	-38.1883	0.9525	-579.6301
-110.0000	-46.3029	-7.1376	-49.5121	0.4953	-675.2639
-112.0000	-54.0705	-8.1723	-62.9975	-1.1629	-806.5845
-114.0000	-63.2342	-9.4064	-78.8244	1.2270	-961.7793
-116.0000	-74.2499	-10.5675	-91.6080	-1.2334	-1147.4620
-118.0000	-84.9692	-12.2693	-92.9465	-1.2599	-1335.8740
-120.0000	-97.4361	-13.9537	-111.1483	0.1053	-1557.9600

STATEMENTS EXECUTED= 1429722

CORE USAGE OBJECT CODE= 15784 BYTES.ARRAY AREA= 8016 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0. NUMBER OF WARNINGS= 0

COMPILE TIME= 1.02 SEC.EXECUTION TIME= 149.51 SEC. 20.07 WATFIV - MAR 196

C$STOP

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Sample Ingot 18

Metal Chemistry - C 3.98 %, Si 2.48 %, C.E. 4.81 %,
Mn 0.52 %, Cr 0.12 %, Cu 0.09 %,
Al 0.023 %, Mg 0.026 %, S 0.005 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
12.0000	40.9976	4.5164	-421.2776	0.3492	-27.7391
10.0000	29.5664	2.9598	11.1547	-0.0175	-15.5114
8.0000	17.3196	1.2421	3.4451	-0.1977	1.9545
6.0000	6.6793	-0.0451	3.1272	[illegible]	3.1312
4.0000	3.8813	-0.7367	-2.5972	0.0777	[illegible]
2.0000	1.9644	-1.0113	-1.0193	0.1323	1.3543
0.0000	[illegible]	-1.3356	-2.7748	2.1104	[illegible]
-2.0000	1.5022	-0.9323	2.2041	-1.7050	1.1221
-4.0000	2.0984	-0.8577	0.7335	-0.3401	1.8914
-6.0000	2.9956	-0.7035	6.3390	-6.7291	3.2139
-8.0000	3.9113	-0.6397	0.9701	0.0210	5.2149
-10.0000	4.2245	-0.4077	0.9633	0.1735	7.2493
-12.0000	5.6407	-0.3771	1.2255	0.2732	9.4956
-14.0000	5.2714	-0.2830	1.2467	0.0572	12.5774
-16.0000	6.6292	-0.2272	1.3942	0.0753	14.9623
-18.0000	6.7281	-0.2015	0.7096	0.1232	10.4753
-20.0000	6.7102	-0.1945	0.7460	0.1211	13.7123
-22.0000	6.4137	-0.2244	0.4105	0.0344	14.0110
-24.0000	5.6732	-0.2374	0.0744	-0.7133	14.5723
-26.0000	5.1523	-0.3737	-0.3237	-0.1011	15.6219
-28.0000	4.6092	-0.4381	-0.2759	-0.1306	17.4575
-30.0000	3.9962	-0.5120	-0.4359	-0.1274	16.7477
-32.0000	3.3537	-0.5693	[illegible]	0.1530	[illegible]
-34.0000	2.7208	-0.6662	-2.0177	1.4254	15.0454
-36.0000	2.1142	-0.7337	23.4232	-24.3249	10.8503
-38.0000	1.5081	-0.9097	-0.9547	-0.3719	[illegible]
-40.0000	1.0000	-0.8667	-2.9116	-0.2632	[illegible]
-42.0000	0.2945	-0.9311	-2.0895	0.2504	2.3753
-44.0000	-0.2252	-1.0537	-1.0570	-0.4494	[illegible]
-46.0000	-0.6552	-1.1075	-1.7157	0.3636	-2.5510
-48.0000	-1.1112	-1.1463	-1.3764	0.1512	[illegible]
-50.0000	-1.5054	-1.1925	-1.9506	0.4392	-9.3544
-52.0000	-2.0501	-1.2637	-1.9117	-0.2102	-13.5734
-54.0000	-2.3364	-1.2919	-0.9724	-0.1552	-15.5473
-56.0000	-2.9685	-1.3293	-1.9417	0.6447	-18.6955
-58.0000	-2.9461	-1.3740	-1.9632	0.2732	[illegible]
-60.0000	-3.2413	-1.4278	-2.1374	0.2775	[illegible]
-62.0000	-3.6593	-1.4725	-2.5531	0.3476	[illegible]
-64.0000	[illegible]	-1.5232	[illegible]	[illegible]	[illegible]
-66.0000	-5.1842	-1.6650	-4.3745	0.5137	-44.7034
-68.0000	-6.2267	-1.7520	-5.3434	0.6515	-54.2772
-70.0000	-6.7510	-1.8724	-3.7987	-0.2125	-62.2797
-72.0000	-7.5006	[illegible]	[illegible]	-0.4253	[illegible]

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-74.0000	-8.2570	-2.0851	-5.1144	-0.1049	-31.7107
-76.0000	-9.2275	-2.2151	-5.8475	-0.2025	-93.0759
-78.0000	-10.4624	-2.3043	-6.9252	-0.1063	-109.2046
-80.0000	-11.7555	-2.5360	-8.1000	-0.1915	[illegible]
-82.0000	-13.2115	-2.7229	-8.1402	-0.2391	-141.5052
-84.0000	-14.2763	-2.8712	-9.8600	0.0443	-154.1375
-86.0000	-15.8265	-3.0589	-10.5330	0.3463	-174.1112
-88.0000	-17.2609	-3.2693	-11.9429	0.5154	-221.7021
-90.0000	-19.0225	-3.5026	-13.5061	0.6492	-227.4757
-92.0000	-20.9457	-3.7647	-14.9395	0.3255	-250.6473
-94.0000	-23.1962	-4.0545	-16.2171	-0.3354	[illegible]
-96.0000	-25.6714	-4.3831	-19.2013	-0.7295	-347.4337
-98.0000	-28.8399	-4.8099	-23.2443	-0.8675	-375.3275
-100.0000	-32.7722	-5.3243	-29.4159	0.8200	-435.2186
-102.0000	-37.1682	-5.9191	-35.2571	1.5358	-434.0614
-104.0000	-42.3407	-6.6091	-46.2103	-0.6302	-544.2422
-106.0000	-48.4723	-7.4515	-51.4324	1.2535	[illegible]
-108.0000	-57.6654	-8.6494	-70.3454	-0.8757	[illegible]
-110.0000	-68.5542	-10.1014	-67.1225	[illegible]	[illegible]
-112.0000	-86.7343	-11.7229	-95.3275	[illegible]	[illegible]

STATEMENTS EXECUTED= 1201329

CORE USAGE OBJECT CODE= 17448 BYTES,ARRAY AREA= 8304 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.82 SEC,EXECUTION TIME= 119.16 SEC, 21.44 WATFIV - [illegible]

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Sample Ingot 19

Metal Chemistry - C 3.71 %, Si 2.54 %, C.E. 4.56 %,
Mn 0.67 %, Cr 0.13 %, Cu 0.08 %,
Al 0.023 %, Mg 0.040 %, S 0.004 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
36.0000	89.3739	10.8518	-673.1191	0.1425	-349.4714
34.0000	59.9043	6.9054	76.8053	-0.0644	-195.9899
32.0000	42.4921	4.5756	43.0352	-0.0249	-109.9696
30.0000	30.7981	3.0002	27.1659	-0.1212	-55.8805
28.0000	22.5784	1.9143	17.1207	-0.0723	-21.7836
26.0000	17.9488	1.2953	8.5664	0.2809	-4.0890
24.0000	15.0266	0.9044	4.5862	0.3115	5.7066
22.0000	13.9370	0.7523	1.2819	0.2574	8.7851
20.0000	12.7986	0.5943	1.1683	0.1208	11.3633
18.0000	11.8313	0.4579	2.6671	-1.8837	12.9300
16.0000	11.1803	0.3613	0.0944	0.1074	13.3334
14.0000	10.6027	0.2724	-0.0171	-0.0261	13.2469
12.0000	8.7193	0.0112	0.1904	0.2081	14.1637
10.0000	6.4425	-0.3003	-2.3238	0.0209	9.5550
8.0000	4.6110	-0.5514	-2.3823	0.5121	5.8179
6.0000	3.1563	-0.7487	-1.1357	-0.0945	3.3577
4.0000	2.0644	-0.8883	-1.1047	0.3615	1.8714
2.0000	1.1987	-0.9267	-6.5316	6.0980	1.0042
0.0000	1.0000	-1.3856	0.3000	-0.7983	0.0074
-2.0000	1.3074	-0.9508	0.9772	-0.4585	1.0449
-4.0000	1.6149	-0.8972	0.1383	0.1344	1.5902
-6.0000	1.9223	-0.8465	0.2050	0.1374	2.2750
-8.0000	2.2298	-0.7977	0.2774	0.1456	3.1212
-10.0000	2.7030	-0.7337	0.8253	-0.2069	4.3580
-12.0000	3.2924	-0.6548	-0.8506	1.6888	6.0346
-14.0000	4.0080	-0.5591	-0.0634	1.1772	8.2622
-16.0000	4.8765	-0.4429	7.0144	-5.5459	11.1995
-18.0000	5.5831	-0.3454	1.9212	-0.4195	14.2031
-20.0000	6.2149	-0.2574	1.1456	0.4431	17.3806
-22.0000	6.8032	-0.1752	1.1902	0.5022	20.7650
-24.0000	7.3233	-0.1020	1.8341	-0.0949	24.2434

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-26.0000	7.7520	-0.0411	4.8956	-3.1771	27.6805
-28.0000	8.0694	0.0050	3.3513	-1.7272	30.9286
-30.0000	8.2600	0.0342	1.6005	-0.1460	33.8376
-32.0000	8.3145	0.0452	1.1199	0.0944	36.2663
-34.0000	8.2520	0.0406	1.2048	-0.2414	38.1925
-36.0000	8.0987	0.0238	0.3321	0.3966	39.6503
-38.0000	7.8231	-0.0093	0.2963	0.0814	40.4056
-40.0000	7.4378	-0.0570	0.0067	0.0050	40.4290
-42.0000	6.5601	-0.1169	-0.9703	0.6206	39.7295
-44.0000	6.4105	-0.1865	-0.7679	0.0799	38.3535
-46.0000	5.8113	-0.2626	-0.6921	-0.2944	36.3808
-48.0000	5.1852	-0.3423	-0.9229	-0.3094	33.9161
-50.0000	4.2513	-0.4578	-1.8800	-0.4458	29.2645
-52.0000	3.4000	-0.5699	-2.2937	-0.1941	24.2886
-54.0000	2.6409	-0.6657	-3.1788	0.8962	19.7234
-56.0000	1.8152	-0.7686	-3.3459	0.6128	14.2573
-58.0000	1.0000	-0.8667	-6.9392	6.0274	8.4340
-60.0000	0.1058	-0.9477	-8.4956	5.0740	1.5911
-62.0000	-1.0620	-1.1406	-4.7239	-0.1109	-8.0783
-64.0000	-2.2742	-1.2903	-4.8521	-0.4585	-18.6997
-66.0000	-3.2577	-1.4163	-5.0587	0.4309	-27.9554
-68.0000	-4.5656	-1.5861	-6.1296	-0.2301	-40.6746
-70.0000	-5.6143	-1.7236	-5.3051	-0.1953	-51.6752
-72.0000	-6.5534	-1.8473	-5.2571	0.0030	-62.1837
-74.0000	-7.6945	-1.9979	-6.3933	-0.1074	-75.1853
-76.0000	-9.0874	-2.1821	-7.4788	-0.6013	-91.3453
-78.0000	-10.7954	-2.4083	-9.2211	-0.8687	-111.5249
-80.0000	-12.8996	-2.6873	-12.0537	-0.6044	-136.8407
-82.0000	-15.3492	-3.0125	-15.5300	0.4234	-157.0537
-84.0000	-17.1208	-3.2481	-13.6104	1.6456	-190.9833
-86.0000	-19.1358	-3.5162	-15.3992	1.5674	-218.6471
-88.0000	-21.4213	-3.8217	-16.9550	0.9402	-250.6766
-90.0000	-24.0509	-4.1704	-18.9391	0.3682	-287.8184
-92.0000	-27.0457	-4.5692	-20.3311	-1.2385	-330.9575
-94.0000	-30.4750	-5.0258	-23.3810	-1.7103	-381.1401
-96.0000	-34.4091	-5.5497	-29.7594	0.5247	-439.6096
-98.0000	-38.5643	-6.1032	-32.8472	1.1188	-503.0664
-100.0000	-43.1795	-6.7181	-36.4025	0.4997	-574.8721
-102.0000	-48.4216	-7.4165	-42.3657	0.9707	-657.6621
-104.0000	-54.3839	-8.2109	-47.2735	-0.5109	-753.2312
-106.0000	-61.2105	-9.1339	-56.3758	0.1918	-865.6050
-108.0000	-69.2645	-10.1938	-64.5835	-0.8467	-996.4653

```
STATEMENTS EXECUTED= 1824502

CORE USAGE        OBJECT CODE=   18800 BYTES.ARRAY AREA=    8016 BYTES BYTES

DIAGNOSTICS         NUMBER OF ERRORS=        0, NUMBER OF WARNINGS=      0

COMPILE TIME=    1.00 SEC.EXECUTION TIME=  201.01 SEC.     12.20.5WATFIV - MAR 1<

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Sample Ingot 20

Metal Chemistry - C 3.62 %, Si 2.60 %, C.E. 4.47%,
Mn 0.58 %, Cr 0.12 %, Cu 0.07 %,
Al 0.020 %, Mg 0.42 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
38.0000	42.0730	4.5292	-520.8816	0.1358	-129.6319
36.0000	38.4176	4.0381	12.3093	-0.0343	-105.0219
34.0000	34.8301	3.5568	11.1605	0.0101	-52.6809
32.0000	31.4730	3.1061	9.8258	-0.1072	-63.2437
30.0000	28.1885	2.6648	8.7985	-0.1279	-45.9028
28.0000	25.5667	2.3114	6.3423	0.2212	-32.7750
26.0000	23.3519	2.0117	4.8606	0.2947	-22.4534
24.0000	22.3492	1.8727	2.3722	0.2560	-17.1371
22.0000	21.2715	1.7364	2.2253	0.1211	-12.4388
20.0000	19.8293	1.5216	3.4882	-0.6413	-6.7450
18.0000	17.6056	1.2204	3.3841	-0.2114	-0.3994
16.0000	13.5301	0.6701	5.4961	-1.0049	5.5832
14.0000	10.2776	0.2300	3.4069	-0.7942	13.8085
12.0000	7.5078	-0.1442	-0.4401	0.0132	12.9545
10.0000	4.9958	-0.4773	-3.0148	0.3050	7.5352
8.0000	3.4390	-0.6517	-1.5937	0.0669	4.4817
6.0000	2.5084	-0.8059	-0.7906	-0.0580	2.7843
4.0000	1.8570	-0.8947	-0.7525	0.2301	1.7394
2.0000	1.1839	-0.9230	-0.3238	-0.0469	0.9979
0.0000	1.0000	-1.3856	0.4456	-0.0412	0.0068
-2.0000	1.2132	-0.9303	0.3519	0.1491	1.0089
-4.0000	1.4264	-0.8947	0.1292	0.1042	1.4759
-6.0000	1.6397	-0.8604	0.2759	0.0024	2.0324
-8.0000	1.8511	-0.8250	-0.3152	0.6651	2.7324
-10.0000	2.1946	-0.7525	0.1321	0.3310	3.6584
-12.0000	2.5565	-0.7341	-0.0190	0.6044	4.8294
-14.0000	2.9735	-0.6751	-2.5729	3.3063	6.2962
-16.0000	3.3204	-0.6292	0.1496	0.6157	7.8326
-18.0000	3.6281	-0.5850	0.5190	0.2939	9.4582
-20.0000	3.9107	-0.5442	0.8707	-0.0098	11.1801
-22.0000	4.1582	-0.5090	1.9580	-1.0737	12.9485
-24.0000	4.3614	-0.4777	-0.6149	1.4940	14.7068
-26.0000	4.5126	-0.4344	0.8923	-0.0495	16.3922
-28.0000	4.5994	-0.4396	0.2621	0.5003	17.9170

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-30.0000	4.6004	-0.4361	0.0625	0.5509	19.1446
-32.0000	4.5252	-0.4413	0.3299	0.1426	20.2596
-34.0000	4.4060	-0.4552	0.2680	0.0430	20.7115
-36.0000	4.2199	-0.4765	0.1065	0.0310	20.9566
-38.0000	3.9830	-0.5046	-0.0169	-0.0225	20.9071
-40.0000	3.7053	-0.5381	-0.0122	-0.1995	20.4839
-42.0000	3.3972	-0.5757	-0.2176	-0.1528	19.7430
-44.0000	3.0700	-0.6158	-0.3128	-0.1960	18.7252
-46.0000	2.5892	-0.6752	-0.8300	-0.2374	16.5905
-48.0000	2.1383	-0.7306	-1.0500	-0.0498	14.3911
-50.0000	1.7319	-0.7500	-1.5113	0.4405	12.2493
-52.0000	1.3340	-0.8277	36.7737	-37.9234	9.9496
-54.0000	0.8992	-0.8751	0.0679	-1.4556	7.1739
-56.0000	0.4644	-0.9243	-2.2763	0.7756	4.1726
-58.0000	0.0000	-1.0000	-1.4493	-0.2571	0.6997
-60.0000	-1.4496	-1.1571	-6.1321	0.3345	-10.8958
-62.0000	-3.0751	-1.3525	-6.6462	0.0279	-24.1320
-64.0000	-4.2919	-1.5492	-5.6340	-0.2525	-35.9051
-66.0000	-5.8042	-1.7468	-7.3795	0.1571	-50.3503
-68.0000	-7.4342	-1.9678	-8.0802	-0.3053	-67.1213
-70.0000	-8.6170	-2.1175	-5.4762	-0.8053	-79.6843
-72.0000	-9.9676	-2.2964	-6.8946	-0.7343	-94.9420
-74.0000	-11.5838	-2.5107	-8.7780	-0.5214	-113.5407
-76.0000	-13.5252	-2.7583	-11.7468	0.3696	-130.2944
-78.0000	-15.3660	-3.0791	-15.4509	1.4305	-164.2354
-80.0000	-18.6989	-3.4556	-15.0379	0.8191	-195.6729
-82.0000	-22.1409	-3.9132	-21.4890	0.1865	-241.2777
-84.0000	-24.9694	-4.2997	-19.9467	1.1600	-278.8508
-86.0000	-28.0994	-4.7051	-18.9711	-2.2402	-321.2732
-88.0000	-31.6597	-5.1806	-24.3777	-0.3270	-370.6426
-90.0000	-35.7522	-5.7256	-29.5117	0.7433	-425.1799
-92.0000	-40.4510	-6.3515	-35.8526	2.2750	-495.3352
-94.0000	-45.8550	-7.0714	-39.1122	-0.1365	-573.8325
-96.0000	-52.2402	-7.9220	-47.7852	0.8185	-667.7661
-98.0000	-59.7370	-8.9205	-57.5114	1.5912	-779.6262
-100.0000	-68.4538	-10.0522	-64.8921	-1.1660	-911.7439

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STATEMENTS EXECUTED= 1619057

CORE USAGE        OBJECT CODE=   18794 BYTES.ARRAY AREA=    8016 BYTI BYTES

DIAGNOSTICS        NUMBER OF ERRORS=      0. NUMBER OF WARNINGS=     0

COMPILE TIME=     0.99 SEC.EXECUTION TIME=   172.60 SEC.    19.29.ATFIV - MAR 198

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Sample Ingot 21

Metal Chemistry - C 3.64 %, Si 2.86 %, C.E. 4.59 %,
Mn 0.75 %, Cr 0.16 %, Cu 0.11 %,
Al 0.022 %, Mg 0.042 %, S 0.006 %.

X(I)	Y(I)	P(I)	C(ODD)	C(EVEN)	SUM(C(I))
42.0000	47.9275	5.3138	-808.9326	-0.4571	-176.6083
40.0000	38.4225	4.0448	29.7774	-0.1930	-117.4396
38.0000	30.9166	3.0428	21.8212	0.1525	-73.4925
36.0000	26.8513	2.4990	11.6955	0.0643	-49.9721
34.0000	23.6762	2.0737	8.7551	-0.0584	-32.6387
32.0000	20.7849	1.6661	7.0623	0.1471	-18.2200
30.0000	19.6158	1.5267	2.7621	0.2373	-12.1219
28.0000	18.7370	1.4052	1.8790	0.3249	-7.7141
26.0000	17.6899	1.2610	1.9566	0.2644	-3.2119
24.0000	16.6547	1.1482	1.5791	0.0214	-0.0267
22.0000	15.6544	0.9786	2.1998	-1.2230	3.9249
20.0000	13.5725	0.6960	3.3065	-0.5737	4.3975
18.0000	11.3610	0.3964	2.9560	-0.6522	13.9979
16.0000	9.4179	0.1321	8.4936	-7.0941	16.8172
14.0000	7.6638	-0.1072	-0.7115	-0.1225	15.1891
12.0000	5.7201	-0.3681	-2.8349	0.2549	10.0293
10.0000	4.2332	-0.5669	-2.1194	0.3430	6.4763
8.0000	3.1458	-0.7120	-1.2521	0.0901	4.1523
6.0000	2.1149	-0.8346	10.4379	-11.2923	2.4435
4.0000	1.3950	-0.9938	6.8125	-7.3045	1.4575
2.0000	1.0868	-0.9955	-0.1155	-0.1310	0.9068
0.0000	1.0000	-1.2856	-0.3761	-0.1025	0.0095
-2.0000	1.2923	-0.9479	4.5923	-4.3765	1.0412
-4.0000	1.5847	-0.8971	0.1207	0.1456	1.5739
-6.0000	1.8770	-0.8490	0.1962	0.1360	2.2382
-8.0000	2.1694	-0.8027	0.2696	0.1392	3.0560
-10.0000	2.5774	-0.7462	1.3895	-0.8239	4.1373
-12.0000	3.1385	-0.6718	0.0416	0.7573	5.7852
-14.0000	3.8323	-0.5797	-0.1566	1.2293	7.9305
-16.0000	4.6911	-0.4655	2.2670	0.3322	10.8001
-18.0000	5.6144	-0.3415	1.7385	0.0319	14.2512
-20.0000	6.2480	-0.2532	3.3910	-1.7958	17.4716
-22.0000	6.8363	-0.1709	1.2791	0.4176	20.8051
-24.0000	7.3541	-0.0981	1.5303	0.2096	24.3451
-26.0000	7.7782	-0.0377	2.3615	-0.6470	27.7740
-28.0000	8.0884	0.0075	2.1565	-0.5423	31.0024
-30.0000	8.2696	0.0354	0.7747	0.6634	33.6798
-32.0000	8.3127	0.0450	-2.0386	3.2296	36.2613
-34.0000	8.2156	0.0359	0.2791	0.9062	38.0299
-36.0000	8.1512	0.0307	-0.1048	1.0426	39.9052
-38.0000	7.9991	0.0137	0.4322	0.2660	41.3017
-40.0000	7.7287	-0.0178	0.4582	-0.0994	42.0392
-42.0000	7.3808	-0.0621	0.0123	0.0141	42.0920

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-44.0000	6.5359	-0.1176	-0.2378	-0.0749	41.4665
-46.0000	6.4329	-0.1818	-0.9051	0.2724	40.2011
-48.0000	5.8787	-0.2523	-0.6597	-0.2596	38.3625
-50.0000	5.0724	-0.3556	-1.5341	-0.3235	34.5477
-52.0000	4.2234	-0.4642	-1.5355	-0.4351	30.0065
-54.0000	3.4500	-0.5627	-1.8739	-0.3503	25.5581
-56.0000	2.7428	-0.6521	-2.2231	0.0403	21.1927
-58.0000	1.9428	-0.7523	-3.3492	0.6189	15.7320
-60.0000	1.1425	-0.8498	-3.8038	0.8610	9.6463
-62.0000	0.3429	-0.9369	-4.3554	1.2057	3.5471
-64.0000	-0.6857	-1.0973	-6.4956	2.0587	-5.1467
-66.0000	-1.8857	-1.2418	-5.6743	0.3038	-15.8374
-68.0000	-3.0857	-1.3947	-5.3829	-0.3051	-27.2636
-70.0000	-4.2857	-1.5504	-5.7792	-0.2299	-39.2797
-72.0000	-5.1511	-1.6638	-4.6836	-0.0394	-48.7256
-74.0000	-6.2403	-1.8069	-5.4213	-0.6364	-60.6410
-76.0000	-7.6195	-1.9885	-7.1165	-0.7023	-76.4786
-78.0000	-9.0560	-2.1757	-9.0974	0.6160	-93.4416
-80.0000	-10.2235	-2.3468	-10.2450	2.2799	-109.3718
-82.0000	-11.8123	-2.5443	-8.9059	-0.0067	-125.3967
-84.0000	-13.5662	-2.7772	-9.8726	-1.5214	-151.1644
-86.0000	-15.6388	-3.0525	-12.3121	-1.3757	-178.5600
-88.0000	-18.0952	-3.3790	-15.6815	-0.8102	-211.5438
-90.0000	-19.9135	-3.6211	-14.2116	0.8896	-238.1678
-92.0000	-21.9444	-3.8915	-17.8643	2.7580	-263.4004
-94.0000	-24.2144	-4.1938	-18.1101	0.9523	-302.6960
-96.0000	-25.7548	-4.5321	-20.0453	0.5615	-341.0636
-98.0000	-29.6011	-4.9112	-22.1155	-0.0399	-385.9610
-100.0000	-33.5014	-5.4306	-30.9175	0.9746	-445.8674
-102.0000	-38.2309	-6.0738	-36.2462	-1.0534	-520.4068
-104.0000	-43.9676	-6.8246	-43.7803	-0.4024	-609.5323
-106.0000	-49.2905	-7.5471	-44.6934	0.5176	-697.1841
-108.0000	-54.5879	-8.2397	-44.2461	0.2474	-785.1516
-110.0000	-60.3913	-9.0131	-47.5076	-2.3203	-884.8374
-112.0000	-66.8776	-9.8775	-59.0597	2.5872	-997.7825
-114.0000	-74.1229	-10.8445	-60.9994	-3.1451	-1125.8730
-116.0000	-82.4058	-11.9471	-71.3557	-2.4926	-1273.5700
-118.0000	-91.7267	-13.1593	-85.9959	1.7045	-1442.1530

STATEMENTS EXECUTED= 24[illegible]190

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Sample Ingot 22

Metal Chemistry - C 3.77 %, Si 2.47 %, C.E. 4.59 %,
Mn 0.62 %, Cr 0.15 %, Cu 0.09 %,
Al 0.020 %, Mg 0.036 %, S 0.008 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
38.0000	58.2605	6.6864	-690.3616	0.0582	-211.3904
36.0000	42.3214	4.5598	43.9501	-0.1081	-123.7066
34.0000	30.7211	3.0095	25.7218	0.0285	-64.2061
32.0000	22.7644	1.9485	18.9095	-0.0698	-26.5265
30.0000	18.2776	1.3496	9.9382	-0.1155	-6.8815
28.0000	16.6504	1.1347	3.0937	0.2190	-0.2563
26.0000	15.3377	0.9505	2.2201	0.2671	4.7150
24.0000	14.1257	0.7548	1.7301	0.1675	8.5132
22.0000	13.1117	0.6438	1.3235	-0.0250	11.1103
20.0000	12.0996	0.5027	5.0271	-4.0122	13.1398
18.0000	10.8434	0.3288	1.1904	-0.1770	15.1664
16.0000	8.9075	0.0661	1.5015	-0.2266	17.7163
14.0000	7.0668	-0.1820	-1.6974	-0.1162	14.0890
12.0000	5.4242	-0.4043	-2.3355	0.0611	9.5400
10.0000	4.1439	-0.5772	-1.7634	0.1692	6.3513
8.0000	3.1503	-0.7115	-1.3378	0.2403	4.1563
6.0000	2.3629	-0.8171	-0.7691	0.0201	2.6581
4.0000	1.7707	-0.8962	-0.7334	0.2477	1.6870
2.0000	1.1622	-0.9174	-0.1146	-0.2331	0.9915
0.0000	1.0000	-1.2856	-0.5238	0.0320	0.0080
-2.0000	1.1116	-0.9033	0.5779	-0.0951	0.9738
-4.0000	1.2222	-0.8860	0.0948	0.0972	1.3578
-6.0000	1.3352	-0.8690	0.1454	0.0639	1.7763
-8.0000	1.4725	-0.8509	-1.3698	1.6223	2.2814
-10.0000	1.6252	-0.8307	-0.0631	0.3625	2.8802
-12.0000	1.7923	-0.8085	4.7679	-4.4163	3.5835
-14.0000	1.8931	-0.7921	0.2065	0.1269	4.2501
-16.0000	1.9756	-0.7782	-2.7700	3.1104	4.9305
-18.0000	2.0368	-0.7672	0.5782	-0.2417	5.6037
-20.0000	2.0745	-0.[illegible]92	0.2380	0.0835	6.2466
-22.0000	2.0695	-0.7366	0.3301	-0.0614	6.7842
-24.0000	2.0009	-0.7617	0.0565	0.1087	7.1145
-26.0000	1.9026	-0.7707	0.1613	-0.0659	7.3051
-28.0000	1.7793	-0.7831	1.0547	-1.0322	7.3501
-30.0000	1.6366	-0.7951	-0.0565	0.0073	7.2517
-32.0000	1.4664	-0.8164	-0.0723	-0.0735	6.9600

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-34.0000	1.0000	-0.8667	0.4937	-1.3564	5.2347
-36.0000	0.6664	-0.8998	-0.6879	0.0217	3.9024
-38.0000	0.2664	-0.9290	-0.8461	-0.0677	2.0748
-40.0000	-0.2229	-1.0668	-1.4731	0.1506	-0.5100
-42.0000	-0.9264	-1.1253	-1.6868	-0.3014	-4.4860
-44.0000	-1.6209	-1.2051	-1.7676	-0.3916	-8.8047
-46.0000	-2.3153	-1.2903	-2.0310	-0.3121	-13.4911
-48.0000	-3.0098	-1.3781	-2.4178	-0.1104	-18.5476
-50.0000	-3.7042	-1.4673	-2.9927	0.2792	-23.9746
-52.0000	-4.1772	-1.5290	-3.3003	1.1683	-28.2387
-54.0000	-4.7245	-1.6007	-2.5351	0.0094	-33.2599
-56.0000	-5.3706	-1.6855	-3.8017	0.7617	-39.3697
-58.0000	-6.1359	-1.7863	-3.7342	0.0610	-46.7161
-60.0000	-7.0457	-1.9063	-4.5847	0.1296	-55.6260
-62.0000	-7.9759	-2.0293	-4.6013	-0.1505	-65.1895
-64.0000	-8.9471	-2.1580	-4.9662	-0.2391	-75.6000
-66.0000	-10.0067	-2.3065	-6.2346	0.1178	-87.8339
-68.0000	-11.3605	-2.4782	-6.8868	-0.3176	-102.2426
-70.0000	-12.8589	-2.6771	-9.6986	1.1942	-119.2514
-72.0000	-14.5987	-2.9083	-10.0245	-0.0373	-139.3751
-74.0000	-16.6236	-3.1774	-11.1427	-0.7893	-163.2391
-76.0000	-18.9862	-3.4916	-13.5255	-0.6565	-191.6030
-78.0000	-21.7495	-3.8592	-17.2017	0.3064	-225.3938
-80.0000	-24.6574	-4.2462	-18.7372	0.3346	-262.1987
-82.0000	-28.0057	-4.6919	-21.7863	0.2008	-305.3694
-84.0000	-31.8820	-5.2081	-25.2242	-0.2096	-356.2371
-86.0000	-36.2786	-5.8069	-29.4905	-0.5319	-416.2820
-88.0000	-41.4052	-6.5030	-36.9965	1.4943	-487.2864
-90.0000	-47.6860	-7.3129	-40.9275	-1.0920	-571.3257
-92.0000	-54.7415	-8.2528	-49.7847	0.1681	-670.5588
-94.0000	-62.9834	-9.3508	-58.5716	-0.3588	-788.4199
-96.0000	-72.6307	-10.6362	-72.0456	1.9272	-925.6567
-98.0000	-83.1889	-12.0430	-79.2644	0.6246	-1085.9360
-100.0000	-96.1533	-13.2379	-71.5972	0.7618	-1227.6070
-102.0000	********	-14.5681	-80.7072	0.5763	-1387.8690
-104.0000	********	-16.0497	-89.8892	-0.7759	-1569.1990

STATEMENTS EXECUTED= 1754223

CORE USAGE OBJECT CODE= 18784 BYTES,ARRAY AREA= 8016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 1.05 SEC,EXECUTION TIME= 189.04 SEC, 20.11. WATFIV - MAR 15

OSEOF

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Sample Ingot 23

Metal Chemistry - C 3.94 %, Si 2.40 %, C.E. 4.74 %,
Mn 0.56 %, Cr 0.11 %, Cu 0.05 %,
Al).020 %, Mg 0.035 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	64.1782	7.5110	-804.2239	-0.2320	-138.3787
20.0000	46.6681	5.1432	30.2637	-0.2337	-78.3155
18.0000	33.4223	3.3514	20.1061	-0.0036	-38.1135
16.0000	24.6822	2.1657	11.4664	0.2192	-14.7422
14.0000	15.1741	1.2811	7.0347	0.1702	-0.3324
12.0000	12.5380	0.6436	4.3473	-0.3898	7.5524
10.0000	10.1010	0.1734	1.9237	-0.0896	11.2505
8.0000	7.0168	-0.2549	-1.3667	0.0388	8.5945
6.0000	4.6051	-0.5924	-1.8930	-0.0666	4.6755
4.0000	2.7806	-0.8454	-1.0484	-0.1182	2.3422
2.0000	1.3798	-0.9641	-0.5095	-0.1240	1.0755
0.0000	1.0000	-1.3856	-0.6245	0.0915	0.0096
-2.0000	1.2298	-0.9551	1.1242	-0.6011	1.0557
-4.0000	1.6596	-0.8972	0.1512	0.1307	1.6196
-6.0000	2.0880	-0.8364	0.3198	0.0806	2.4202
-8.0000	2.6585	-0.7596	0.7343	-0.1427	3.6033
-10.0000	3.2716	-0.6743	0.6135	0.1569	5.1443
-12.0000	3.7885	-0.5987	0.6972	0.1556	6.8409
-14.0000	4.2569	-0.5296	0.7803	0.1633	8.7369
-16.0000	4.6413	-0.4716	1.3882	-0.4110	10.6910
-18.0000	4.9101	-0.4291	0.9656	-0.0260	12.5699
-20.0000	5.0404	-0.4049	0.6346	0.1906	14.2204
-22.0000	5.1470	-0.3850	0.9452	-0.1197	15.8713
-24.0000	5.1826	-0.3747	1.9391	-1.1972	17.3551
-26.0000	5.0986	-0.3806	-0.1997	0.7399	18.4352
-28.0000	4.8612	-0.4065	0.0810	0.1515	18.9001
-30.0000	4.3869	-0.4528	-0.3176	0.0159	18.2970
-32.0000	3.8504	-0.5278	-1.2871	0.7187	17.1600
-34.0000	3.2824	-0.5967	0.5497	-1.3280	15.6035
-36.0000	2.7213	-0.6646	1.5048	-2.4175	13.7779
-38.0000	2.2002	-0.7272	-0.6154	-0.3450	11.8573
-40.0000	1.7293	-0.7830	-0.6811	-0.2834	9.9285

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-42.0000	1.2981	-0.8331	-0.7991	-0.1792	7.9716
-44.0000	0.8155	-0.8862	-1.4732	0.2421	5.5094
-46.0000	0.2408	-0.9309	-0.6694	-0.6829	2.8049
-48.0000	-0.1188	-1.0593	-1.3664	-0.0428	-0.0134
-50.0000	-0.5315	-1.0834	-0.7302	-0.6819	-2.8374
-52.0000	-0.9442	-1.1270	-3.0936	1.5901	-5.8444
-54.0000	-1.3408	-1.1722	-8.6309	7.0776	-8.9509
-56.0000	-1.6446	-1.2104	-1.0528	-0.2596	-11.5757
-58.0000	-2.0453	-1.2603	-1.3124	-0.4551	-15.1108
-60.0000	-2.5791	-1.3250	-2.0799	-0.3261	-19.9229
-62.0000	-2.8629	-1.3646	-1.3830	-0.1332	-22.9552
-64.0000	-3.1550	-1.4025	-2.1201	0.4930	-26.2098
-66.0000	-3.4906	-1.4463	-1.9860	0.0694	-30.0030
-68.0000	-3.8773	-1.4968	-2.4839	0.2666	-34.4373
-70.0000	-4.2225	-1.5554	-3.0872	0.4876	-39.6368
-72.0000	-4.8408	-1.6223	-3.9111	0.8540	-45.7507
-74.0000	-5.4412	-1.7023	-4.3938	0.7881	-52.9625
-76.0000	-6.1401	-1.7945	-4.4845	0.2190	-61.4935
-78.0000	-6.9563	-1.9022	-4.5894	-0.4719	-71.6162
-80.0000	-7.9122	-2.0287	-5.4615	-0.5624	-83.6642
-82.0000	-9.0351	-2.1774	-7.1188	-0.0726	-98.0469
-84.0000	-10.2264	-2.3354	-7.9894	0.1155	-113.7946
-86.0000	-10.9484	-2.4315	-5.0501	-0.4519	-124.7988
-88.0000	-11.7284	-2.5353	-5.5882	-0.4464	-136.8651
-90.0000	-12.5714	-2.6476	-6.0683	-0.5529	-150.1105
-92.0000	-13.4832	-2.7690	-6.7683	1.5011	-164.6447
-94.0000	-14.4697	-2.9003	-7.4218	-0.5569	-180.6020
-96.0000	-15.5277	-3.0426	-8.8312	0.0650	-198.1254
-98.0000	-16.6945	-3.1967	-9.9120	0.2836	-217.3852
-100.0000	-17.9482	-3.3636	-11.1463	0.5640	-238.5499
-102.0000	-19.3076	-3.5447	-12.6051	0.9700	-261.8198
-104.0000	-20.9878	-3.7685	-14.5492	0.3276	-290.2629
-106.0000	-23.2068	-4.0639	-18.0934	-0.3832	-327.2161
-108.0000	-25.7012	-4.3961	-20.2268	-0.8243	-369.3166
-110.0000	-28.5988	-4.7700	-23.6410	-0.3715	-417.3438
-112.0000	-31.6733	-5.1914	-27.4215	-0.0039	-472.1946
-114.0000	-35.2448	-5.6672	-32.5383	1.1761	-534.9187
-116.0000	-39.2811	-6.2049	-36.6744	0.7658	-606.7358
-118.0000	-44.4176	-6.8592	-45.1860	-0.4521	-698.0120
-120.0000	-50.5562	-7.7070	-53.2784	-1.7465	-808.0618
-122.0000	-57.6692	-8.6547	-65.6549	1.0738	-937.2241
-124.0000	-65.9199	-9.7541	-74.6660	-1.2178	-1038.9910
-126.0000	-75.2104	-11.0054	-86.0558	-1.6002	-1264.3030
-128.0000	-86.2183	-12.4591	-102.8866	0.7604	-1470.5150

STATEMENTS EXECUTED= 2046558

CORE USAGE OBJECT CODE= 18784 BYTES,ARRAY AREA= 8016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.90 SEC,EXECUTION TIME= 218.60 SEC, 23.33.45WATFIV - MAR 1'

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Sample Ingot 24

Metal Chemistry - C 3.86 %, Si 2.70 %, C.E. 4.76 %,
Mn 0.52 %, Cr 0.12 %, Cu 0.07 %
Al 0.020 %, Mg 0.026 %, S 0.006 %.

X(I)	Y(I)	A(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	41.2931	4.4585	-750.7498	-0.1900	-50.9118
14.0000	25.0947	2.2256	18.9362	-0.0975	-13.2352
12.0000	17.7171	1.2159	6.8344	0.2757	0.9848
10.0000	12.2708	0.4658	3.6515	0.1307	5.5492
8.0000	8.3681	-0.0774	0.6875	0.0135	9.9515
6.0000	5.5558	-0.4252	-2.0481	0.0362	5.9279
4.0000	3.8966	-0.7356	-1.5725	0.1656	3.1139
2.0000	1.0229	-1.0119	-1.0156	0.1406	1.3642
0.0000	1.0000	-1.3856	-1.0948	0.4166	0.0076
-2.0000	1.4765	-0.9758	-0.8536	1.4064	1.1131
-4.0000	1.5529	-0.8922	-0.0976	0.4414	1.8008
-6.0000	2.5254	-0.8045	-41.8963	42.3960	2.7994
-8.0000	3.4146	-0.6842	0.6271	0.2003	4.4541
-10.0000	4.6005	-0.5241	1.0398	0.2255	6.9847
-12.0000	5.6126	-0.3813	1.3524	0.0800	9.8496
-14.0000	6.3971	-0.2673	1.4715	0.0106	12.8140
-16.0000	6.9720	-0.1814	1.2546	0.2087	15.7403
-18.0000	7.2663	-0.1329	1.0039	0.2716	18.2910
-20.0000	7.2410	-0.1269	1.0432	-0.1175	20.1420
-22.0000	7.1706	-0.1282	0.6560	0.1980	21.8500
-24.0000	7.2925	-0.1060	1.1053	0.0411	24.1429
-26.0000	7.2186	-0.1099	1.0600	-0.2214	25.8290
-28.0000	6.9548	-0.1390	-2.4307	2.8946	26.7475
-30.0000	6.5219	-0.1906	0.0208	0.0343	26.8579
-32.0000	5.9529	-0.2602	-0.2137	-0.1371	26.1560
-34.0000	5.25[illegible]	-0.3425	-0.7769	0.0586	24.7199
-36.0000	4.4445	-0.4479	-1.9174	0.5910	22.0671
-38.0000	3.5071	-0.5648	-3.0801	1.2919	18.4910
-40.0000	2.6758	-0.6675	-3.8019	2.0481	14.9834
-42.0000	1.8270	-0.7706	-1.5534	-0.4703	10.9360
-44.0000	1.0000	-0.8667	-1.8015	-0.3830	6.5672
-46.0000	0.0000	-1.0000	-2.9525	0.0192	0.7005
-48.0000	-0.2963	-1.0645	1.1501	-2.0908	-1.1811
-50.0000	-0.6161	-1.0912	-0.7041	-0.3874	-3.3644

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-52.0000	1.1253	-0.8522	5.3324	0.6011	8.5027
-54.0000	-1.1480	-1.1505	-8.7248	0.0909	-7.5648
-56.0000	-1.5120	-1.1942	-3.9093	2.3980	-10.5875
-58.0000	-1.7605	-1.2250	-0.9093	-0.2542	-12.9146
-60.0000	-1.9545	-1.2494	-0.6741	-0.3345	-14.9315
-62.0000	-2.1817	-1.2782	-0.9989	-0.1999	-17.3292
-64.0000	-2.4490	-1.3124	-1.9914	0.5606	-20.1907
-66.0000	-2.7647	-1.3521	-2.0627	0.3480	-23.6199
-68.0000	-3.1287	-1.4015	-2.1308	0.0673	-27.7467
-70.0000	-3.5536	-1.4594	-2.6253	0.1318	-32.7336
-72.0000	-4.1148	-1.5288	-3.5140	0.4881	-38.7855
-74.0000	-4.7514	-1.6122	-4.4597	0.7719	-46.1609
-76.0000	-5.5176	-1.7129	-5.4477	0.9337	-55.1857
-78.0000	-6.4437	-1.8349	-5.6100	0.0606	-66.2875
-80.0000	-7.5678	-1.9834	-6.3004	-0.5521	-79.9925
-82.0000	-8.9385	-2.1647	-7.9213	-0.5781	-96.9911
-84.0000	-10.0904	-2.3174	-7.5605	-0.0796	-112.2713
-86.0000	-10.8478	-2.4182	-5.6241	-0.0629	-123.6454
-88.0000	-11.6715	-2.5278	-5.8418	-0.4357	-136.2003
-90.0000	-12.5678	-2.6471	-6.3111	-0.6222	-150.0670
-92.0000	-13.5449	-2.7770	-7.9850	0.3236	-165.3897
-94.0000	-14.6077	-2.9186	-7.9742	-0.4962	-182.3306
-96.0000	-15.7677	-3.0731	-9.4368	0.0664	-201.0715
-98.0000	-17.0335	-3.2416	-10.5278	0.1570	-221.8130
-100.0000	-18.4158	-3.4257	-11.7576	0.2727	-244.7524
-102.0000	-19.9263	-3.6269	-13.4083	0.6832	-270.2327
-104.0000	-21.5781	-3.8469	-15.1369	1.0294	-298.4475
-106.0000	-23.3974	-4.0892	-15.4398	-0.2912	-329.9094
-108.0000	-25.3954	-4.3554	-16.9655	-0.5377	-364.9158
-110.0000	-27.5869	-4.6474	-18.7698	-0.6651	-403.8259
-112.0000	-29.9926	-4.9679	-21.1962	-0.4418	-447.1015
-114.0000	-32.7909	-5.3394	-26.6689	1.4822	-497.4751
-116.0000	-35.9685	-5.8972	-37.4829	0.7308	-570.9790
-118.0000	-41.7767	-6.5376	-42.3702	-0.3746	-656.4635
-120.0000	-47.3061	-7.2743	-47.7402	-2.0586	-756.0662
-122.0000	-53.8933	-8.1519	-61.3162	1.4414	-875.8159
-124.0000	-63.1877	-9.3902	-82.5225	-1.4832	-1043.8270
-126.0000	-74.3096	-10.8721	-100.0694	-1.7638	-1247.4940
-128.0000	-85.0717	-12.3063	-102.5072	0.7750	-1450.9510

STATEMENTS EXECUTED= 1824474

CORE USAGE OBJECT CODE= 18784 BYTES,ARRAY AREA= 5016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.94 SEC,EXECUTION TIME= 199.83 SEC, 1.58.51 WATFIV - MAR

C$ECF

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Sample Ingot 25

Metal Chemistry - C 4.02 %, Si 2.44 %, C.E. 4.83 %,
Mn 0.66 %, Cr 0.13 %, Cu 0.10 %,
Al 0.020 %, Mg 0.033 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	65.4171	5.2546	-729.6008	-0.2249	-140.1505
18.0000	51.2856	5.7952	29.4964	-0.2580	-81.6737
16.0000	37.7629	3.9566	19.3016	0.0493	-42.9719
14.0000	27.3655	2.5389	12.5165	0.2031	-17.5327
12.0000	19.4656	1.4569	7.6839	0.1767	-1.8116
10.0000	12.4010	0.6207	4.4531	-0.0020	7.0903
8.0000	5.2228	0.0394	1.4840	0.0621	10.1926

6.0000	3.1929	-0.3941	-2.0174	0.0019	6.1516
4.0000	2.4023	-0.7891	-1.6151	-0.0767	2.7650
2.0000	1.5166	-0.9840	-0.6715	-0.1471	1.1308
0.0000	1.0000	-1.3856	-1.9783	1.4171	0.0083
-2.0000	1.0000	-0.8667	0.5713	-0.1068	0.9376
-4.0000	1.0000	-0.8667	0.0746	0.0737	1.2341
-6.0000	1.0000	-0.8667	0.1105	0.0233	1.5016
-8.0000	1.0000	-0.8667	0.0762	0.0571	1.7684
-10.0000	1.0000	-0.8667	0.0575	0.0758	2.0350
-12.0000	1.0000	-0.8667	0.1183	0.0151	2.3017
-14.0000	1.0000	-0.8667	0.0938	0.0395	2.5684
-16.0000	1.0000	-0.8667	-0.1307	0.2540	2.8350
-18.0000	1.0000	-0.8667	0.0890	0.0443	3.1016
-20.0000	1.0000	-0.8667	0.0469	0.0864	3.3684
-22.0000	1.0000	-0.8667	0.0994	0.0339	3.6352
-24.0000	1.0000	-0.8667	0.1540	-0.0207	3.9017
-26.0000	1.0000	-0.8667	0.0140	0.1194	4.1685
-28.0000	1.0000	-0.8667	0.1507	-0.0173	4.4354
-30.0000	1.0000	-0.8667	0.0748	0.0585	4.7021
-32.0000	1.0000	-0.8667	0.0656	0.0677	4.9687
-34.0000	1.0000	-0.8667	0.4494	-0.3161	5.2352
-36.0000	1.0000	-0.8667	0.0410	0.0924	5.5018
-38.0000	1.0000	-0.8667	0.0591	0.0742	5.7656
-40.0000	0.8242	-0.8853	-0.3016	-0.0337	5.0980
-42.0000	0.6119	-0.9067	0.1253	-0.6117	4.1312
-44.0000	0.3982	-0.9258	-0.3084	-0.2333	3.0477
-46.0000	0.1822	-0.9380	-0.5896	-0.0055	1.8577

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-48.0000	0.0000	-1.0000	-0.4116	-0.1663	0.7020
-50.0000	-0.6515	-1.0954	-2.3313	0.1607	-3.6392
-52.0000	-1.2189	-1.1587	-23.9478	21.8933	-7.7489
-54.0000	-1.7862	-1.2274	-1.8678	-0.3359	-12.1562
-56.0000	-2.2416	-1.2844	-1.5152	-0.4214	-16.0295
-58.0000	-2.7052	-1.3434	-1.8103	-0.2798	-20.2095
-60.0000	-3.2007	-1.4200	-2.5914	-0.1496	-25.6916
-62.0000	-4.0473	-1.5168	-3.5126	-0.0113	-32.7393
-64.0000	-4.4882	-1.5747	-2.4785	0.0591	-37.5780
-66.0000	-4.9952	-1.6413	-3.1551	0.3271	-43.2342
-68.0000	-5.5797	-1.7183	-3.8799	0.5652	-49.8637
-70.0000	-6.2555	-1.8075	-4.3965	0.2006	-57.6557
-72.0000	-7.0386	-1.9110	-4.4440	-0.1476	-66.8388
-74.0000	-7.9467	-2.0314	-5.1201	-0.3064	-77.6917
-76.0000	-9.0093	-2.1718	-6.1388	-0.2923	-90.5539
-78.0000	-9.7163	-2.2655	-5.0117	0.1351	-100.3070
-80.0000	-10.4631	-2.3652	-5.3363	0.0586	-110.8623
-82.0000	-11.2763	-2.4734	-5.5020	-0.3370	-122.5404
-84.0000	-12.1622	-2.5913	-6.3321	-0.1313	-135.4673
-86.0000	-13.1250	-2.7199	-6.8320	-0.3257	-149.7825
-88.0000	-14.1817	-2.8602	-10.7805	2.5500	-165.6437
-90.0000	-15.3220	-3.0133	-8.3982	-0.3932	-183.2265
-92.0000	-16.5887	-3.1507	-9.4185	-0.3319	-202.7277
-94.0000	-17.9625	-3.3636	-10.7026	-0.1169	-224.3666
-96.0000	-19.4573	-3.5627	-12.2303	0.2709	-248.2854
-98.0000	-21.0608	-3.7763	-13.3305	0.2622	-274.4219
-100.0000	-22.9125	-4.0097	-14.1079	-0.3764	-303.3901
-102.0000	-24.7275	-4.2648	-15.4731	-0.5885	-335.5132
-104.0000	-26.8222	-4.5439	-17.0115	-0.8066	-371.1494
-106.0000	-29.1151	-4.8494	-20.2269	0.4508	-410.7017
-108.0000	-31.8826	-5.2191	-24.5159	0.7144	-458.3106
-110.0000	-35.1748	-5.6567	-28.6707	0.2511	-515.0901
-112.0000	-38.8551	-6.1470	-31.4407	-0.7243	-579.4204
-114.0000	-42.9740	-6.6958	-36.3336	-0.1451	-652.3779
-116.0000	-47.5886	-7.3107	-42.2823	0.8722	-735.1982
-118.0000	-55.6624	-8.3562	-65.7199	-0.1273	-874.8926
-120.0000	-67.2133	-9.9251	-95.2746	-0.5366	-1074.5140
-122.0000	-81.1738	-11.7852	-122.5588	0.3742	-1319.4840

STATEMENTS EXECUTED= 1754144

CORE USAGE   OBJECT CODE= 15784 BYTES,ARRAY AREA= 8016 BYTES

DIAGNOSTICS   NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 1.02 SEC,EXECUTION TIME= 190.48 SEC, 2.36, WATFIV - MAR 19

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Sample Ingot 26

Metal Chemistry - C 4.14 %, Si 2.52 %, C.E. 4.98 %,
Mn 0.65 %, Cr 0.14 %, Cu 0.09 %,
Al 0.020 %, Mg 0.024 %, S 0.005 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
26.0000	109.8003	13.5292	-751.1624	-0.2518	-320.3667
24.0000	98.2701	10.7668	45.8713	-0.2986	-229.2219
22.0000	71.4535	8.5023	34.5688	0.0021	-160.0803
20.0000	57.0845	6.5642	26.5795	0.1914	-106.5397
18.0000	44.1360	4.8125	20.9581	0.2435	-64.1355
16.0000	32.4636	3.2274	16.1932	0.1463	-31.4564
14.0000	23.3075	1.9854	11.0005	-0.2643	-9.9838
12.0000	16.5582	1.0571	6.5136	-0.1099	2.8235
10.0000	13.0175	0.5680	2.5139	-0.1313	7.5886
8.0000	9.6555	0.1013	1.4312	-0.2347	9.9818
6.0000	6.4574	-0.3559	-1.7474	-0.0451	6.4008
4.0000	3.4471	-0.7545	-1.9794	0.1759	2.7998
2.0000	1.4864	-0.9804	-0.9224	0.0823	1.1194
0.0000	1.0000	-1.3856	2.8099	-3.3652	0.0090
-2.0000	0.9857	-0.8013	0.7431	-0.2808	0.9336
-4.0000	0.9857	-0.8650	0.0225	0.1241	1.2270
-6.0000	0.9857	-0.9662	0.0755	0.0564	1.4909
-8.0000	0.9857	-0.8658	0.0651	0.0664	1.7538
-10.0000	0.9857	-0.8671	0.0937	0.0377	2.0165
-12.0000	0.9857	-0.8674	-0.0959	0.2272	2.2793
-14.0000	0.9879	-0.8674	0.0775	0.0559	2.5462
-16.0000	1.0311	-0.8644	0.0558	0.1221	2.9019
-18.0000	1.0743	-0.8607	0.1257	0.0637	3.2806
-20.0000	1.1175	-0.8565	0.1589	0.0420	3.6823
-22.0000	1.1696	-0.8511	-0.9978	1.2233	4.1336
-24.0000	1.2452	-0.8431	-0.9539	1.2310	4.6876
-26.0000	1.3363	-0.8329	0.2463	0.0780	5.3360
-28.0000	1.4457	-0.8203	0.2851	0.1147	5.1015
-30.0000	1.4857	-0.8150	0.1475	0.1254	6.6477
-32.0000	1.4921	-0.8135	-0.1102	0.1014	7.0709
-34.0000	1.4943	-0.8125	0.6571	-0.4532	7.4757
-36.0000	1.4924	-0.8121	-0.0305	0.2251	7.8681
-38.0000	1.4564	-0.8122	0.0897	0.0949	8.2355
-40.0000	1.4136	-0.8201	-0.0267	0.0306	8.2432
-42.0000	1.0688	-0.8591	-0.3890	-0.3885	6.6876
-44.0000	0.7239	-0.8961	-1.0643	0.1904	4.9507

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-46.0000	0.3791	-0.9251	-0.7435	-0.2128	3.0380
-48.0000	0.0000	-1.0000	-1.4912	0.3234	0.7023
-50.0000	-0.4047	-1.0719	0.2336	-1.5787	-1.9850
-52.0000	-0.8542	-1.1169	-1.3119	-0.3040	-5.2199
-54.0000	-1.3036	-1.1689	-1.4972	-0.2344	-8.6831
-56.0000	-1.6841	-1.2127	-1.2139	-0.3048	-11.7206
-58.0000	-2.0404	-1.2597	-1.4311	-0.2447	-15.0721
-60.0000	-2.5340	-1.3222	-2.0511	-0.1949	-19.5624
-62.0000	-3.0309	-1.3851	-2.6839	0.2936	-24.3432
-64.0000	-3.2789	-1.[illegible]	-1.8287	0.3670	-27.2666
-66.0000	-3.5568	-1.4548	-2.2602	0.6012	-30.5844
-68.0000	-3.8665	-1.4957	-2.9409	1.0543	-34.3579
-70.0000	-4.2188	-1.5417	-1.5422	-0.3075	-38.6577
-72.0000	-4.6132	-1.5936	-2.4216	-0.0332	-43.5671
-74.0000	-5.0580	-1.6522	-2.6937	-0.1149	-49.1844
-76.0000	-5.5606	-1.7136	-3.0933	-0.1265	-55.6242
-78.0000	-6.1296	-1.7937	-4.0240	0.3252	-63.0218
-80.0000	-6.7748	-1.8791	-4.2365	-0.0211	-71.5370
-82.0000	-7.5051	-1.9762	-4.6292	-0.2516	-81.3587
-84.0000	-8.3432	-2.0868	-5.4362	-0.2396	-92.7101
-86.0000	-9.2959	-2.2[illegible]	-6.3133	-0.2550	-105.8567
-88.0000	-10.3853	-2.3577	-12.9437	4.4151	-121.1137
-90.0000	-11.6334	-2.5234	-8.2472	-0.6245	-138.8570
-92.0000	-12.9621	-2.5999	-8.8474	-0.8513	-155.2542
-94.0000	-12.8952	-2.8242	-7.2429	-0.3312	-173.4027
-96.0000	-14.9041	-2.9585	-8.4123	0.1035	-190.0202
-98.0000	-15.9957	-3.1039	-9.2932	0.1756	-205.2551
-100.0000	-17.1773	-3.2513	-10.0325	0.0236	-225.2730
-102.0000	-18.4571	-3.4318	-10.8227	-0.1667	-250.2557
-104.0000	-19.8429	-3.6165	-11.5015	-0.5725	-274.4038
-106.0000	-21.3474	-3.8158	-15.1259	1.8568	-300.9419
-108.0000	-23.0683	-4.0461	-14.9314	-0.3041	-331.4126
-110.0000	-25.3942	-4.3558	-20.4552	0.3255	-371.6714
-112.0000	-27.9923	-4.7220	-22.7600	-0.0295	-417.2505
-114.0000	-30.9009	-5.0893	-24.9516	-0.8454	-465.9043
-116.0000	-34.9600	-5.6307	-34.2195	-1.3319	-540.0071
-118.0000	-40.6602	-6.3592	-50.1614	0.7121	-635.9258
-120.0000	-47.4255	-7.2902	-59.3098	-0.2273	-757.9797
-122.0000	-56.9309	-8.5564	-83.2115	-0.4054	-925.2139
-124.0000	-71.5735	-10.5371	-129.7815	0.4668	-1132.4430

STATEMENTS EXECUTED= 2046294

CORE USAGE OBJECT CODE= 13424 BYTES,ARRAY AREA= 8016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.67 SEC,EXECUTION TIME= 216.49 SEC, 12.00.3 WATFIV - MAR

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Sample Ingot 27

Metal Chemistry - C 4.00 %, Si 2.18 %, C.E. 4.73 %,
Mn 0.61 %, Cr 0.14 %, Cu 0.07 %,
Al 0.020 %, Mg 0.022 %, S 0.007 %.

X(I)	Y(I)	[illegible]P(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	60.6827	7.0355	-527.1325	-0.3146	-127.9750
20.0000	47.2402	5.2272	24.2496	-0.2524	-30.0008
15.0000	24.1055	3.4129	20.1280	0.0050	-39.7434

16.0000	23.2751	1.0740	13.7820	0.2144	-11.7507
14.0000	16.0450	1.0000	7.4260	0.1574	3.4770
12.0000	11.1124	0.3223	4.2196	-0.3422	11.2327
10.0000	7.9193	-0.1127	0.5604	-0.4115	11.5425
8.0000	5.4532	-0.4511	-2.3758	-0.0023	6.7961
6.0000	3.5574	-0.7057	-1.4024	-0.1192	3.7427
4.0000	2.2279	-0.8912	-0.7215	-0.1521	1.9754
2.0000	1.2217	-0.9822	-0.3733	-0.1115	1.0119
0.0000	[illegible]	-1.0456	-0.4252	0.3224	0.0070
-2.0000	1.2703	-0.9432	0.5547	-0.0430	1.0321
-4.0000	1.5475	-0.9667	0.1340	0.1172	1.5443
-6.0000	1.8402	-0.8517	0.2947	0.0377	2.2057
-8.0000	2.2540	-0.7950	0.5433	-0.0739	3.1475
-10.0000	2.7454	-0.7294	0.4636	0.1705	4.4154
-12.0000	[illegible]	-0.6631	0.5693	0.1334	5.8220
-14.0000	3.5231	-0.6157	0.5745	0.1942	7.3306
-16.0000	[illegible]	-0.5692	-0.5747	1.3725	9.0355
-18.0000	4.0581	-0.5323	0.0379	0.1545	10.5202
-20.0000	4.2275	-0.5042	0.7171	0.0324	12.0594
-22.0000	4.3160	-0.4845	0.3444	-0.2054	13.4105
-24.0000	4.2974	-0.4957	-2.3359	2.3491	14.5006
-26.0000	4.2072	-0.4821	-0.1125	0.7005	15.6768
-28.0000	4.3110	-0.4750	-0.9550	1.4346	15.8259
-30.0000	1.2044	-0.4407	0.3120	0.1321	17.7238
-32.0000	4.1171	-0.4082	0.1602	0.1276	18.2996
-34.0000	3.7451	-0.5737	-0.2465	-0.2503	17.7949
-36.0000	3.2343	-0.5977	-0.2733	-0.4517	16.3657
-38.0000	2.7693	-0.6372	-0.5470	-0.2632	14.7449
-40.0000	2.1961	-0.7267	-0.9262	-0.2362	12.4202
-42.0000	1.6631	-0.7972	-1.3814	0.2493	10.1561
-44.0000	1.2281	-0.8409	0.7910	-1.9165	7.9949

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-46.0000	0.7134	-0.8975	-1.2595	-0.1535	5.0797
-48.0000	0.1795	-0.9343	-0.5436	-0.6736	2.0042
-50.0000	-0.3544	-1.0672	-2.5259	1.4490	-1.6554
-52.0000	-0.5345	-1.1223	-4.2471	2.2843	-5.7795
-54.0000	-1.8142	-1.1942	-1.8719	-0.3359	-10.2011
-56.0000	-2.0714	-1.2631	-1.7910	-0.4993	-14.7614
-58.0000	-2.4425	-1.3165	-1.6054	-0.2984	-19.5689
-60.0000	-3.0227	-1.3957	-2.3229	-0.1079	-23.5505
-62.0000	-3.7304	-1.4750	-3.6574	0.3711	-30.1230
-64.0000	-4.2572	-1.5447	-2.8227	0.0792	-35.6097
-66.0000	-4.0754	-1.5907	-2.5262	0.4255	-39.8112
-68.0000	-4.9031	-1.6413	-3.0943	0.7250	-44.5459
-70.0000	-5.4238	-1.6987	-3.9836	-1.3094	-49.8992
-72.0000	-5.9037	-1.7022	-3.8761	0.4523	-55.9575
-74.0000	-6.4391	-1.8330	-3.2292	-0.1983	-62.8052
-76.0000	-7.0373	-1.9123	-3.3757	-0.5147	-70.5820
-78.0000	-7.7747	-2.0210	-4.0280	-0.3924	-79.4176
-80.0000	-8.4553	-2.1045	-5.1594	0.1324	-89.4719
-82.0000	-9.2789	-2.2122	-5.7340	-0.2361	-100.9300
-84.0000	-10.2450	-2.3379	-6.1242	-0.3150	-114.0092
-86.0000	-11.3112	-2.4795	-7.1038	-0.3715	-129.9556
-88.0000	-12.1951	-2.6237	-9.1631	1.2932	-144.6931
-90.0000	-13.2265	-2.7343	-9.7395	0.1127	-157.9696
-92.0000	-14.1177	-2.8537	-6.7591	-0.4700	-172.4259
-94.0000	-15.9720	-2.9404	-7.5454	-0.0299	-193.1738
-96.0000	-16.1035	-3.1172	-8.4284	0.2499	-205.3319
-98.0000	-17.2723	-3.2541	-10.1752	0.8230	-224.0253
-100.0000	-18.3968	-3.4219	-11.0442	0.5545	-244.3956
-102.0000	-19.6593	-3.5514	-10.7092	-0.3917	-266.5970
-104.0000	-21.2262	-3.7736	-11.3880	-0.7122	-290.7956
-106.0000	-22.4963	-3.9695	-12.7715	-0.4142	-317.1797
-108.0000	-24.3775	-4.1372	-13.7713	-0.6832	-345.9429
-110.0000	-25.7784	-4.4250	-17.2251	1.5427	-377.0059
-112.0000	-27.6234	-4.5570	-17.9124	0.4304	-411.5129
-114.0000	-30.7942	-5.0751	-27.4244	-0.4573	-457.2530
-116.0000	-34.4305	-5.5594	-30.3696	-2.1511	-531.7253
-118.0000	-38.8541	-6.1160	-33.6575	1.5523	-605.9350
-120.0000	-43.2799	-6.7371	-41.3452	-1.4452	-691.5156
-122.0000	-48.0387	-7.4522	-47.6579	-1.7531	-790.3584
-124.0000	-55.2673	-8.3354	-62.3661	1.0935	-912.9036

STATEMENTS EXECUTED= 1464462

CORE USAGE OBJECT CODE= 13784 BYTES,ARRAY AREA= 4016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 1.44 SEC,EXECUTION TIME= 176.32 SEC, 17.25.33 WATFIV - MAR

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Sample Ingot 28

Metal Chemistry - C 3.91 %, Si 3.05 %, C.E. 4.93 %,
Mn 0.64 %, Cr 0.13 %, Cu 0.04 %,
Al 0.025 %, Mg 0.037 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	54.0378	6.1479	-702.5254	-0.2599	-98.2672
18.0000	34.4514	3.4900	29.0419	-0.1981	-40.5797
16.0000	22.4255	1.8600	15.2832	0.0322	-9.9493
14.0000	15.5097	0.9225	7.0157	0.2225	4.5273
12.0000	11.1022	0.3225	3.1623	0.1907	11.2331
10.0000	7.5318	-0.1663	-0.1051	-0.0031	11.0168
8.0000	4.5205	-0.5619	-2.7021	0.0505	5.7136
6.0000	2.9723	-0.7600	-1.2865	0.0264	3.1935
4.0000	2.0631	-0.8884	-0.5800	-0.0818	1.8699
2.0000	1.2349	-0.9353	-0.3063	-0.1202	1.0170
0.0000	1.0000	-1.3856	-0.7019	0.1969	0.0072
-2.0000	1.2524	-0.9393	-0.7231	1.2313	1.0238
-4.0000	1.5107	-0.8964	0.1269	0.1245	1.5266
-6.0000	1.8360	-0.8512	0.2468	0.0904	2.2011
-8.0000	2.2545	-0.7956	0.4115	0.0622	3.1485
-10.0000	2.6844	-0.7356	0.4763	0.1154	4.3319
-12.0000	3.0537	-0.6811	0.5263	0.1292	5.6428
-14.0000	3.3953	-0.6304	0.5619	0.1653	7.0972
-16.0000	3.6899	-0.5859	1.1787	-0.4117	8.6313
-18.0000	3.9193	-0.5501	1.2133	-0.4467	10.1645
-20.0000	4.2002	-0.5088	0.6956	0.2014	11.9586
-22.0000	4.5007	-0.4656	1.0268	-0.0258	13.9605
-24.0000	4.7579	-0.4262	1.3492	-0.3379	15.9832
-26.0000	4.9623	-0.3978	2.9693	-1.4815	17.9590
-28.0000	4.7781	-0.4170	0.1208	0.1934	18.5872
-30.0000	4.4800	-0.4513	-0.0487	0.0856	13.6613
-32.0000	4.1021	-0.4960	0.0200	-0.2307	18.2401
-34.0000	3.6706	-0.5481	-0.0832	-0.3536	17.3667
-36.0000	3.2075	-0.6042	-2.4836	1.8563	16.1163
-38.0000	2.7994	-0.6535	-0.3864	-0.2223	14.8990
-40.0000	2.4127	-0.7001	-0.4698	-0.1905	13.5784
-42.0000	2.2276	-0.7451	-1.1746	0.4443	12.1176
-44.0000	1.6863	-0.7870	-0.6103	-0.1500	10.5971
-46.0000	1.2351	-0.8282	-0.6679	-0.1854	8.8906
-48.0000	0.9661	-0.8705	-0.4052	-0.5982	6.8540
-50.0000	0.5570	-0.9100	12.3707	-14.4707	4.6843
-52.0000	0.2280	-0.9408	7.6111	-8.8015	2.3040
-54.0000	-0.2626	-1.0595	-1.4119	-0.3303	-1.1605
-56.0000	-0.9533	-1.1250	-2.1742	-0.4436	-6.4161
-58.0000	-1.5329	-1.1970	-2.0764	-0.2911	-11.1508
-60.0000	-1.7458	-1.2234	-0.9383	-0.1173	-13.2621
-62.0000	-2.0037	-1.2559	-1.4147	0.1169	-15.8576
-64.0000	-2.3173	-1.2958	-1.6045	-0.0002	-19.0667

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-66.0000	-2.7008	-1.3449	-2.3456	0.3504	-23.0571
-68.0000	-3.1723	-1.4058	-3.1571	0.6621	-28.0471
-70.0000	-3.7542	-1.4815	-3.8432	0.7049	-34.3237
-72.0000	-4.4776	-1.5760	-4.0550	0.6842	-42.2650
-74.0000	-5.3815	-1.6945	-4.7855	-0.2688	-52.3737
-76.0000	-6.4268	-1.8321	-5.5174	-0.4939	-64.3964
-78.0000	-6.9780	-1.9051	-3.5196	-0.2028	-71.5414
-80.0000	-7.5895	-1.9862	-4.6081	0.4175	-80.2224
-82.0000	-8.2687	-2.0763	-4.2398	-0.4840	-89.6700
-84.0000	-9.0241	-2.1766	-5.1642	-0.1672	-100.3328
-86.0000	-9.8653	-2.2883	-5.5952	-0.4300	-112.3829
-88.0000	-10.8034	-2.4130	-8.1281	1.3106	-126.0179

-90.0000	-11.8510	-2.5522	-7.3281	-0.3963	-141.4665
-92.0000	-13.0224	-2.7079	-8.5924	-0.1706	-158.9926
-94.0000	-14.2340	-2.8824	-10.0606	0.1064	-178.9012
-96.0000	-15.6048	-3.0780	-11.7881	0.4661	-201.5454
-98.0000	-17.3298	-3.2810	-13.1510	1.0821	-225.6832
-100.0000	-18.9642	-3.4985	-13.2112	0.0067	-252.0920
-102.0000	-20.7792	-3.7402	-14.5792	-0.2589	-281.8251
-104.0000	-22.7970	-4.0059	-16.0176	-0.7407	-315.3447
-106.0000	-25.0428	-4.3079	-17.9896	-0.9175	-353.1589
-108.0000	-27.9536	-4.6955	-21.4054	1.1126	-401.7444
-110.0000	-31.8009	-5.2078	-32.6684	0.7321	-465.0109
-112.0000	-36.2665	-5.8025	-37.4333	-0.1439	-540.7712
-114.0000	-41.5107	-6.5010	-42.9871	-1.6972	-630.1401
-116.0000	-49.2032	-7.5256	-66.5710	1.5593	-760.1633
-118.0000	-58.5220	-8.7683	-78.5170	-1.4161	-920.0295
-120.0000	-69.8813	-10.2804	-97.0231	-1.5576	-1117.1900
-122.0000	-80.4239	-11.6853	-95.9842	0.9361	-1307.2570

STATEMENTS EXECUTED= 1754112

CORE USAGE   OBJECT CODE= 18432 BYTES, ARRAY AREA= 5016 BYTES BYTES

DIAGNOSTICS   NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 1.05 SEC, EXECUTION TIME= 191.60 SEC, 20.31.0 WATFIV - MAR

C$ECF

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Sample Ingot 29

Metal Chemistry - C 3.90 %, Si 2.70 %, C.E. 4.80 %,
Mn 0.66 %, Cr 0.13 %, Cu 0.04 %,
Al 0.021 %, Mg 0.039 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM C(I)
20.0000	72.0265	9.7509	-716.3201	-0.2215	-190.2243
18.0000	54.9659	6.3019	29.7995	-0.1493	-92.7259
16.0000	35.5497	3.7593	25.0951	0.1036	-40.8257
14.0000	23.3434	1.9595	16.4204	0.2507	-9.9866
12.0000	14.5567	0.7850	7.7910	0.1545	5.9524
10.0000	9.4462	0.0566	3.0164	-0.0369	11.9175
8.0000	6.5772	-0.2749	-1.5024	0.0333	5.3794
6.0000	4.6052	-0.5925	-1.3575	0.0029	4.6701
4.0000	2.7810	-0.3454	-1.2715	-0.0931	2.3412
2.0000	1.2791	-0.9679	-0.4473	-0.1404	1.7723
0.0000	1.0000	-1.3050	-0.3417	0.3068	3.0080
-2.0000	1.2025	-0.9439	-12.2377	10.7556	1.0434
-4.0000	1.6151	-0.5772	0.1413	0.1293	1.5844
-6.0000	1.9759	-0.3434	0.2712	-0.0474	2.3212
-8.0000	2.4692	-0.7769	0.4753	0.0535	3.3558
-10.0000	2.9964	-0.6991	0.6734	0.0425	4.5214
-12.0000	3.5124	-0.6331	0.6187	0.1582	6.2950
-14.0000	3.9551	-0.5453	0.6624	0.2277	9.1622
-16.0000	4.3474	-0.5721	1.1739	-0.2355	10.0358
-18.0000	4.6412	-0.4622	4.7545	-3.5456	11.9167
-20.0000	4.8347	-0.4374	1.0941	0.2124	13.6597
-22.0000	4.8268	-0.4238	0.6446	-0.0023	14.9545
-24.0000	4.6853	-0.4373	2.0169	-1.6158	15.7505
-26.0000	4.4751	-0.4675	0.7357	0.1027	15.7296
-28.0000	4.0277	-0.5114	-0.0692	-0.3573	15.7765
-30.0000	3.5747	-0.5649	-0.4967	0.1222	15.0259
-32.0000	3.0512	-0.6237	2.9769	-1.4369	13.8636
-34.0000	2.5315	-0.6873	3.3346	-1.1049	12.4151
-36.0000	2.1011	-0.7493	-0.5673	2.3555	10.7345
-38.0000	1.0610	-0.7919	-0.5354	-0.3214	9.1209
-40.0000	1.2173	-0.8426	-0.7238	-0.2394	7.1944
-42.0000	0.7522	-0.8929	-1.2691	0.1292	4.9147
-44.0000	0.2871	-0.9329	5.3042	-7.3634	2.4038
-46.0000	-0.1751	-1.0505	-0.2533	-0.4197	-0.2407

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-48.0000	-0.6226	-1.0935	-2.1775	0.0752	-3.3447
-50.0000	-1.0901	-1.1436	-2.1745	0.5044	-6.5658
-52.0000	-1.5476	-1.1972	-4.3513	2.6204	-10.0269
-54.0000	-1.9237	-1.2443	-1.4010	-0.1561	-13.1451
-56.0000	-2.2790	-1.2890	-1.3244	-0.2575	-16.3087
-58.0000	-2.7251	-1.3403	-1.6752	-0.3627	-20.3855
-60.0000	-3.2556	-1.4109	-2.4545	-0.1641	-25.6438
-62.0000	-3.7097	-1.4731	-2.6603	0.5212	-29.9419
-64.0000	-3.9012	-1.5133	-1.9471	0.2481	-33.3399
-66.0000	-4.2025	-1.5514	-2.1901	0.2323	-37.1515
-68.0000	-4.6492	-1.5972	-2.8274	0.0366	-41.4325
-70.0000	-5.0227	-1.6476	-3.[illegible]635	1.0554	-45.2491
-72.0000	-5.4553	-1.7029	-3.1754	0.4024	-51.6752
-74.0000	-5.9314	-1.7665	-3.0233	-0.0378	-57.7969
-76.0000	-6.4581	-1.8362	-2.9934	-0.4647	-64.7127
-78.0000	-7.0452	-1.9140	-3.4807	-0.4322	-72.5396
-80.0000	-7.7009	-2.0079	-4.4165	-0.2175	-81.4073
-82.0000	-8.4335	-2.0981	-4.8980	-0.1236	-91.4707
-84.0000	-9.2540	-2.2077	-5.2315	-0.3867	-102.9070
-86.0000	-10.1741	-2.3291	-6.9693	-0.5357	-115.9230
-88.0000	-11.2076	-2.4664	-7.9473	0.5295	-132.7585
-90.0000	-12.2700	-2.6239	-8.9556	0.4685	-147.6929
-92.0000	-13.5207	-2.7749	-8.1211	-0.5645	-155.1037
-94.0000	-14.5215	-2.9072	-9.7290	-0.0447	-151.2495
-96.0000	-15.5061	-3.0516	-9.0922	0.2257	-199.7025
-98.0000	-16.7643	-3.2093	-10.4716	0.7077	-215.5302
-100.0000	-18.0545	-3.3753	-11.5981	0.3543	-247.0192
-102.0000	-19.4443	-3.5628	-11.4810	-0.3464	-263.6731
-104.0000	-20.9469	-3.7033	-12.4708	-0.5457	-259.7241
-106.0000	-22.5946	-3.9912	-13.5287	-0.5115	-313.4246
-108.0000	-24.2632	-4.2132	-15.1115	-0.7342	-357.7564
-110.0000	-26.9700	-4.5653	-23.7371	1.3755	-394.7793
-112.0000	-30.0670	-5.[illegible]	-31.7452	0.5973	-457.0752
-114.0000	-34.3012	-5.6257	-26.7642	-0.5524	-530.3751
-116.0000	-39.4172	-6.2496	-41.2295	-1.4234	-615.5720
-118.0000	-45.7727	-7.0643	-52.7653	1.4376	-719.3274
-120.0000	-55.2849	-8.3100	-79.3251	-1.2521	-880.5017
-122.0000	-66.5563	-9.8385	-99.1149	-1.5295	-1051.7900
-124.0000	-77.6593	-11.3177	-101.3642	0.7384	-1293.0410

STATEMENTS EXECUTED= 122[illegible]

CORE USAGE OBJECT CODE= [illegible] BYTES,ARRAY AREA= [illegible] BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= [illegible] SEC,EXECUTION TIME= 192.93 SEC, [illegible]WATFIV - MAR

C$EOF

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Sample Ingot 30

Metal Chemistry - C 4.00 %, Si 2.50 %, C.E. 4.83 %,
Mn 0.67 %, Cr 0.14 %, Cu 0.05 %,
Al 0.024 %, Mg 0.030 %, S 0.006 %.

X(I)	Y(I)	P(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	37.0207	3.3542	-709.4078	-0.1046	-41.3553
14.0000	27.4121	2.5454	11.0754	-0.1172	-17.6247
12.0000	19.4420	1.4536	7.7071	0.2177	-1.7751
10.0000	14.2722	0.7411	3.7269	0.1356	5.9450
8.0000	9.9965	0.1442	1.3766	0.0265	9.7543
6.0000	6.0596	-0.4117	-1.9152	0.0516	6.0252
4.0000	3.9293	-0.7544	-1.7561	-0.1369	2.7551
2.0000	1.4293	-1.0046	-0.7709	0.0130	1.2594
0.0000	[illegible]	-1.3956	-0.3655	0.3356	0.0077
-2.0000	1.2931	-0.9430	-0.4579	0.9749	1.0417
-4.0000	1.5963	-0.4972	-0.0066	0.2693	1.5790
-6.0000	1.9216	-0.8459	0.2925	0.0697	2.2532
-8.0000	2.3853	-0.7943	0.3489	0.1574	3.2955
-10.0000	2.9345	-0.7100	0.6202	0.0705	4.6770
-12.0000	3.4507	-0.6371	0.9255	-0.0271	6.2949
-14.0000	3.9245	-0.5659	0.7433	0.1642	8.1031
-16.0000	4.3651	-0.5031	0.7754	0.2191	10.0923
-18.0000	4.7485	-0.4439	1.1641	-0.1219	12.1765
-20.0000	4.9767	-0.4129	0.7959	0.1396	14.0477
-22.0000	5.0562	-0.3752	0.7507	0.0264	15.6018
-24.0000	5.0767	-0.3841	1.0298	-0.3229	17.0094
-26.0000	5.0843	-0.3824	2.6646	-1.9772	18.3844
-28.0000	4.9981	-0.3904	-0.1506	0.5459	19.3752
-30.0000	4.6715	-0.4245	0.0417	0.3263	19.5107
-32.0000	3.8472	-0.5232	-1.3197	0.2224	17.3165
-34.0000	3.1753	-0.6127	-2.9336	1.5747	14.7987
-36.0000	2.3925	-0.7349	-4.0167	2.7150	12.1953
-38.0000	1.6617	-0.7917	-1.2665	-0.2595	9.1234
-40.0000	1.0007	-0.8567	-1.2089	-0.3359	6.0339
-42.0000	0.3190	-0.9294	-1.6038	-0.1017	2.5033
-44.0000	-0.2597	-1.0546	-2.9549	1.3119	-0.8928
-46.0000	-0.7351	-1.1049	-1.0555	-0.4389	-3.8117
-48.0000	-1.1331	-1.1595	-1.8431	0.4795	-6.5579
-50.0000	-1.5677	-1.2024	-2.0993	0.4238	-9.9017

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-52.0000	-1.7640	-1.2242	22.5181	-23.3304	-11.5256
-54.0000	-1.9690	-1.2499	-0.8179	-0.1545	-13.4702
-56.0000	-2.2121	-1.2927	-0.8395	-0.3310	-15.8092
-58.0000	-2.5016	-1.3176	-1.2057	-0.2074	-18.6359
-60.0000	-2.8474	-1.3521	-2.1226	0.4057	-22.0679
-62.0000	-3.2622	-1.4157	-2.2979	0.1946	-26.2547
-64.0000	-3.7621	-1.4807	-2.5899	0.0238	-31.3969
-66.0000	-4.3069	-1.5596	-3.4140	0.2530	-37.7098
-68.0000	-5.1120	-1.6506	-4.3907	-0.4775	-45.5354
-70.0000	-6.0000	-1.7740	-5.4678	0.5903	-55.2727
-72.0000	-7.1022	-1.9102	-6.5781	0.4900	-67.4487
-74.0000	-8.4617	-2.0939	-7.3091	-0.3427	-82.7523
-76.0000	-10.1479	-2.3220	-9.1231	-0.5441	-102.0869
-78.0000	-11.9816	-2.5651	-10.7462	-0.1385	-122.8565
-80.0000	-12.8363	-2.6759	-6.2246	0.2701	-135.1655
-82.0000	-13.7555	-2.8014	-6.3348	-0.4007	-149.6354
-84.0000	-14.7444	-2.9332	-6.8574	-0.5130	-164.3769
-86.0000	-15.8035	-3.0750	-8.4133	0.3479	-150.5074
-88.0000	-16.9529	-3.2276	-8.4215	-0.4043	-193.1591
-90.0000	-18.1969	-3.3919	-9.7195	0.0621	-217.4738
-92.0000	-19.5148	-3.5640	-10.5325	0.2647	-235.6291
-94.0000	-20.9451	-3.7595	-11.9453	0.3821	-261.7356
-96.0000	-22.5271	-3.9717	-13.6879	0.7232	-287.6946
-98.0000	-24.4485	-4.2264	-15.8455	0.3543	-318.6775
-100.0000	-26.5403	-4.5050	-16.6162	-0.3636	-353.2971
-102.0000	-28.8392	-4.8102	-18.2333	-0.3744	-391.2952
-104.0000	-31.3289	-5.1444	-20.3072	-0.4272	-433.7642
-106.0000	-34.7192	-5.5047	-25.9271	0.7657	-489.8970
-108.0000	-39.0025	-6.1652	-26.3174	0.9546	-560.8123
-110.0000	-43.3945	-6.9170	-41.2075	0.1303	-642.0435
-112.0000	-49.6114	-7.5813	-47.5901	-1.7391	-740.3075
-114.0000	-56.6462	-8.5159	-61.1735	1.2527	-860.1470
-116.0000	-64.7962	-9.6016	-69.4862	-1.0974	-1001.2540
-118.0000	-74.2223	-10.8713	-82.3145	-1.2592	-1163.4210
-120.0000	-84.1541	-12.4492	-104.3042	0.2474	-1377.6550

```
STATEMENTS EXECUTED= 1554237

CORE USAGE        OBJECT CODE=    14784 BYTES,ARRAY AREA=     8012 BYT96   BYTES

DIAGNOSTICS          NUMBER OF ERRORS=        0, NUMBER OF WARNINGS=        0

COMPILE TIME=      0.92 SEC,EXECUTION TIME=    141.35 SEC,      13.20.4  WATFIV - MAR

          C$STOP
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Sample Ingot 31

Metal Chemistry - C 3.93 %, Si 2.81 %, C.E. 4.87 %,
Mn 0.65 %, Cr 0.13 %, Cu 0.13 %,
Al 0.021 %, Mg 0.036 %, S 0.066 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	58.6182	5.9014	-429.0520	-0.1956	-111.2500
18.0000	43.7102	4.6582	25.0587	-0.1359	-61.3544
16.0000	29.2823	2.7919	18.3210	0.0760	-24.5905
14.0000	20.4529	1.5922	9.7828	0.2413	-4.5423
12.0000	14.1205	0.7251	5.4191	0.1705	5.6369
10.0000	9.5947	0.1352	2.6180	-0.3421	11.7997
8.0000	6.2172	-0.2567	-2.1045	0.0467	7.6730
6.0000	3.7347	-0.6549	-1.9979	0.1231	3.9234
4.0000	2.4421	-0.9692	-0.8704	-0.0326	2.1172
2.0000	1.2427	-0.9575	-0.4358	-0.0726	1.0634
0.0000	1.0000	-1.3950	-0.6362	0.1605	0.0091
-2.0000	1.3792	-0.9640	-0.3354	0.8683	1.0750
-4.0000	1.7584	-0.3964	0.1312	0.1715	1.6875
-6.0000	2.2352	-0.8254	0.3209	0.1129	2.5491
-8.0000	2.9299	-0.7355	0.4925	0.1703	3.5954
-10.0000	3.7295	-0.6241	0.8949	0.0508	5.7779
-12.0000	4.2885	-0.5406	0.9372	0.0296	7.6713
-14.0000	4.7325	-0.4725	0.8119	0.1737	9.6423
-16.0000	5.0117	-0.4262	0.7350	0.1376	11.4933
-18.0000	5.2032	-0.3503	0.7597	0.2259	13.5245
-20.0000	5.5706	-0.3386	1.7517	-0.7204	15.6470
-22.0000	5.6342	-0.3161	0.7058	0.2139	17.4994
-24.0000	5.5942	-0.3139	0.6439	0.0581	18.9023
-26.0000	5.5373	-0.3197	1.1994	-0.4929	20.1372
-28.0000	5.5515	-0.3138	-25.9927	27.0550	21.4895
-30.0000	5.4092	-0.3334	0.0223	0.4273	22.3858
-32.0000	5.1652	-0.3011	0.1057	0.3934	22.7973
-34.0000	4.7707	-0.4097	-0.4277	0.2183	22.3687
-36.0000	4.2922	-0.4686	-11.1265	10.5457	21.2976
-38.0000	3.7547	-0.5330	10.3925	-11.1405	19.7719
-40.0000	3.2272	-0.5956	0.2925	-1.2725	17.9320
-42.0000	2.6297	-0.5727	-0.9024	-0.3434	15.4402
-44.0000	2.0533	-0.7424	-1.0295	-0.3140	12.7547
-46.0000	1.5611	-0.8215	-1.1394	-0.3963	10.2792

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-48.0000	1.0000	-0.8647	-3.8211	-2.2327	7.1022
-50.0000	0.4604	-0.9230	-1.1239	-0.5385	3.7775
-52.0000	0.0000	-1.0000	-1.5424	0.0047	0.7023
-54.0000	-0.4984	-1.0793	-1.1494	-0.6026	-2.8516
-56.0000	-0.9240	-1.1245	-2.4657	0.5114	-6.1959
-58.0000	-1.3495	-1.1747	-2.5358	0.7575	-9.7324
-60.0000	-1.6953	-1.2166	-1.2474	-0.2969	-12.8211
-62.0000	-2.0373	-1.2601	-1.2779	-0.3809	-16.1380
-64.0000	-2.4829	-1.3167	-1.9155	-0.2543	-20.4779
-66.0000	-3.0453	-1.3893	-2.7300	-0.0739	-26.0559
-68.0000	-3.2747	-1.4190	-1.7095	0.2530	-29.9774
-70.0000	-3.5295	-1.4524	-1.6244	-0.0007	-32.2276
-72.0000	-3.8127	-1.4895	-1.9522	0.1522	-35.8879
-74.0000	-4.1264	-1.5311	-3.6942	0.5399	-40.0164
-76.0000	-4.4803	-1.5774	-3.1739	0.3412	-44.6819
-78.0000	-4.8733	-1.6292	-3.4453	0.3050	-49.9623
-80.0000	-5.2129	-1.6873	-3.6291	0.6353	-55.9492
-82.0000	-5.8055	-1.7524	-3.3431	-0.3571	-62.7496
-84.0000	-6.2582	-1.8255	-3.3664	-0.5021	-70.4964
-86.0000	-6.9796	-1.9077	-4.1677	-0.2414	-79.3044
-88.0000	-7.5792	-2.0004	-5.0359	0.6051	-89.3722
-90.0000	-8.4023	-2.1050	-5.2955	-0.4616	-100.8865
-92.0000	-9.3593	-2.2233	-6.5766	-0.0194	-114.0794
-94.0000	-10.2689	-2.3573	-7.3248	-0.2456	-129.2192
-96.0000	-11.5132	-2.5092	-8.3968	0.6927	-146.6275
-98.0000	-12.3130	-2.6819	-9.5871	-0.4381	-166.6778
-100.0000	-13.9459	-2.8326	-8.7922	-0.4773	-195.1959
-102.0000	-15.0713	-2.9324	-9.6794	0.1674	-204.2185
-104.0000	-16.3734	-3.1465	-10.9140	0.3623	-225.3210
-106.0000	-17.6535	-3.3252	-12.4301	0.7729	-248.7475
-108.0000	-19.1342	-3.5234	-14.3021	1.2905	-274.7727
-110.0000	-20.7592	-3.7399	-14.3927	-0.0729	-303.7058
-112.0000	-22.5444	-3.9775	-15.8991	-0.1960	-335.8958
-114.0000	-24.5069	-4.2399	-17.2510	-0.6380	-371.7334
-116.0000	-26.6603	-4.5266	-19.7566	-1.2083	-411.6636
-118.0000	-29.2153	-4.8002	-24.2467	0.6383	-458.8804
-120.0000	-32.8494	-5.2172	-31.4942	0.9216	-520.0054
-122.0000	-36.2255	-5.8132	-35.7430	0.6065	-590.0954
-124.0000	-40.6032	-6.3437	-39.6656	-0.3765	-670.5825
-126.0000	-45.4733	-7.0919	-45.7754	-0.5674	-763.1254
-128.0000	-52.2792	-7.9396	-65.0277	0.3934	-891.3970
-130.0000	-62.4795	-9.2591	-93.9073	-0.8373	-1080.8870
-132.0000	-74.6103	-10.9139	-114.2392	-1.4409	-1312.2470
-134.0000	-86.6575	-12.5134	-118.1955	0.7353	-1547.2270

STATEMENTS EXECUTED= 2204130

CORE USAGE   OBJECT CODE= 14794 BYTES,ARRAY AREA= [illegible] BYTES BYTES

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Sample Ingot 32

Metal Chemistry - C 4.03 %, Si 2.13 %, C.E. 4.74 %,
Mn 0.59 %, Cr 0.10 %, Cu 0.07 %,
Al 0.018 %, Mg 0.020 %, S 0.007 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
16.0000	37.5525	3.9276	-644.5652	-0.1710	-42.5129
14.0000	21.4749	1.7295	18.2299	-0.1944	-5.4440
12.0000	12.7417	0.5435	7.4153	0.1597	9.7257

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
10.0000	5.2735	-0.0530	1.4443	0.1598	11.9047
8.0000	5.4176	-0.4450	-2.6171	0.0336	6.8279
6.0000	2.5540	-0.8022	-2.0124	0.0115	2.8262
4.0000	1.7437	-0.4999	-0.6771	0.0394	1.6797
2.0000	1.2421	-0.9377	-0.2519	-0.0425	1.0214
0.0000	1.0005	-1.3656	-0.9735	0.4732	0.0035
-2.0000	1.2912	-0.3475	-0.3917	0.7074	1.0395
-4.0000	1.5924	-0.3071	0.0072	0.2597	1.5715
-6.0000	1.7518	-0.5446	0.2836	0.0815	2.3016
-8.0000	2.4182	-0.7514	0.3479	0.1060	3.3332
-10.0000	2.9252	-0.7117	0.5625	0.1035	4.6650
-12.0000	3.4302	-0.6394	0.4157	-0.1177	6.2510
-14.0000	3.9489	-0.5060	0.7503	0.1942	3.1500
-16.0000	4.3093	-0.4947	0.9933	0.1265	10.1595
-18.0000	4.6970	-0.4553	0.7292	0.2020	12.0518
-20.0000	4.8550	-0.4252	2.2951	-1.4134	13.7571
-22.0000	4.3734	-0.4135	0.6175	0.0434	15.0778
-24.0000	4.7244	-0.4315	1.4170	-1.0117	15.8920
-26.0000	4.4527	-0.4620	0.0375	0.1056	16.1821
-28.0000	4.0947	-0.5143	-0.0429	-0.0478	15.9885
-30.0000	3.5445	-0.5502	-0.2157	-0.1234	15.3053
-32.0000	3.1401	-0.6130	-0.7442	0.1026	14.2750
-34.0000	2.6627	-0.6733	4.3442	-5.5537	12.7960
-36.0000	2.1904	-0.7307	0.5230	-1.3295	11.1751
-38.0000	1.7351	-0.7331	-26.3235	25.9827	9.4054
-40.0000	1.2952	-0.8337	-0.6152	-0.3172	7.6301
-42.0000	0.8632	-0.8914	-0.8003	-0.2404	5.5352
-44.0000	0.4274	-0.9235	-1.6043	0.4440	3.2161
-46.0000	[illegible]	-1.0000	-1.5772	0.3213	0.7003
-48.0000	-0.7250	-1.1033	-2.1213	-0.1975	-3.9355
-50.0000	-1.3719	-1.1756	-1.3792	-0.6743	-5.4445

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-52.0000	-2.0477	-1.2591	-3.1246	0.6073	-13.4871
-54.0000	-2.5773	-1.3290	-2.9762	0.6442	-17.8511
-56.0000	-2.8226	-1.3579	-1.1052	-0.1555	-20.3724
-58.0000	-3.1153	-1.3943	-1.1456	-0.3192	-23.3020
-60.0000	-3.4267	-1.4364	-1.5016	-0.2053	-26.7159
-62.0000	-3.8011	-1.4850	-2.0645	0.0594	-30.7062
-64.0000	-4.2307	-1.5413	-2.2728	0.2340	-35.3836
-66.0000	-4.7274	-1.6055	-2.9143	0.2643	-40.5927
-68.0000	-5.2946	-1.6824	-3.6501	0.4269	-47.3699
-70.0000	-5.9753	-1.7709	-4.5307	0.5942	-55.0425
-72.0000	-6.7567	-1.8741	-5.2127	0.6607	-64.1469
-74.0000	-7.6729	-1.9952	-5.4400	0.0325	-74.9814
-76.0000	-8.7483	-2.1375	-5.5139	-0.5533	-87.9160
-78.0000	-10.0143	-2.3053	-7.2132	-0.5313	-103.4051
-80.0000	-10.9441	-2.4297	-6.2852	-0.0075	-115.9914
-82.0000	-11.9752	-2.5526	-6.2709	-0.2768	-129.0968
-84.0000	-12.8992	-2.6848	-7.0551	-0.2512	-143.7104
-86.0000	-14.2264	-2.8399	-7.7727	-0.4034	-160.0916
-88.0000	-15.2684	-3.0042	-9.3126	0.0575	-178.7910
-90.0000	-16.6387	-3.1845	-10.1374	-0.0545	-198.8949
-92.0000	-18.1400	-3.3874	-11.7159	0.2275	-221.8731
-94.0000	-19.8202	-3.6102	-13.1071	0.3122	-247.6431
-96.0000	-21.5477	-3.8432	-14.7507	0.3744	-275.0254
-98.0000	-23.3792	-4.0427	-15.5092	0.6934	-304.6559
-100.0000	-25.7764	-4.3506	-16.4979	0.7225	-337.5705
-102.0000	-27.5691	-4.6425	-17.7650	-0.5235	-374.1501
-104.0000	-29.5724	-4.9627	-19.4411	-0.8946	-414.8215
-106.0000	-32.0245	-5.3140	-21.5731	-1.0481	-459.0642
-108.0000	-35.5016	-5.6995	-26.4310	1.2567	-510.4138
-110.0000	-39.2704	-6.2016	-32.3325	0.9061	-575.1467
-112.0000	-43.5532	-6.7722	-37.1791	-0.0302	-649.5635
-114.0000	-48.3067	-7.4125	-40.9799	-1.4029	-734.3291
-116.0000	-53.7927	-8.1353	-45.6730	1.3471	-830.9807
-118.0000	-59.8840	-8.9444	-53.9513	-1.2075	-941.2983
-120.0000	-67.6174	-9.9730	-68.2953	-1.5555	-1080.0700
-122.0000	-76.7502	-11.1959	-83.0227	0.6513	-1247.5430

STATEMENTS EXECUTED= 1617142

CORE USAGE OBJECT CODE= 13794 BYTES,ARRAY AREA= 9015 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 7.43 SEC,EXECUTION TIME= 171.22 SEC, 19.18.1 WATFIV - MAR

C$ECF

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Sample Ingot 33

Metal Chemistry - C 3.89 %, Si 2.58 %, C.E. 4.75 %,
Mn 0.66 %, Cr 0.11 %, Cu 0.05 %,
Al 0.023 %, Mg 0.024 %, S 0.007 %.

X(I)	Y(I)	P(I)	C(300)	C(EVEN)	SUM(C(I))
14.0000	11.1733	3.2965	-624.3123	-0.2535	-25.7204
12.0000	21.4201	1.6546	11.4937	-0.2148	-4.1624
10.0000	12.9528	0.5592	5.7309	0.2090	7.6694
8.0000	4.8336	-0.3167	2.1249	-1.3410	5.0370
6.0000	3.5720	-0.7073	-2.1089	-0.0443	3.7293
4.0000	2.2772	-0.4735	-0.6950	0.0374	2.0650
2.0000	1.3232	-0.3530	-0.0142	0.1054	1.0506
0.0000	1.[illegible]	-1.2356	-3.3176	3.7959	0.0071
-2.0000	1.3700	-0.9624	-3.3074	3.5355	1.0692
-4.0000	1.7700	-0.8961	-3.1747	0.4047	1.6892
-6.0000	2.2216	-0.8202	-1.3656	0.3315	2.6210
-8.0000	2.9431	-0.7427	0.4140	0.1790	3.8050
-10.0000	3.3724	-0.6743	0.4935	0.1733	5.1429
-12.0000	3.5492	-0.6315	0.5897	0.[illegible]	5.3275
-14.0000	3.7925	-0.5343	0.3167	-0.1507	7.8574
-16.0000	3.9665	-0.5520	0.5113	0.1705	9.2340
-18.0000	4.0[illegible]	-0.5395	0.4597	0.[illegible]	10.3712
-20.0000	3.8566	-0.5459	0.2624	0.1234	11.1425
-22.0000	3.9105	-0.5335	-2.4229	2.9407	12.2170
-24.0000	3.8583	-0.5401	4.7587	-4.3232	13.0852
-26.0000	3.7200	-0.5530	0.3170	0.2554	13.6348
-28.0000	3.4101	-0.5391	-0.3515	-0.3301	13.4592
-30.0000	2.9583	-0.6427	-0.3257	-0.1392	12.5233
-32.0000	2.4755	-0.6970	-0.4797	-0.1541	11.2753
-34.0000	2.1134	-0.7510	-1.1091	0.2795	9.9347
-36.0000	1.5944	-0.8037	5.0751	-6.4462	9.2147
-38.0000	1.1274	-0.8550	1.5327	-2.4854	6.3110
-40.0000	0.6400	-0.9025	-0.6755	-0.3948	4.1687
-42.0000	0.1024	-0.9743	-0.3274	-0.3554	1.8111
-44.0000	-0.2415	-1.0543	-0.9905	-0.2521	-0.5941
-46.0000	-0.4551	-1.0965	-1.3020	0.5725	-3.3344
-48.0000	-1.1743	-1.1413	-1.6352	0.2132	-6.1792
-50.0000	-1.4415	-1.1502	-1.3739	-0.2223	-9.2411

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-52.0000	-1.[illegible]	-1.2410	-1.0131	-0.0204	-12.5250
-54.0000	-2.2220	-1.2527	-5.2059	0.7964	-15.3700
-56.0000	-2.5423	-1.3222	-3.0144	1.5427	-19.2733
-58.0000	-2.9152	-1.3701	-1.3249	-0.4553	-21.5334
-60.0000	-3.3469	-1.4289	-1.5797	-0.3141	-26.2216
-62.0000	-3.9144	-1.4[illegible]	-2.9772	0.2555	-31.6539
-64.0000	-4.3742	-1.5547	-2.4776	0.1735	-35.2670
-66.0000	-4.8612	-1.5978	-2.0749	0.3607	-40.2967
-68.0000	-5.0206	-1.6454	-2.3069	0.2561	-44.7980
-70.0000	-5.4167	-1.6979	-2.9249	0.4076	-49.9324
-72.0000	-5.5336	-1.7556	-3.5550	0.7366	-55.4693
-74.0000	-6.2260	-1.9135	-4.1203	0.9779	-61.7892
-76.0000	-6.8492	-1.8902	-3.3417	-0.1944	-68.8975
-78.0000	-7.4597	-1.9685	-3.4292	-0.5565	-75.8502
-80.0000	-8.1140	-2.0552	-4.0315	-0.4516	-85.8167
-82.0000	-8.8471	-2.1517	-5.1153	0.0654	-95.9167
-84.0000	-9.5855	-2.2512	-5.1192	-0.2554	-106.6650
-86.0000	-10.3217	-2.3486	-5.1925	-0.2529	-117.6153
-88.0000	-11.1201	-2.4549	-5.7122	-0.3467	-129.7341
-90.0000	-11.9912	-2.5797	-7.5861	0.3779	-143.1534
-92.0000	-12.9624	-2.5973	-7.5949	0.5569	-153.0129
-94.0000	-13.9327	-2.8357	-8.7200	0.4911	-174.4019
-96.0000	-15.1139	-2.9879	-9.3094	0.1512	-192.7703
-98.0000	-16.3622	-3.1527	-10.3229	0.1731	-213.0594
-100.0000	-17.7265	-3.3342	-11.8504	0.5129	-235.5952
-102.0000	-19.2203	-3.5332	-12.4162	-0.1067	-257.6406
-104.0000	-20.8602	-3.7515	-13.3642	-0.5536	-288.4961
-106.0000	-22.6604	-3.9913	-14.5294	-0.8707	-319.4961
-108.0000	-24.6284	-4.2549	-16.1100	-1.1506	-354.0195
-110.0000	-27.2725	-4.6190	-25.1383	1.7980	-400.6978
-112.0000	-30.8201	-5.0204	-29.1723	0.9576	-455.1270
-114.0000	-34.1133	-5.5162	-31.1047	-0.1711	-517.6755
-116.0000	-39.2023	-6.2324	-42.3507	-1.0204	-606.4448
-118.0000	-45.9119	-7.0749	-58.1145	1.3646	-719.9443
-120.0000	-53.5192	-8.1149	-67.2913	-1.2549	-857.3564
-122.0000	-62.9511	-9.3581	-81.3652	-1.5564	-1023.1250
-124.0000	-74.[illegible]	-10.5371	-101.[illegible]	0.2594	-1223.3970

STATEMENTS EXECUTED= 1419174

CORE USAGE OBJECT CODE= 13784 BYTES,ARRAY AREA= 9016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.99 SEC,EXECUTION TIME= 171.57 SEC, 19.15.1 WATFIV - MAR

C$EOF

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Sample Ingot 34

Metal Chemistry - C 3.90 %, Si 2.75 %, C.E. 4.82 %,
Mn 0.62 %, Cr 0.11 %, Cu 0.05 %,
Al 0.016 %, Mg 0.027 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	67.5550	7.9709	-752.7109	-0.2956	-148.4454
20.0000	52.9075	5.9936	26.7710	-0.1493	-95.2020
18.0000	35.2416	3.5975	26.2596	0.0954	-42.4920
16.0000	23.9107	2.0609	14.4377	0.2582	-13.1003
14.0000	17.0450	1.1287	7.2018	0.2156	1.7345
12.0000	11.6106	0.3902	4.7046	-0.3367	10.4704
10.0000	7.4288	-0.1756	0.8095	-0.5845	10.9203
8.0000	4.6315	-0.5256	-2.3795	-0.0462	6.0708
6.0000	3.1938	-0.7451	-1.2071	-0.1329	3.3908
4.0000	2.1816	-0.8834	-0.5745	-0.1479	1.9461
2.0000	1.2936	-0.9480	-0.3794	-0.0739	1.0392
0.0000	1.0000	-1.3556	-1.1371	0.6210	0.0070
-2.0000	1.2260	-0.9334	0.5497	-0.0462	1.0139
-4.0000	1.4532	-0.8953	0.1321	0.1069	1.4920
-6.0000	1.7005	-0.8575	0.2755	0.0207	2.0845
-8.0000	2.0219	-0.8144	0.5664	-0.2642	2.8889
-10.0000	2.3994	-0.7636	0.3579	0.1676	3.9396
-12.0000	2.7582	-0.7098	0.5750	0.0594	5.2083
-14.0000	3.1795	-0.6550	0.7002	0.0394	6.6872
-16.0000	3.5551	-0.5993	-4.8669	5.7256	8.4045
-18.0000	3.9968	-0.5407	0.8343	0.1396	10.3523
-20.0000	4.4055	-0.4836	0.8160	0.2636	12.5115
-22.0000	4.6157	-0.4514	0.8773	0.0160	14.2950
-24.0000	4.3858	-0.4747	-0.2569	0.5005	14.7855
-26.0000	4.0381	-0.5137	-0.0107	-0.0122	14.7396
-28.0000	3.6020	-0.5644	-0.2066	-0.0738	14.1797
-30.0000	3.1127	-0.6221	-1.0177	0.5154	13.1740
-32.0000	2.6064	-0.6820	2.5410	-2.2104	11.8355
-34.0000	2.1143	-0.7399	-0.7921	0.0210	10.2932
-36.0000	1.6616	-0.7925	-0.9957	0.1568	8.6794
-38.0000	1.2354	-0.8408	-0.5842	-0.2755	6.9602
-40.0000	0.6576	-0.9018	-1.1553	-0.2199	4.2097
-42.0000	0.0000	-1.0000	-2.2361	0.4813	0.6998
-44.0000	-0.3977	-1.0733	5.6219	-6.7539	-1.6240

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-46.0000	-0.8593	-1.1179	-1.0615	-0.4115	-4.5698
-48.0000	-1.2274	-1.1594	-1.9849	0.6923	-7.1552
-50.0000	-1.7625	-1.2236	-2.5535	0.6077	-11.0468
-52.0000	-1.9643	-1.2488	0.8404	-1.7743	-12.9146
-54.0000	-2.1392	-1.2710	-0.8229	-0.2681	-14.6966
-56.0000	-2.2399	-1.2967	-0.8096	-0.2244	-16.7645
-58.0000	-2.5707	-1.3263	-0.9372	-0.2666	-19.1715
-60.0000	-2.8367	-1.3607	-1.2230	-0.1831	-21.9841
-62.0000	-3.1441	-1.4005	-1.5970	-0.0507	-25.2795
-64.0000	-3.5000	-1.4469	-2.1654	0.2284	-29.1536
-66.0000	-3.9135	-1.5009	-2.5341	0.2494	-33.7229
-68.0000	-4.3950	-1.5640	-3.3659	0.8623	-39.1301
-70.0000	-4.9575	-1.6375	-4.1112	0.9013	-45.5498
-72.0000	-5.6167	-1.7246	-4.2134	0.3899	-53.1970
-74.0000	-6.3913	-1.8268	-4.7821	0.2124	-62.3363
-76.0000	-7.3053	-1.9475	-5.0519	-0.4281	-73.2960
-78.0000	-8.3864	-2.0905	-6.0944	-0.4994	-86.4836
-80.0000	-9.6700	-2.2605	-7.8756	-0.0828	-102.4062
-82.0000	-11.1990	-2.4632	-10.1564	0.5108	-121.6973
-84.0000	-12.4125	-2.6244	-7.7353	-0.5513	-139.2705
-86.0000	-13.2605	-2.7374	-6.4536	-0.0622	-151.3018
-88.0000	-14.1704	-2.8587	-7.0867	-0.0185	-165.5117
-90.0000	-15.1471	-2.9898	-9.4715	1.7231	-181.0057
-92.0000	-16.1957	-3.1285	-7.9256	-0.5212	-197.9083
-94.0000	-17.3213	-3.2796	-8.4784	-0.7368	-216.3387
-96.0000	-18.5316	-3.4398	-9.9717	-0.0788	-236.4393
-98.0000	-19.8314	-3.6130	-11.2981	0.3368	-258.3616
-100.0000	-21.2284	-3.7992	-12.7764	0.8202	-282.2737
-102.0000	-22.7303	-3.9994	-13.4695	0.4280	-308.3574
-104.0000	-24.3454	-4.2146	-13.7942	-0.4328	-336.8118
-106.0000	-26.0827	-4.4462	-14.7223	-0.7990	-367.8545
-108.0000	-28.1917	-4.7272	-18.9653	0.3061	-405.1736
-110.0000	-30.8745	-5.0846	-23.3784	-0.0539	-452.0373
-112.0000	-33.8492	-5.4809	-27.5027	1.1911	-504.6814
-114.0000	-37.1494	-5.9206	-29.8355	0.2448	-563.8630
-116.0000	-40.8146	-6.4090	-32.3555	-0.9377	-630.4495
-118.0000	-45.9154	-7.0589	-43.7199	-1.8648	-721.6199
-120.0000	-52.8441	-7.9717	-60.5915	1.4721	-839.8584
-122.0000	-60.2662	-9.0005	-68.6905	-1.1106	-979.4604
-124.0000	-69.2545	-10.2022	-81.0831	-1.4909	-1144.6090
-126.0000	-80.8622	-11.7450	-107.5236	1.0502	-1357.5550

STATEMENTS EXECUTED= 1570581

CORE USAGE OBJECT CODE= 18784 BYTES,ARRAY AREA= 8016 BYTES BYTES

DIAGNOSTICS . NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.97 SEC,EXECUTION TIME= 210.56 SEC. 21.27.2 WATFIV - MAR

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Sample Ingot 35

Metal Chemistry - C 4.01 %, Si 2.66 %, C.E. 4.89 %,
Mn 0.67 %, Cr 0.09 %, Cu 0.05 %,
Al 0.020 %, Mg 0.021 %, S 0.005 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	42.8257	4.6209	-589.0361	-0.2356	-67.9587
18.0000	30.3251	2.9298	18.8930	-0.2251	-30.6232
16.0000	20.5861	1.6119	12.2586	0.0212	-6.0638
14.0000	13.6795	0.6792	6.7236	0.2195	7.8222
12.0000	9.0312	0.0515	2.9055	0.1977	14.0255
10.0000	5.9595	-0.3603	-2.5616	-0.0114	8.8825
8.0000	4.0264	-0.6150	-1.8958	0.0325	5.1499
6.0000	2.8443	-0.7775	-1.0003	-0.0342	3.0808
4.0000	1.5886	-0.5910	-0.5227	-0.1061	1.8230
2.0000	1.1875	-0.9240	-0.2820	-0.1295	0.9997
0.0000	1.0000	-1.3856	-0.7547	0.2584	0.0069
-2.0000	1.1975	-0.9264	1.2555	-0.7574	1.0031
-4.0000	1.3950	-0.8935	0.1124	0.1146	1.4571
-6.0000	1.6113	-0.8615	0.1912	0.0843	2.0082
-8.0000	1.8879	-0.8245	0.3342	0.0316	2.7395
-10.0000	2.2116	-0.7512	0.4814	-0.0104	3.6513
-12.0000	2.4682	-0.7432	0.3621	0.1396	4.6846
-14.0000	2.6572	-0.7129	0.3655	0.1401	5.6961
-16.0000	2.7986	-0.6890	0.3450	0.1587	6.7253
-18.0000	2.8836	-0.6725	0.0113	0.4627	7.6535
-20.0000	2.5802	-0.6674	-0.2951	0.6733	8.4101
-22.0000	2.7642	-0.6765	0.2160	-0.0046	8.8327
-24.0000	2.5529	-0.6943	0.0125	0.0632	8.9848
-26.0000	2.3499	-0.7190	-0.0290	-0.0329	8.8610
-25.0000	2.0816	-0.7483	-0.1136	-0.0763	8.4811
-30.0000	1.6424	-0.7974	-0.7415	0.1380	7.2740
-32.0000	1.2026	-0.8454	5.7005	-6.4216	5.8319
-34.0000	0.7929	-0.8574	0.1751	-0.9432	4.2958
-36.0000	0.3485	-0.9238	-1.5591	0.6056	2.3592
-38.0000	-0.1199	-1.0703	-0.7053	-0.4119	0.1487
-40.0000	-0.6755	-1.0998	-1.1874	-0.3370	-2.9002
-42.0000	-1.2210	-1.1592	-1.5246	-0.1215	-6.1926
-44.0000	-1.7866	-1.2249	-2.7999	1.0078	-9.7770
-46.0000	-2.2272	-1.2794	-1.0106	-0.5771	-12.9524

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-48.0000	-2.6760	-1.3361	-1.7923	0.0607	-16.4154
-50.0000	-3.2554	-1.4191	-1.7650	-0.5209	-20.9871
-52.0000	-4.0782	-1.5073	-3.5735	0.5325	-27.0693
-54.0000	-4.3666	-1.5545	-4.9995	3.1750	-30.7165
-56.0000	-4.7664	-1.6075	-1.7855	-0.2958	-34.8792
-58.0000	-5.2197	-1.6670	-1.9516	-0.4280	-39.6382
-60.0000	-5.7273	-1.7341	-2.4196	-0.3056	-45.0886
-62.0000	-6.2994	-1.8097	-2.9651	-0.1617	-51.3417
-64.0000	-6.9451	-1.8952	-3.6659	0.0723	-58.5259
-66.0000	-7.6753	-1.9919	-4.1922	0.0547	-66.8040
-68.0000	-8.5027	-2.1016	-5.2160	0.4439	-76.3482
-70.0000	-9.2574	-2.2019	-5.2565	0.6321	-85.6571
-72.0000	-9.8218	-2.2785	-4.9805	0.9900	-93.6386
-74.0000	-10.4400	-2.3597	-4.5216	0.2113	-102.2592
-76.0000	-11.0836	-2.4455	-4.2002	-0.4522	-111.5638
-78.0000	-11.7648	-2.5364	-4.4537	-0.5653	-121.6018
-80.0000	-12.4654	-2.6325	-5.1684	-0.2420	-132.4242
-82.0000	-13.2477	-2.7342	-6.0132	0.1521	-144.0866
-84.0000	-14.0539	-2.8417	-5.7985	-0.4818	-156.6470
-86.0000	-14.9064	-2.9554	-6.5371	-0.2234	-170.1678
-88.0000	-15.8077	-3.0756	-7.0772	-0.1966	-184.7156
-90.0000	-16.7602	-3.2027	-9.0749	1.2529	-200.3595
-92.0000	-17.7669	-3.3370	-8.8612	0.4535	-217.1749
-94.0000	-18.8304	-3.4798	-8.6732	-0.3595	-235.2404
-96.0000	-20.0256	-3.6385	-10.2899	0.1124	-255.5955
-98.0000	-21.3208	-3.8109	-11.4323	0.3207	-277.8194
-100.0000	-22.6965	-3.9942	-12.7930	0.7805	-301.8430
-102.0000	-24.1611	-4.1595	-13.2095	0.2254	-327.8115
-104.0000	-25.7202	-4.3974	-13.4125	-0.6170	-355.8706
-106.0000	-27.3802	-4.6187	-14.2195	-0.9387	-386.1868
-108.0000	-29.1736	-4.8578	-16.2759	-0.2857	-419.2101
-110.0000	-31.6123	-5.1529	-21.7843	0.0100	-462.8599
-112.0000	-34.2780	-5.5230	-25.5408	1.4284	-511.0937
-114.0000	-37.1922	-5.9263	-27.2759	0.5612	-564.5134
-116.0000	-40.3802	-6.3512	-28.6959	-0.9106	-623.7324
-118.0000	-43.8701	-6.8163	-31.6385	-1.1953	-689.3999
-120.0000	-48.4892	-7.4319	-43.7452	0.9492	-774.9919
-122.0000	-53.7139	-8.1280	-48.3345	-0.6189	-872.8987
-124.0000	-59.5752	-8.9091	-54.3645	-1.2435	-984.1145
-126.0000	-66.1575	-9.7863	-63.9467	0.7198	-1110.5680

STATEMENTS EXECUTED= 1896595

CORE USAGE OBJECT CODE= 19784 BYTES,ARRAY AREA= 8016 BYTES, BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.92 SEC,EXECUTION TIME= 202.41 SEC, 21.39.13 WATFIV - MAR

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Sample Ingot 36

Metal Chemistry - C 4.04 %, Si 2.51 %, C.E. 4.88 %,
Mn 0.65 %, Cr 0.11 %, Cu 0.05 %,
Al 0.015 %, Mg 0.021 %, S 0.006 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
20.0000	41.8974	4.4949	-744.3003	-0.2458	-65.4598
18.0000	25.8599	2.8608	18.2036	-0.2257	-29.5037
16.0000	20.2980	1.5731	12.0097	0.0139	-5.4568
14.0000	12.8272	0.6978	6.2929	0.2150	7.5588
12.0000	8.8767	0.0315	3.0735	0.2083	14.1226
10.0000	5.5843	-0.4063	-2.8739	-0.0079	8.3589
8.0000	3.8092	-0.6419	-1.7506	0.0231	4.9039
6.0000	2.7251	-0.7879	-0.9372	-0.0262	2.9772
4.0000	1.8129	-0.8955	-0.5204	-0.1111	1.7142
2.0000	1.1604	-0.9169	-0.2425	-0.1183	0.9920
0.0000	1.0000	-1.3856	-0.7375	0.2461	0.0093
-2.0000	1.2021	-0.9276	2.3655	-1.8666	1.0073
-4.0000	1.4060	-0.8941	0.1120	0.1174	1.4060
-6.0000	1.6181	-0.8612	0.1886	0.0866	2.0165
-8.0000	1.9006	-0.8236	0.3393	0.0305	2.7560
-10.0000	2.2328	-0.7793	0.5246	-0.0462	3.7127
-12.0000	2.5908	-0.7306	0.4323	0.1551	4.8873
-14.0000	2.8581	-0.6865	0.4850	0.1489	6.1551
-16.0000	3.1990	-0.6433	0.5259	0.1827	7.5724
-18.0000	3.4845	-0.6021	-0.5809	1.3508	9.1121
-20.0000	3.7452	-0.5643	0.8842	-0.0716	10.7371
-22.0000	3.8233	-0.5492	0.6071	0.0051	11.9615
-24.0000	3.5616	-0.5765	0.0108	0.0761	12.1353
-26.0000	3.2130	-0.6154	-0.0089	-0.0648	11.5678
-28.0000	2.7684	-0.6666	-0.2632	-0.1424	11.0563
-30.0000	2.2642	-0.7250	-0.7189	0.0756	9.7698
-32.0000	1.7854	-0.7799	-6.3916	5.0691	8.3244
-34.0000	1.3321	-0.8308	0.3322	-1.1238	6.7411
-36.0000	0.8501	-0.8821	-2.1114	1.1319	4.7822
-38.0000	0.2682	-0.9243	-0.7052	-0.3958	2.5801
-40.0000	-0.1449	-1.0605	-0.9711	-0.3326	-0.0273
-42.0000	-0.7589	-1.1077	-1.6025	-0.1579	-3.5478
-44.0000	-1.3729	-1.1758	-2.6534	0.7512	-7.3524
-46.0000	-1.9057	-1.2400	-1.2601	-0.5549	-10.9825
-48.0000	-2.4093	-1.3027	-1.8519	-0.0120	-14.7103
-50.0000	-3.0969	-1.3903	-2.0538	-0.0635	-19.9449
-52.0000	-3.6169	-1.4574	-2.9752	0.7624	-24.3725
-54.0000	-3.8634	-1.4897	14.4609	-15.8231	-27.0979
-56.0000	-4.1293	-1.5249	-1.2244	-0.2623	-30.1113
-58.0000	-4.4157	-1.5632	-1.2889	-0.3801	-33.4494
-60.0000	-4.7339	-1.6049	-1.5738	-0.2758	-37.1486
-62.0000	-5.0777	-1.6504	-1.8847	-0.1666	-41.2510
-64.0000	-5.4525	-1.7001	-2.3617	0.0849	-45.8046
-66.0000	-5.8625	-1.7545	-2.5949	0.0658	-50.8625

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-68.0000	-6.2105	-1.8139	-3.2806	0.4690	-56.4858
-70.0000	-6.8007	-1.8789	-3.8258	0.6976	-62.7422
-72.0000	-7.3376	-1.9502	-4.5041	1.0210	-69.7083
-74.0000	-7.9263	-2.0254	-4.1975	0.3161	-77.4710
-76.0000	-8.5723	-2.1142	-3.9198	-0.4090	-86.1286
-78.0000	-9.2818	-2.2085	-4.2717	-0.5599	-95.7917
-80.0000	-10.0620	-2.3122	-5.1100	-0.2871	-106.5859
-82.0000	-10.9206	-2.4264	-6.2535	0.2195	-118.6539
-84.0000	-11.8664	-2.5522	-6.2954	-0.4560	-132.1506
-86.0000	-12.8043	-2.6770	-6.6998	-0.2581	-146.0724
-88.0000	-13.8567	-2.7906	-6.4699	-0.2370	-159.4861
-90.0000	-14.5692	-2.9122	-8.4793	1.1845	-174.0759
-92.0000	-15.5463	-3.0424	-8.3434	0.4089	-189.9449
-94.0000	-16.5928	-3.1819	-8.2497	-0.3804	-207.2048
-96.0000	-17.7140	-3.3313	-9.5131	0.1266	-225.9778
-98.0000	-18.9153	-3.4914	-10.5390	0.3297	-246.3963

-100.0000	-20.2029	-3.6630	-11.8775	0.7735	-268.6042
-102.0000	-21.5631	-3.8470	-12.4113	0.3340	-292.7598
-104.0000	-23.0630	-4.0442	-12.5868	-0.5503	-319.0339
-106.0000	-25.0667	-4.3111	-16.3338	-0.8978	-353.4973
-108.0000	-27.4276	-4.6256	-19.9543	-0.3836	-394.1738
-110.0000	-30.0435	-4.9741	-22.6901	-0.1469	-439.8477
-112.0000	-32.9446	-5.3606	-27.1164	1.4527	-491.1750
-114.0000	-36.1650	-5.7896	-29.4579	0.5941	-548.9026
-116.0000	-40.2846	-6.3384	-35.8757	-0.7993	-622.2529
-118.0000	-46.0819	-7.1107	-49.5325	-1.4368	-724.1917
-120.0000	-52.8406	-8.0111	-61.2401	1.0358	-844.6003
-122.0000	-60.7357	-9.0631	-70.4290	-0.8193	-987.0972
-124.0000	-70.4417	-10.3563	-86.9609	-1.3590	-1163.7360
-126.0000	-84.7952	-12.2689	-120.7439	0.8045	-1423.6150

STATEMENTS EXECUTED= 1696388

CORE USAGE OBJECT CODE= 18432 BYTES,ARRAY AREA= 5016 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.97 SEC,EXECUTION TIME= 195.59 SEC, 21.17.3 WATFIV - MAR

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Sample Ingot 37

Metal Chemistry - C 4.19 %, Si 2.35 %, C.E. 4.97 %,
Mn 0.59 %, Cr 0.09 %, Cu 0.04 %,
Al 0.016 %, Mg 0.023 %, S 0.003 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
22.0000	70.3053	5.3457	-907.6702	-0.2163	-156.6523
20.0000	45.6839	5.5539	35.3164	-0.2260	-36.4719
18.0000	34.9170	3.5533	22.4055	-0.0230	-41.7062
16.0000	24.6829	2.1658	13.2874	0.1929	-14.7456
14.0000	17.3766	1.1734	7.7359	0.2012	1.1256
12.0000	12.0845	0.4531	4.6311	-0.3178	0.7552
10.0000	7.2420	-0.1994	0.5370	-0.0506	10.6680
8.0000	4.2774	-0.5697	-2.6073	-0.0084	5.4366
6.0000	2.7969	-0.7517	-1.0719	-0.1267	3.0393
4.0000	1.9848	-0.8912	-0.4786	-0.1303	1.8209
2.0000	1.2310	-0.9344	-0.2967	-0.1257	1.0161
0.0000	1.0000	-1.3856	-0.6822	0.1779	0.0074
-2.0000	1.2498	-0.9387	0.7039	-0.1962	1.0230
-4.0000	1.4995	-0.8962	0.1300	0.1186	1.5203
-6.0000	1.8057	-0.8525	0.2589	0.0685	2.1750
-8.0000	2.1991	-0.8002	0.5763	-0.1202	3.0871
-10.0000	2.6349	-0.7405	0.4236	0.1649	4.2643
-12.0000	3.0246	-0.6843	0.5399	0.1259	5.5959
-14.0000	3.4080	-0.6259	0.6323	0.1307	7.1217
-16.0000	3.7692	-0.5765	1.2581	-0.4173	8.8033
-18.0000	4.0913	-0.5292	1.5807	-0.6907	10.5832
-20.0000	4.3602	-0.4892	0.7259	0.1771	12.3894
-22.0000	4.5582	-0.4585	0.9782	-0.1075	14.1306
-24.0000	4.6722	-0.4389	1.8940	-1.1055	15.7077
-26.0000	4.6956	-0.4309	-0.5617	1.2300	17.0444
-28.0000	4.6388	-0.4346	0.0406	0.4700	18.0656
-30.0000	4.4932	-0.4496	0.1722	0.1524	18.7149
-32.0000	4.2351	-0.4793	0.0225	0.0229	18.8059
-34.0000	3.6226	-0.5525	0.3627	-1.1684	17.1945
-36.0000	3.0279	-0.6266	7.1753	-8.1466	15.2517
-38.0000	2.4524	-0.6963	-0.6926	-0.3649	13.1370
-40.0000	1.8952	-0.7632	-0.8458	-0.3158	10.8138
-42.0000	1.3101	-0.8317	-1.2233	-0.1642	8.0387
-44.0000	0.7251	-0.8960	-1.9815	0.4402	4.9562
-46.0000	0.1401	-0.9376	-1.0632	-0.6129	1.6041

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-48.0000	-0.4610	-1.0775	-1.9532	0.0298	-2.2427
-50.0000	-1.0670	-1.1410	-1.4294	-0.6553	-6.4119
-52.0000	-1.6152	-1.2061	-2.8521	0.8105	-10.4953
-54.0000	-2.1195	-1.2686	-3.7820	1.7526	-14.5542
-56.0000	-2.8340	-1.3591	-2.6716	-0.2760	-20.4402
-58.0000	-3.2006	-1.4065	-1.3753	-0.4190	-24.0379
-60.0000	-3.4768	-1.4426	-1.2699	-0.2609	-27.0996
-62.0000	-3.7876	-1.4833	-1.5707	-0.1767	-30.5944
-64.0000	-4.1380	-1.5293	-2.3430	0.3441	-34.5923
-66.0000	-4.5336	-1.5813	-2.3687	0.0772	-39.1755
-68.0000	-4.9812	-1.6402	-2.9941	0.3615	-44.4406
-70.0000	-5.4886	-1.7072	-3.6244	0.5936	-50.5321
-72.0000	-6.0648	-1.7833	-4.3832	0.8865	-57.4955
-74.0000	-6.7207	-1.8700	-4.6803	0.6373	-65.5815
-76.0000	-7.4687	-1.9690	-4.7375	0.0532	-74.9504
-78.0000	-8.3236	-2.0822	-4.9086	-0.5312	-85.8299
-80.0000	-9.3028	-2.2120	-5.7664	-0.5640	-98.4909
-82.0000	-10.0212	-2.3076	-5.1685	0.0019	-108.8243
-84.0000	-10.7079	-2.3990	-5.2319	0.0513	-119.1852
-86.0000	-11.4471	-2.4974	-5.2207	-0.4438	-130.5143
-88.0000	-12.2431	-2.6034	-5.7349	-0.4608	-142.9058
-90.0000	-13.1008	-2.7177	-6.2331	-0.5445	-156.4608
-92.0000	-14.0253	-2.8408	-6.9327	1.5167	-171.2928
-94.0000	-15.0141	-2.9725	-7.6603	-0.4052	-157.4238
-96.0000	-16.0718	-3.1134	-8.3048	0.0351	-204.9632
-98.0000	-17.2114	-3.2652	-9.8612	0.2740	-224.1377
-100.0000	-18.4399	-3.4289	-11.0919	0.0086	-245.1044
-102.0000	-19.7646	-3.6054	-12.4225	0.9575	-268.0344
-104.0000	-21.1939	-3.7958	-12.6923	0.1498	-293.1194
-106.0000	-22.7362	-4.0014	-13.2613	-0.4617	-320.5664
-108.0000	-24.4014	-4.2233	-14.1339	-0.8854	-350.6050
-110.0000	-27.3162	-4.6114	-24.2899	-0.3356	-399.8562
-112.0000	-30.7081	-5.0631	-29.1086	0.1444	-457.7547
-114.0000	-34.6256	-5.5549	-35.1106	1.2407	-525.5242
-116.0000	-40.6668	-6.3893	-52.0415	0.7220	-625.1633
-118.0000	-47.7176	-7.3285	-60.2541	-0.6247	-749.9209
-120.0000	-55.8754	-8.4152	-70.0647	-1.5486	-593.1472
-122.0000	-65.6298	-9.7149	-87.7307	0.9590	-1066.6900
-124.0000	-76.5029	-11.1637	-97.6371	-0.9811	-1263.9260
-126.0000	-86.1964	-12.4555	-90.1220	-1.4896	-1447.1490
-125.0000	-97.2703	-13.9315	-106.7055	0.7288	-1659.1040

STATEMENTS EXECUTED= 2046562

CORE USAGE OBJECT CODE= 18794 BYTES,ARRAY AREA= 8016 BYTES5 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

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Sample Ingot 38

Metal Chemistry - C 3.98 %, Si 2.32 %, C.E. 4.75 %,
Mn 0.60 %, Cr 0.10 %, Cu 0.05 %,
Al 0.015 %, Mg 0.018 %, S 0.004 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
32.0000	75.2747	8.9794	-926.9529	-0.1546	-250.3191
30.0000	49.2292	5.4744	60.5485	-0.2066	-129.6344
28.0000	33.5284	3.3723	33.6504	0.0619	-62.2095
26.0000	23.4320	2.0224	19.6096	-0.0668	-22.7261
24.0000	16.7803	1.1344	11.4738	0.0370	0.2954
22.0000	11.6229	0.4495	7.2891	0.2063	15.2963
20.0000	8.1180	-0.0144	3.1113	0.2762	22.0611
18.0000	4.2375	-0.5116	-5.7965	0.2347	10.9375
16.0000	1.5741	-0.8181	-3.2334	-0.2024	4.0662
14.0000	1.1681	-0.8553	-0.4416	-0.1500	2.8632
12.0000	1.0933	-0.8615	-0.1254	-0.0875	2.4516
10.0000	1.0755	-0.8639	-0.1674	0.0098	2.1365
8.0000	1.0587	-0.8659	-0.0448	-0.1075	1.8318
6.0000	1.0425	-0.8679	-0.0514	-0.0963	1.5364
4.0000	1.0187	-0.8688	-0.0554	-0.0904	1.2445
2.0000	1.0046	-0.8654	-0.0634	-0.0891	0.9395
0.0000	1.0000	-1.3856	-8.2326	7.8173	0.0088
-2.0000	0.9946	-0.8647	0.4315	0.0322	0.9363
-4.0000	0.9946	-0.8660	0.0693	0.0793	1.2315
-6.0000	0.9946	-0.8665	0.1749	-0.0418	1.4977
-8.0000	0.9946	-0.8657	-0.1078	0.2404	1.7629
-10.0000	0.9940	-0.8668	0.0621	0.0705	2.0252
-12.0000	0.9946	-0.8669	0.0962	0.0365	2.2933
-14.0000	0.9943	-0.8670	0.0582	0.0742	2.5582
-16.0000	0.9941	-0.8671	0.0925	0.0396	2.8226
-18.0000	0.9938	-0.8671	-0.2541	0.4163	3.0871
-20.0000	0.9939	-0.8672	0.0513	0.0512	3.3524
-22.0000	0.9941	-0.8672	0.0533	0.0796	3.6184
-24.0000	0.9944	-0.8672	0.0774	0.0555	3.8844
-26.0000	0.9669	-0.8698	0.0425	0.0423	4.0546
-28.0000	0.8043	-0.8849	-0.2881	0.1140	3.7051
-30.0000	0.6417	-0.8995	-0.1349	-0.0319	3.2727
-32.0000	0.4791	-0.9129	-0.1672	-0.0915	2.7555
-34.0000	0.2165	-0.9234	-0.2214	-0.0776	2.1576
-36.0000	0.1539	-0.9261	0.1240	-0.4565	1.4924
-38.0000	0.0000	-1.0000	-0.6200	0.2250	0.7025

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-40.0000	-0.5756	-1.0975	-1.1304	-0.4026	-2.3637
-42.0000	-1.1220	-1.1469	-2.5383	1.2297	-5.5809
-44.0000	-1.6685	-1.2175	-1.7154	-0.0327	-9.0531
-46.0000	-2.2149	-1.2779	-2.0520	0.1850	-12.8752
-48.0000	-2.0625	-1.3344	-5.2828	3.5571	-16.3256
-50.0000	-3.0658	-1.3855	-1.4961	-0.2119	-19.7424
-52.0000	-3.5659	-1.4527	-1.9429	-0.1979	-24.0041
-54.0000	-4.1772	-1.5301	-2.9257	0.2515	-29.3525
-56.0000	-4.9331	-1.6253	-3.1595	-0.2172	-36.1059
-58.0000	-5.2946	-1.6767	-1.8011	-0.2533	-40.2149
-60.0000	-5.6578	-1.7250	-1.9009	-0.2573	-44.5313
-62.0000	-6.0495	-1.7771	-2.3521	-0.0207	-49.2759
-64.0000	-6.4722	-1.8333	-3.2593	0.6500	-54.4958
-66.0000	-6.9256	-1.8940	-3.9137	1.0437	-60.2359
-68.0000	-7.4215	-1.9595	-3.7553	0.5978	-66.5577
-70.0000	-7.9542	-2.0304	-2.9539	-0.5206	-73.5000
-72.0000	-8.5301	-2.1070	-3.4284	-0.3958	-81.1483
-74.0000	-9.1332	-2.1900	-3.8641	-0.3422	-89.5658
-76.0000	-9.8275	-2.2797	-4.6531	0.0165	-98.8416
-78.0000	-10.5560	-2.3749	-5.4319	0.3244	-109.0559
-80.0000	-11.3494	-2.4823	-5.2559	-0.3614	-120.3137
-82.0000	-12.2073	-2.5965	-6.0353	-0.1668	-132.7147
-84.0000	-13.1378	-2.7204	-6.5169	-0.3204	-146.3896
-86.0000	-14.1477	-2.8549	-7.4079	-0.1323	-161.4699
-88.0000	-15.1713	-2.9013	-10.3320	2.4415	-177.2506
-90.0000	-16.0795	-3.1124	-8.6703	1.1992	-192.1929
-92.0000	-17.0394	-3.2434	-7.5534	-0.4760	-208.2527
-94.0000	-18.0535	-3.3757	-7.9719	-0.6544	-225.5049
-96.0000	-19.1250	-3.5156	-9.3527	0.0904	-244.0313
-98.0000	-20.2567	-3.6695	-10.5909	0.0484	-263.9105
-100.0000	-21.4519	-3.8249	-10.4548	-0.2131	-285.2520
-102.0000	-22.7140	-3.9972	-10.8325	-0.6084	-308.1340
-104.0000	-24.0463	-4.1749	-11.4713	-0.7935	-332.6636
-106.0000	-25.5645	-4.4305	-15.5877	-1.1720	-366.1831
-108.0000	-26.8769	-4.8183	-20.9744	2.5469	-415.0391
-110.0000	-32.1695	-5.2568	-28.4884	0.4971	-471.0208
-112.0000	-35.9973	-5.7567	-32.2416	0.3757	-536.7524
-114.0000	-40.6495	-6.3464	-39.6746	-0.4755	-617.0530
-116.0000	-45.9958	-7.0936	-44.8713	-1.8859	-710.5671
-118.0000	-52.1504	-7.9186	-54.6872	0.1470	-819.6475
-120.0000	-60.4044	-9.0183	-73.0257	0.0517	-965.5957
-122.0000	-70.9873	-10.4234	-94.9615	0.3504	-1153.5170
-124.0000	-83.6797	-12.1196	-114.5734	0.2043	-1382.5560
-126.0000	-96.7183	-13.8572	-121.0370	0.3759	-1623.8750

STATEMENTS EXECUTED= 2369231

CORE USAGE   OBJECT CODE=   15424 BYTES.ARRAY AREA=   5016 BYTES   BYTES

DIAGNOSTICS   NUMBER OF ERRORS=   0. NUMBER OF WARNINGS=   0

COMPILE TIME=   0.93 SEC.EXECUTION TIME=   259.57 SEC.   12.34.1   WATFIV - MAR

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Sample Ingot 39

Metal Chemistry - C 3.80 %, Si 2.50 %, C.E. 4.63 %,
Mn 0.80 %, Cr 0.12 %, Cu 0.10 %,
Al 0.020 %, Mg 0.039 %, S 0.008 %.

X(I)	Y(I)	P(I)	C(ODD)	C(EVEN)	SUM(C(I))
26.0000	101.8334	12.5832	-799.9160	-0.2510	-295.8386
24.0000	82.1295	9.9317	43.4999	-0.2056	-239.2502
22.0000	64.7044	7.5827	34.5899	0.0014	-139.9490
20.0000	47.5956	5.2700	29.3977	0.1581	-80.6360
18.0000	32.6525	3.2455	22.0776	0.2244	-36.2324
16.0000	21.1389	1.6931	14.2680	0.1807	-7.3351
14.0000	13.1513	0.6051	8.3118	-0.2622	8.7640
12.0000	7.2602	-0.1529	2.0084	-0.0296	12.7216
10.0000	4.4244	-0.5471	-2.9548	-0.0497	6.7127
8.0000	3.0991	-0.7167	-1.1976	-0.1098	4.0979
6.0000	2.3216	-0.8292	-0.6173	-0.1208	2.6217
4.0000	1.6215	-0.8972	-0.4582	-0.0554	1.5946
2.0000	1.1284	-0.9042	-0.2434	-0.0642	0.9796
0.0000	1.0000	-1.3956	-9.3653	8.9795	0.0051
-2.0000	1.0536	-0.8953	0.5869	-0.1138	0.9545
-4.0000	1.1255	-0.8793	0.0823	0.0926	1.3042
-6.0000	1.2036	-0.8699	0.2074	-0.0260	1.6670
-8.0000	1.2868	-0.8595	0.1317	0.0737	2.0778
-10.0000	1.3791	-0.8477	0.1304	0.1033	2.5454
-12.0000	1.4817	-0.8347	0.9553	-0.7186	3.0786
-14.0000	1.5960	-0.8200	0.1149	0.1900	3.6884
-16.0000	1.7234	-0.8037	0.1483	0.2010	4.3871
-18.0000	1.8655	-0.7853	0.2406	0.1606	5.1894
-20.0000	2.0245	-0.7647	0.3575	0.1019	6.1123
-22.0000	2.2025	-0.7416	0.6134	-0.0815	7.1751
-24.0000	2.3639	-0.7200	-1.8157	2.3684	8.2513
-26.0000	2.4121	-0.7117	0.3754	0.3230	9.0780
-28.0000	2.4419	-0.7058	0.3025	0.0743	9.8314
-30.0000	2.4525	-0.7024	0.2086	0.1378	10.5242
-32.0000	2.4437	-0.7017	3.6369	-3.3292	11.1395
-34.0000	2.4157	-0.7035	0.1492	0.1127	11.6634
-36.0000	2.3692	-0.7075	1.4102	-1.2002	12.0930
-38.0000	2.3650	-0.7071	-0.3132	0.6181	12.6929
-40.0000	2.3827	-0.7039	0.1770	0.1554	13.4131
-42.0000	2.3916	-0.7017	0.0449	0.2952	14.1025
-44.0000	2.3913	-0.7008	-0.0773	0.3952	14.7356

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-46.0000	2.3821	-0.7011	0.0626	0.2276	15.3191
-48.0000	2.3639	-0.7025	-0.2745	0.5338	15.8376
-50.0000	2.3370	-0.7052	0.0950	0.1303	16.2683
-52.0000	2.3017	-0.7090	0.2751	-0.0162	16.6664
-54.0000	2.2584	-0.7138	0.0631	0.0875	16.9677
-56.0000	1.9171	-0.7559	-0.6906	-0.2836	15.0196
-58.0000	1.5618	-0.7994	-0.9239	-0.1955	12.7807
-60.0000	1.2524	-0.8358	-0.8970	-0.1322	10.7212
-62.0000	0.9416	-0.8735	-0.9605	-0.1576	8.4849
-64.0000	0.6008	-0.9119	-1.2747	-0.0526	5.8302
-66.0000	0.2601	-0.9447	-1.5985	0.1857	3.0040
-68.0000	-0.2367	-1.0525	-2.6246	0.4078	-1.4297
-70.0000	-1.2367	-1.1619	-5.2035	0.4979	-10.8409
-72.0000	-2.0961	-1.2691	-4.4524	0.1640	-19.4150
-74.0000	-3.0762	-1.3949	-5.3314	0.2194	-29.6420
-76.0000	-3.6385	-1.4641	-2.9995	-0.1065	-35.8538
-78.0000	-4.2618	-1.5495	-3.6671	-0.2098	-43.6077
-80.0000	-5.0678	-1.6552	-4.6675	-0.1972	-53.3376
-82.0000	-6.0673	-1.7307	-6.0620	-0.0757	-65.6127
-84.0000	-7.3135	-1.9511	-7.4667	-0.3156	-81.1932
-86.0000	-8.8759	-2.1577	-9.4565	-0.4433	-101.0427
-88.0000	-10.8456	-2.4185	-13.4587	0.7234	-126.5132
-90.0000	-12.9633	-2.6995	-15.3819	1.2328	-154.8115
-92.0000	-14.0907	-2.8495	-7.9040	-0.7387	-172.0968
-94.0000	-15.3342	-3.0149	-8.7521	-0.8563	-191.4336
-96.0000	-16.7064	-3.1976	-10.5376	-0.2973	-213.0833
-98.0000	-18.2223	-3.3994	-12.3051	0.1754	-237.3426
-100.0000	-19.9987	-3.6226	-14.3799	0.7064	-264.5493
-102.0000	-21.7544	-3.8697	-15.7609	0.4918	-295.0876
-104.0000	-23.8815	-4.1530	-17.4260	-0.2203	-330.3799
-106.0000	-26.2984	-4.4749	-19.7446	-0.5161	-370.9011
-108.0000	-28.9987	-4.8345	-22.5144	0.8692	-416.7913
-110.0000	-32.0190	-5.2369	-25.6462	-0.3654	-468.8145
-112.0000	-35.4012	-5.6874	-29.8152	0.2964	-527.8518
-114.0000	-39.1929	-6.1926	-33.6360	0.1539	-594.9160
-116.0000	-43.7679	-6.8021	-39.9396	-0.6615	-676.1150
-118.0000	-49.7778	-7.6027	-51.3723	-1.7330	-782.3269
-120.0000	-56.7352	-8.5297	-63.6658	1.3791	-906.9005
-122.0000	-63.9147	-9.4864	-64.8153	-1.1293	-1039.7950
-124.0000	-70.4407	-10.3562	-61.3571	-1.1047	-1163.7150
-126.0000	-77.7055	-11.3245	-71.2999	0.8907	-1304.5370

```
STATEMENTS EXECUTED= 2124151

CORE JSAGE        OBJECT CODE=   13424 BYTES,ARRAY AREA=    8016 BYTE  BYTES

DIAGNOSTICS        NUMBER OF ERRORS=        0. NUMBER OF WARNINGS=      0

COMPILE TIME=    0.88 SEC,EXECUTION TIME=   232.55 SEC.     13.47.2 WATFIV - MAR 19.

      CSEOF
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Sample Ingot 40

Metal Chemistry - C 3.55 %, Si 2.70 %, C.E. 4.45 %,
Mn 0.75 %, Cr 0.12 %, Cu 0.12 %,
Al 0.020 %, Mg 0.033 %, S 0.010 %.

-46.0000	4.4025	-0.4446	-0.9487	-0.2024	27.7255
-48.0000	3.8066	-0.5199	-1.0942	-0.2294	25.0815
-50.0000	3.2341	-0.5920	-12.3358	10.9324	22.2747
-52.0000	2.7001	-0.6589	-0.0050	-1.4164	19.4297
-54.0000	2.1613	-0.7260	563.8101	-565.3914	16.2693
-56.0000	1.5932	-0.7959	-1.5820	-0.2529	12.5999
-58.0000	1.0000	-0.8667	-2.4537	0.3716	8.4355
-60.0000	0.4565	-0.9259	-2.0542	0.0173	4.3616
-62.0000	-0.4103	-1.0690	-3.2990	-0.2235	-2.6836
-64.0000	-1.4236	-1.3092	-5.6863	0.0414	-17.9731
-66.0000	-4.5236	-1.5800	-9.1633	-0.3937	-39.0872
-68.0000	-5.5201	-1.7105	-4.7410	-0.3769	-49.3228
-70.0000	-6.7971	-1.8785	-5.9759	-0.7134	-62.7075
-72.0000	-8.4454	-2.0959	-5.0976	-0.7165	-80.3354
-74.0000	-10.5855	-2.3793	-11.6549	-0.0388	-103.7231
-76.0000	-12.3956	-2.7512	-17.1705	1.5419	-134.9802
-78.0000	-15.6612	-3.0520	-14.8100	1.2471	-162.1057
-80.0000	-18.0361	-3.3743	-15.4818	0.4654	-192.1384
-82.0000	-20.9633	-3.7569	-19.1387	1.0044	-229.4072
-84.0000	-24.3875	-4.2124	-19.7451	-2.2189	-272.3350
-86.0000	-28.4754	-4.7564	-25.9089	-0.7723	-325.6970
-88.0000	-33.4554	-5.4193	-33.8205	0.8175	-391.7029
-90.0000	-39.4633	-6.2192	-42.5752	2.0790	-472.7014
-92.0000	-46.7294	-7.1866	-49.0947	-0.7080	-572.3066
-94.0000	-55.1420	-8.3072	-59.8096	0.8720	-690.1819
-96.0000	-63.3782	-9.4045	-61.9332	1.8870	-810.2739
-98.0000	-72.0054	-10.6875	-70.2396	-1.1071	-952.9673

STATEMENTS EXECUTED= 1619031

CORE USAGE OBJECT CODE= 17546 BYTES,ARRAY AREA= 8008 BYTES BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.88 SEC,EXECUTION TIME= 166.76 SEC, 10.35.0 ATFIV - MAR 19

C$ECF

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X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
40.0000	66.0575	7.7314	-608.8711	0.1966	-264.3679
38.0000	50.0850	5.5968	47.1346	0.0159	-170.0669
36.0000	38.2446	4.0150	22.9192	0.0145	-104.1992
34.0000	29.4110	2.8355	22.9911	-0.0554	-58.3279
32.0000	22.7784	1.9504	16.0135	-0.1440	-26.5889
30.0000	19.1164	1.4606	8.1505	0.0597	-10.1685
28.0000	18.1418	1.3265	2.0600	0.2513	-3.5459
26.0000	17.1529	1.1909	1.7244	0.3377	-1.4214
24.0000	15.9996	1.0313	1.8254	0.2416	2.7138
22.0000	14.2244	0.7901	2.5343	0.0920	7.9714
20.0000	12.3669	0.5377	2.4209	-0.1772	12.4590
18.0000	10.7132	0.3118	7.8648	-4.3657	15.4573
16.0000	8.9626	0.0732	-0.4834	1.5689	17.6284
14.0000	6.0756	-0.3074	-2.6201	-0.0947	12.1992
12.0000	4.2654	-0.5433	-2.5589	0.2744	7.6299
10.0000	3.1388	-0.6885	-1.3180	-0.0182	4.9575
8.0000	2.3908	-0.7839	-0.7819	-0.0469	3.3000
6.0000	1.9185	-0.8467	-0.5510	0.0363	2.2708
4.0000	1.5144	-0.8964	-0.4836	0.1123	1.5251
2.0000	1.1093	-0.9026	0.0829	-0.3613	0.9712
0.0000	1.0000	-1.3856	0.0729	-0.5554	0.0063
-2.0000	1.1470	-0.9133	0.3505	0.1385	0.9844
-4.0000	1.2939	-0.8898	0.1190	0.0874	1.3970
-6.0000	1.4484	-0.8667	1.0093	-0.7730	1.8694
-8.0000	1.6415	-0.8412	0.1052	0.1930	2.4656
-10.0000	1.8619	-0.8119	0.1225	0.2454	3.2012
-12.0000	2.1392	-0.7761	-0.0643	0.5370	4.1465
-14.0000	2.5068	-0.7292	0.0675	0.5041	5.4097
-16.0000	2.9644	-0.6702	0.5113	0.3144	7.0623
-18.0000	3.5375	-0.5958	0.9884	0.0992	9.2375
-20.0000	4.2601	-0.5015	2.3304	-0.8899	12.1184
-22.0000	5.1770	-0.3812	1.3083	0.6111	15.9570
-24.0000	5.6686	-0.3134	1.6309	-0.1528	18.9131
-26.0000	5.9842	-0.2681	2.6475	0.0548	21.5178
-28.0000	6.2301	-0.2321	-2.5475	3.8038	24.0300
-30.0000	6.3966	-0.2067	1.0062	0.1560	26.3542
-32.0000	6.4655	-0.1942	0.9292	0.0702	28.3513
-34.0000	6.4223	-0.1966	0.6919	0.0692	29.8738
-36.0000	6.2872	-0.2113	0.4130	0.1163	30.9324
-38.0000	6.0662	-0.2373	0.1925	0.0831	31.4834
-40.0000	5.7686	-0.2736	0.0037	0.0387	31.5085
-42.0000	5.4066	-0.3184	-0.1280	-0.1194	31.0137
-44.0000	4.9942	-0.3699	-0.3143	-0.1772	30.0305

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Sample Ingot 41

Metal Chemistry - C 3.76 %, Si 2.60 %, C.E. 4.63 %,
Mn 0.76 %, Cr 0.14 %, Cu 0.10 %,
Al 0.018 %, Mg 0.025 %, S 0.011 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
26.0000	102.2724	12.6429	-435.1772	-0.1792	-297.3825
24.0000	92.8658	10.0323	42.9768	-0.1130	-211.6560
22.0000	65.5387	7.6962	34.5977	0.0133	-142.4331
20.0000	48.5203	5.3954	29.3855	0.1667	-83.3241
18.0000	34.0532	3.4358	21.0240	0.2298	-39.6154
16.0000	22.6995	2.0323	12.3637	0.1158	-12.6575
14.0000	16.1543	1.0123	8.4535	-0.4579	3.2407
12.0000	10.7567	0.2772	4.2513	-0.0470	11.7405
10.0000	7.1808	-0.2072	-1.0089	0.4207	13.5549
8.0000	4.6257	-0.5296	-2.4049	0.1935	5.0424
6.0000	2.2272	-0.7419	-1.4419	0.1316	3.6220
4.0000	1.9400	-0.8925	-0.7479	-0.2005	1.7930
2.0000	1.1502	-0.9221	-0.2107	-0.1315	0.9338
0.0000	1.0000	-1.3856	-0.4805	-0.3144	0.0788
-2.0000	1.2592	-0.9471	-0.3201	0.5413	1.0394
-4.0000	1.5952	-0.8972	0.1251	0.1363	1.5422
-6.0000	1.9093	-0.8472	0.2564	0.0553	2.2553
-8.0000	2.2511	-0.7873	-2.9344	4.1305	3.2532
-10.0000	2.9203	-0.7175	0.5387	0.1562	4.6676
-12.0000	3.6511	-0.6144	0.9245	0.0516	5.6239
-14.0000	4.2227	-0.5217	0.3720	0.2465	8.3617
-16.0000	4.9071	-0.4291	1.2672	-0.0587	11.2661
-18.0000	5.4570	-0.3612	0.8940	0.4216	13.8972
-20.0000	5.9449	-0.2915	1.0345	0.3429	16.0541
-22.0000	6.3445	-0.2330	1.2601	0.1175	19.4170
-24.0000	6.6627	-0.1807	1.3311	-0.2277	22.1170
-26.0000	7.1504	-0.1136	1.3037	-0.1099	25.5446
-28.0000	7.5713	-0.0594	5.8532	-4.1190	29.0619
-30.0000	7.9099	-0.0112	-11.9463	13.0345	32.4372
-32.0000	8.1533	0.0243	3.8631	-2.2910	35.5776
-34.0000	8.2919	0.0458	1.9298	-0.5306	38.3759
-36.0000	8.3453	0.0560	0.8324	0.3947	40.8412
-38.0000	8.5943	0.0913	1.2999	0.4512	44.3233
-40.0000	8.7650	0.1160	1.4571	0.1426	47.5355
-42.0000	8.5622	0.1314	2.0591	-0.0379	50.4015
-44.0000	8.5744	0.1352	-0.5352	1.7500	52.8322
-46.0000	8.8041	0.1280	0.0571	0.0156	54.7573
-48.0000	8.6755	0.1129	0.8415	-0.0216	55.2944
-50.0000	8.5229	0.1340	43.3330	-42.1859	59.5790
-52.0000	8.9204	0.1484	2.5580	-1.2451	62.0059
-54.0000	8.9664	0.1559	1.1740	0.1792	65.3137

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-56.0000	8.9599	0.1564	1.0563	0.1147	67.6547
-58.0000	8.9013	0.1520	1.6201	-0.0530	69.5879
-60.0000	8.7914	0.1307	0.3323	-0.1363	71.0798
-62.0000	8.6222	0.1169	-0.0376	0.5463	72.1054
-64.0000	8.4264	0.0909	0.0656	0.2360	72.6455
-66.0000	8.1715	0.0553	0.0009	0.0002	72.[illegible]
-68.0000	7.8504	0.0159	0.6479	-1.0155	71.[illegible]
-70.0000	7.4960	-0.0298	-0.4827	-0.1264	70.6952
-72.0000	7.1141	-0.0783	-0.7064	-0.1288	69.0278
-74.0000	6.7106	-0.1306	-0.9138	-0.1323	66.9406
-76.0000	6.3472	-0.1777	-1.0261	0.0595	65.0452
-78.0000	6.0503	-0.2161	0.4755	-1.1772	63.5476
-80.0000	5.7388	-0.2564	-0.2713	-0.5846	61.9352
-82.0000	5.4164	-0.2952	0.8713	-1.8093	59.0401
-84.0000	5.0869	-0.3409	-0.8329	-0.2909	57.6923
-86.0000	4.7539	-0.3841	-0.8992	-0.3323	55.2293
-88.0000	4.4207	-0.4273	-2.2441	0.9225	52.5352
-90.0000	4.0906	-0.4701	-1.2325	-0.1596	47.8309
-92.0000	2.9901	-0.6132	-6.3922	0.1857	37.3870
-94.0000	2.0025	-0.7404	-5.1407	-0.0455	25.8037
-96.0000	0.8637	-0.8833	-7.3013	0.2781	11.7577
-98.0000	-0.3452	-1.0568	-7.2806	-0.4995	-3.5025
-100.0000	-1.7738	-1.2305	-8.0366	-0.9352	-22.0451
-102.0000	-3.1204	-1.4045	-9.1753	-0.2157	-41.7279
-104.0000	-4.3535	-1.5662	-8.9967	0.0324	-59.6552
-106.0000	-6.0212	-1.7931	-12.2532	0.0274	-84.0968
-108.0000	-7.0956	-1.9277	-9.5423	0.3640	-101.4535
-110.0000	-8.4312	-2.1346	-13.0383	0.2993	-122.9317
-112.0000	-10.0580	-2.3215	-14.0543	0.7114	-149.6195
-114.0000	-12.0323	-2.5838	-17.1603	0.5121	-182.9143
-116.0000	-14.5715	-2.9194	-20.7624	-0.0957	-224.6308
-118.0000	-17.6608	-3.3200	-22.5723	-2.5694	-277.1133
-120.0000	-21.2272	-3.8177	-31.2375	-0.0947	-340.6775
-122.0000	-25.1165	-4.3219	-33.7545	0.0957	-407.7932
-124.0000	-29.6885	-4.9305	-42.7146	1.5755	-490.0737
-126.0000	-35.2225	-5.6674	-51.7853	1.3482	-590.9478
-128.0000	-41.2205	-6.4795	-55.8302	-0.3954	-704.3947
-130.0000	-45.6275	-7.4529	-70.3717	1.5429	-842.0549
-132.0000	-57.4114	-8.6231	-81.2899	-2.4917	-1009.5940
-134.0000	-66.1631	-9.7593	-93.5317	-2.2932	-1181.2480
-136.0000	-75.7821	-11.0711	-96.6751	0.6340	-1373.2922

STATEMENTS EXECUTED= 2542916

CORE USAGE OBJECT CODE= 19424 BYTES,ARRAY AREA= 9016 BYTES [illegible] BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 1.00 SEC,EXECUTION TIME= 272.74 SEC, [illegible]

C$ECF

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Sample Ingot 42

Metal Chemistry - C 3.68 %, Si 2.74 %, C.E. 4.59 %,
Mn 0.70 %, Cr 0.12 %, Cu 0.13 %,
Al 0.020 %, Mg 0.050 %, S 0.007 %.

X(I)	Y(I)	P(I)	C(000)	C(EVEN)	SUM(C(I))
20.0000	75.2966	9.0632	-507.6799	0.0587	-156.2429
18.0000	55.6487	6.3961	32.0018	-0.0863	-92.4114
16.0000	39.5558	4.2500	22.1465	0.1730	-47.7724
14.0000	26.7378	2.4480	15.5258	0.2166	-16.2878
12.0000	17.5793	1.1969	8.9426	-0.1975	1.2025
10.0000	12.9732	0.5619	3.2562	-0.0659	7.6432
8.0000	10.7536	0.2496	0.6321	0.0761	9.0593
6.0000	8.4096	-0.0849	-0.5711	0.0470	8.0110
4.0000	7.8041	-0.1169	-1.1535	0.1254	5.9550
2.0000	2.7248	-0.9674	-2.1301	0.0720	1.7355
0.0000	1.0000	-1.3856	-5.6321	4.7657	0.0058
-2.0000	4.4059	-0.5731	1.9062	-0.4393	2.9394
-4.0000	4.9251	-0.6013	0.3638	0.1064	3.8795
-6.0000	5.0113	-0.5443	0.5972	-0.0153	5.0434
-8.0000	4.9458	-0.5116	0.4249	0.1559	6.2051
-10.0000	5.2887	-0.4301	1.1547	-0.2461	8.0523
-12.0000	5.1722	-0.4350	0.3260	0.1938	9.1220
-14.0000	4.3750	-0.5155	0.0660	-0.1479	8.9583
-16.0000	3.2093	-0.6421	-0.4763	-0.2072	7.5913
-18.0000	2.0665	-0.7639	-0.7299	-0.2257	5.6741
-20.0000	1.6196	-0.8079	-0.2899	-0.0353	5.0237
-22.0000	1.2491	-0.8435	22.2713	-22.6012	4.3643
-24.0000	0.9790	-0.8686	-0.1858	-0.0803	3.8319
-26.0000	0.9789	-0.8687	0.1320	-0.0019	4.0923
-28.0000	0.9790	-0.8687	0.0421	0.0886	4.3537
-30.0000	0.8981	-0.8776	-0.0623	0.0112	4.2520
-32.0000	0.5983	-0.9040	-0.5044	0.0064	3.2563
-34.0000	0.3084	-0.9237	-0.7616	0.1929	2.1186
-36.0000	0.0000	-1.0000	-0.5867	-0.1229	0.6993
-38.0000	-0.4727	-1.0826	-1.8710	0.6790	-1.6883
-40.0000	-0.9777	-1.1309	-1.4936	0.0802	-4.5150
-42.0000	-1.4005	-1.1757	-1.0443	-0.2693	-7.1421
-44.0000	-1.8554	-1.2332	-1.2405	-0.2790	-10.1810
-46.0000	-2.4877	-1.3117	-2.3259	0.1420	-14.5486
-48.0000	-3.0016	-1.3770	-3.6596	1.7153	-18.4973

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-50.0000	-2.6665	-1.4625	-2.9484	0.3336	-23.7267
-52.0000	-4.5250	-1.5751	-3.8113	0.3157	-30.7181
-54.0000	-5.6784	-1.7244	-4.9232	0.2060	-40.1526
-56.0000	-7.1985	-1.9238	-6.5679	0.1406	-53.0074
-58.0000	-9.2393	-2.1926	-5.4661	-0.3771	-70.6938
-60.0000	-10.5253	-2.3631	-5.1625	-0.2114	-83.4416
-62.0000	-11.5604	-2.5016	-5.6399	-0.0647	-94.8509
-64.0000	-12.7236	-2.6556	-6.2995	-0.1781	-107.8048
-66.0000	-14.0109	-2.8270	-6.9837	-0.3741	-122.5206
-68.0000	-15.4720	-3.0215	-8.7582	0.2994	-139.4952
-70.0000	-17.1345	-3.2425	-9.0263	-0.7920	-159.1346
-72.0000	-18.9992	-3.4910	-12.2378	1.0067	-181.5968
-74.0000	-21.0926	-3.7597	-13.6089	0.7523	-207.3103
-76.0000	-23.4454	-4.0831	-15.3694	0.6404	-236.7583
-78.0000	-26.0929	-4.4357	-16.8455	-0.0420	-270.5430
-80.0000	-29.0750	-4.8329	-18.9453	-0.4325	-309.2988
-82.0000	-32.1928	-5.2483	-20.9556	0.0408	-351.1254
-84.0000	-35.6470	-5.7085	-24.0129	0.3636	-398.3870
-86.0000	-39.5043	-6.2225	-27.3459	0.4859	-452.1054
-88.0000	-43.8150	-6.7969	-30.2479	-0.3003	-513.2048
-90.0000	-48.6361	-7.4393	-34.8173	0.0579	-582.7236
-92.0000	-54.0361	-8.1589	-38.7768	-0.8171	-661.9114
-94.0000	-60.2252	-8.9837	-46.2569	0.2793	-753.8667
-96.0000	-67.1952	-9.9112	-52.0637	-0.4964	-855.9868

```
STATEMENTS EXECUTED=   997998
CORE USAGE        OBJECT CODE=   18424 BYTES,ARRAY AREA=   9016 BYTES  BYTES
DIAGNOSTICS        NUMBER OF ERRORS=      0, NUMBER OF WARNINGS=      0
COMPILE TIME=     0.91 SEC,EXECUTION TIME=   102.74 SEC,   11.37.43WATFIV - MAR
        C$EOF
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Sample Ingot 43

Metal Chemistry - C 3.50 %, Si 2 70 %, C.E. 4.40 %,
Mn 0.59 %, Cr 0.13 %, Cu 0.14 %,
Al 0.020 %, Mg 0.049 %, S 0.010 %.

X(I)	Y(I)	R(I)	C(ODD)	C(EVEN)	SUM(C(I))
44.0000	80.8276	9.7067	-476.7056	-0.5941	-378.0017
42.0000	67.6440	7.9447	46.1054	-0.4848	-286.7605
40.0000	56.4966	6.4547	36.6015	0.0534	-213.4510
38.0000	47.1039	5.1991	29.1195	0.1037	-155.3110
36.0000	41.6006	4.4624	17.4433	-0.0461	-120.2169
34.0000	38.5987	4.0591	10.3484	-0.0672	-99.6547
32.0000	35.7275	3.6729	9.0378	0.1609	-81.2575
30.0000	34.5943	3.5182	4.8269	0.1506	-71.3029
28.0000	32.3562	3.3533	4.8550	-0.0455	-61.6836
26.0000	32.1252	3.1910	4.1209	0.4524	-52.5368
24.0000	30.8900	3.0120	3.6709	0.5189	-44.1577
22.0000	29.1503	2.7793	4.6589	-0.1151	-35.0704
20.0000	26.2432	2.3949	6.0743	-0.5024	-23.9266
18.0000	22.8583	1.9226	5.4394	0.1354	-12.7773
16.0000	17.6464	1.2174	6.2993	0.1356	0.0919
14.0000	13.0779	0.5983	4.2691	0.1315	5.8931
12.0000	8.9834	0.0453	4.6964	-2.1129	14.0599
10.0000	6.1882	-0.3320	-1.7305	-0.6991	9.2007
8.0000	4.2567	-0.5921	-1.6913	-0.2037	5.4109
6.0000	2.9211	-0.7706	-10.4974	0.3655	3.1475
4.0000	1.9281	-0.8929	-0.1424	-0.5395	1.7836
2.0000	1.1784	-0.9216	-0.1165	-0.2776	0.9957
0.0000	1.0000	-1.3856	-0.1125	-0.3520	0.0063
-2.0000	0.9565	-0.8500	0.3385	0.1193	0.9222
-4.0000	0.9565	-0.5613	2.1533	-2.0099	1.2055
-6.0000	0.9565	-0.3650	0.0679	0.0601	1.4646
-8.0000	0.9549	-0.3669	0.1278	-0.0011	1.7151
-10.0000	0.9511	-0.5682	0.0425	0.0823	1.9674
-12.0000	0.9473	-0.8692	0.3000	-0.1762	2.2148
-14.0000	0.9444	-0.8700	0.3840	-0.2605	2.4617
-16.0000	0.9482	-0.8702	-0.2467	0.3767	2.7217
-18.0000	0.9520	-0.8703	0.0666	0.0544	2.9835
-20.0000	0.9558	-0.8703	0.0758	0.0562	3.2475
-22.0000	0.9553	-0.5705	-0.2975	0.4050	3.5027
-24.0000	0.9550	-0.8707	0.0604	0.0657	3.7550

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-26.0000	0.9542	-0.5710	0.0810	0.0449	4.0056
-28.0000	0.9541	-0.8711	0.0734	0.0537	4.2607
-30.0000	0.9549	-0.8711	1.8775	-1.7486	4.5154
-32.0000	0.9557	-0.8712	0.0456	0.0835	4.7764
-34.0000	0.9179	-0.8751	0.0808	-0.0452	4.8596
-36.0000	0.3623	-0.9231	-1.1190	-0.0846	2.4525
-38.0000	-0.3183	-1.0721	-1.0470	-0.6279	-0.8972
-40.0000	-1.2333	-1.1592	-2.1801	-0.3105	-5.8791
-42.0000	-2.0155	-1.2519	-3.3948	1.0432	-10.5816
-44.0000	-2.9526	-1.3599	-3.5124	0.4958	-16.6146
-46.0000	-3.7297	-1.4657	-2.6517	-0.0577	-22.0334
-48.0000	-4.3356	-1.5470	-1.5700	-0.6253	-27.0235
-50.0000	-5.1091	-1.6450	-2.8352	-0.3184	-33.3309
-52.0000	-6.0704	-1.7740	1.9514	-5.9619	-41.3515
-54.0000	-7.2722	-1.9321	-10.1206	4.9885	-51.6157
-56.0000	-8.7841	-2.1314	-5.7017	-0.9077	-64.8347
-58.0000	-10.6981	-2.3544	-7.3639	-1.2027	-81.9676
-60.0000	-12.1371	-2.7074	-10.2185	-0.9566	-104.3176
-62.0000	-15.3704	-3.0038	-10.1454	-0.3313	-126.2708
-64.0000	-17.3254	-3.2639	-9.7591	-0.6273	-147.0437
-66.0000	-19.5675	-3.5623	-11.1268	-1.0443	-171.3857
-68.0000	-22.1443	-3.9052	-21.5242	7.5426	-199.9490
-70.0000	-25.1059	-4.2998	-17.5769	0.7950	-233.5127
-72.0000	-28.5271	-4.7549	-19.1742	-0.5729	-273.0068
-74.0000	-32.4747	-5.2806	-21.2521	-2.0165	-319.5444
-76.0000	-36.6822	-5.8410	-24.9905	-0.6407	-370.8196
-78.0000	-41.3697	-6.4655	-28.9375	-0.3176	-429.3301
-80.0000	-46.7174	-7.1779	-32.4509	-1.5729	-497.3777
-82.0000	-52.8251	-7.9917	-41.2146	1.6120	-576.5825

STATEMENTS EXECUTED= 1255537

CORE USAGE OBJECT CODE= 19400 BYTES,ARRAY AREA= 8016 BYTI BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0

COMPILE TIME= 0.85 SEC,EXECUTION TIME= 131.52 SEC, 10.39.WATFIV - MAR 19

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VITA AUCTORIS

1938	Born in Split, Croatia, Yugoslavia
1963	Research and Development Engineer, Corrosion and Surface Protection, Yugovynil Plastics Manufacturing, Split, Croatia, Yugoslavia
1965	Graduated with Degree of B.Sc., Department of Chemical Engineering and Metallurgy, University of Zagreb, Croatia, Yugoslavia
1966	Metallurgical Engineer, Steel and Cast Iron Foundry, Valdevit & Verganty Fonderie, Modena, Italy
1969	Quality Control and Melting Engineer, Ford of Canada, Windsor, Ontario, Canada
1978	Part time Graduate Student in the Department of Engineering Materials, University of Windsor, Windsor, Ontario, Canada.

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