HEAT AND CORROSION-RESISTANT ALLOY CASTINGS OF THE UNITED STATES OF AMERICA

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THIS paper will summarize the properties, design considerations and uses of cast heat and corrosion-resistant alloys. Obviously, it is not possible to cover in detail the almost limitless fields involved and, therefore, it must be borne in mind that the purpose of this paper is to point out the more important aspects of the overall problem of material selection.

Heat-resistant alloys may be defined as alloys of iron and chromium or iron-chromium and nickel to which other elements are added for the improvement of chemical, physical and mechanical properties. This definition is accepted even though the addition element may be more than 50 per cent. Consequently, in the heat-resistant alloys the chromium content may be approximately from 10 to 30 per cent and the nickel may be as high as 70 per cent.

The heat-resistant alloys are those which are normally used, either continuously or intermittently, at temperatures usually above 1000°F. These alloys include the chromium-iron, the chromium-nickel-iron and the nickel-chromium-iron types. The alloys must meet two requirements: they must have satisfactory surface film stability (that is, high temperature corrosion or oxidation resistance) and satisfactory high temperature mechanical strength and ductility.

The corrosion-resistant alloys are those which are normally used at room temperature or slightly above or below. These include the chromium-iron, the chromium-nickel-iron and, in some cases, the nickel-chromium-iron types. In these alloys the chromium content ranges from about 12 to 30 per cent and the nickel content up to 30 per cent. These alloys play a very important role in combating corrosion ranging in severity from simple atmosphere exposure to highly corrosive conditions found in the chemical industries.

The Alloy Casting Institute[1] standard designations and corresponding chemical compositions of the heat and corrosion-resistant alloys are given in Table 1.

Before an alloy is assigned a standard designation, it must individually account for at least one-half of one per cent of the total high-alloy production in its own category. Hence, some other compositions are produced, but only in relatively small quantities.

Fig. 1 shows the position of the heat-resistant alloys on an iron-chrome-nickel ternary diagram. Although the corresponding corrosion-resistant alloys do not necessarily have the same carbon content or range of nickel and chromium, their positions on the ternary diagram are essentially the same.

Heat-resistant Alloys

Classification and Structure — The chromium-iron alloys, containing from 8 to 14 per cent chromium and significant amounts of carbon, are similar to steel in that their mechanical properties may be altered by suitable heat treatment. Alloys of higher chromium content do not exhibit phase changes; hence, they are non-hardenable by heat treatment and their mechanical properties depend principally upon their composition. The addition of nickel, 8 per cent or more, to chromium-iron alloys results in the stabilization of the gamma-phase at temperatures well below −100°F.

Role of Individual Elements — Chromium is important in that it imparts resistance to

1. An association of high alloy castings producers in the United States and Canada.
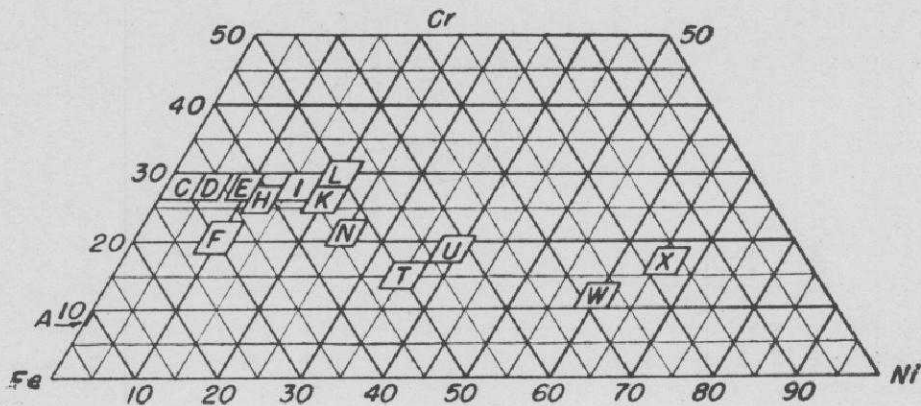
FIG. 1

oxidation and, in some alloys, helps the carburization resistance. Structurally speaking, it is a ferrite-forming element.

Nickel in sufficient quantity imparts high temperature strength and creep resistance, and provides resistance to carburizing and nitriding atmospheres and thermal fatigue. Its function is accepted to be that of an austenite-forming element

Carbon is also an austenite-forming element and has a marked effect on strength and creep resistance. At high temperatures there is a tendency for oxidation to be more severe as the carbon content increases.

Manganese, though important in the melting operations, has little or no effect on the mechanical properties when present in moderate amounts. It is an austenite-forming element.

Silicon has a pronounced beneficial effect on the oxidation and carburization resistance and is very effective in providing high temperature corrosion resistance to alloys having an otherwise inadequate chromium content. It is a ferrite-forming element.

Molybdenum improves high temperature strength and in some instances increases the high temperature corrosion resistance. In a stagnant oxidizing atmosphere at very high temperatures it may, in high percentages, cause 'catastrophic' failure due to the high vapour pressure of molybdic oxide. Molybdenum is a ferrite-promoting element.

Nitrogen is sometimes used to promote grain refinement in the Cr-Fe alloys; it usually has beneficial effects on strength at elevated temperatures. It is an austenite-former.

Tungsten, which improves the high temperature strength, has little effect upon the resistance to scaling. It is a ferrite-promoting element.

Other additions have been studied, but are not as yet incorporated into 'standard' heat-resistant alloys.

To summarize, the effects of the individual elements on the structural characteristics of commercial alloys are as follows: the austenitizing elements are carbon, nitrogen, nickel, manganese, copper and possibly cobalt. The elements which promote the formation of ferrite are chromium, molybdenum, niobium, silicon, titanium, vanadium, aluminum, tungsten and tantalum. It should be noted that the effects of these elements are not the same. For example, the most powerful austenite-forming elements are carbon and nitrogen. A tabulation of the relative effects of various elements on the formation of either austenite or ferrite is given below:

Austenite-forming:

Ni	C	N_2	Mn	Cu
1	30-35	10-26	0·5	0·5

Ferrite-forming:

Cr	Mo	Si	V	Al	Ti	Nb	Ta	W
1	4-6	5-6	10-11	12-15	6-8	4-5	2	2

TABLE 1 — STANDARD DESIGNATIONS AND CHEMICAL COMPOSITION RANGES FOR HEAT AND CORROSION-RESISTANT CASTINGS

CAST ALLOY DESIGNATION	WROUGHT ALLOY TYPE (see NOTE A)	COMPOSITION, PER CENT (BALANCE Fe)							
		C	Mn max.	Si max.	P max.	S max.	Cr	Ni	Other elements
CA-15	410	0·15 max.	1·00	1·50	0·04	0·04	11·5-14·0	1 max.	Mo 0·5 max.†
CA-40	420	0·20-0·40	1·00	1·50	0·04	0·04	11·5-14·0	1 max.	Mo 0·5 max.†
CB-30	431	0·30 max.	1·00	1·00	0·04	0·04	18-22	2 max.	—
CC-50	446	0·50 max.	1·00	1·00	0·04	0·04	26-30	4 max.	—
CE-30	—	0·30 max.	1·50	2·00	0·04	0·04	26-30	8-11	—
CF-8	304	0·08 max.	1·50	2·00	0·04	0·04	18-21	8-11	—
CF-20	302	0·20 max.	1·50	2·00	0·04	0·04	18-21	8-11	—
CF-8M	316	0·08 max.	1·50	1·50	0·04	0·04	18-21	9-12	Mo 2·0-3·0
CF-12M	316	0·12 max.	1·50	1·50	0·04	0·04	18-21	9-12	Mo 2·0-3·0
CF-8C	347	0·08 max.	1·50	2·00	0·04	0·04	18-21	9-12	Cb 8 × C min., 1·0 max., or Cb-Ta 10 × C min., 1·35 max.
CF-16F	303	0·16 max.	1·50	2·00	0·17	0·04	18-21	9-12	Mo 1·5 max., Se 0·20-0·35
CH-20	309	0·20 max.	1·50	2·00	0·04	0·04	22-26	12-15	—
CK-20	310	0·20 max.	1·50	2·00	0·04	0·04	23-27	19-22	—
CN-7M	—	0·07 max.	1·50	*	0·04	0·04	18-22	21-31	Mo-Cu*
HA	—	0·20 max.	0·35-0·65	1·00	0·04	0·04	8-10	—	Mo 0·90-1·20
HC	446	0·50 max.	1·00	2·00	0·04	0·04	26-30	4 max.	Mo 0·5 max.†
HD	327	0·50 max.	1·50	2·00	0·04	0·04	26-30	4-7	Mo 0·5 max.†
HE	—	0·20-0·50	2·00	2·00	0·04	0·04	26-30	8-11	Mo 0·5 max.†

†Molybdenum not intentionally added.

*There are several proprietary alloy compositions falling within the stated chromium and nickel ranges, and containing varying amounts of silicon, molybdenum and copper. Such alloys are available from licensed producers only.

TABLE 1 — STANDARD DESIGNATIONS AND CHEMICAL COMPOSITION RANGES FOR HEAT AND CORROSION-RESISTANT CASTINGS — *Continued*

Cast Alloy Designation	Wrought Alloy Type (see Note A)	Composition, per cent (balance Fe)							
		C	Mn max.	Si max.	P max.	S max.	Cr	Ni	Other elements
HF	302B	0·20-0·40	2·00	2·00	0·04	0·04	19-23	9-12	Mo 0·5 max.†
HH	309	0·20-0·50	2·00	2·00	0·04	0·04	24-28	11-14	Mo 0·5 max.† N 0·2 max.
HI	—	0·20-0·50	2·00	2·00	0·04	0·04	26-30	14-18	Mo 0·5 max.†
HK	310	0·20-0·60	2·00	3·00	0·04	0·04	24-28	18-22	Mo 0·5 max.†
HL	—	0·20-0·60	2·00	3·00	0·04	0·04	28-32	18-22	Mo 0·5 max.†
HN	—	0·20-0·50	2·00	2·00	0·04	0·04	19-23	23-27	Mo 0·5 max.†
HT	330	0·35-0·75	2·00	2·50	0·04	0·04	13-17	33-37	Mo 0·5 max.†
HU	—	0·35-0·75	2·00	2·50	0·04	0·04	17-21	37-41	Mo 0·5 max.†
HW	—	0·35-0·75	2·00	2·50	0·04	0·04	10-14	58-62	Mo 0·5 max.†
HX	—	0·35-0·75	2·00	2·50	0·04	0·04	15-19	64-68	Mo 0·5 max.†

†Molybdenum not intentionally added.

Designations with the initial letter 'C' indicate alloys generally used to resist corrosive attack at temperatures less than 1200°F. Designations with the initial letter 'H' indicate alloys generally used under conditions where the metal temperature is in excess of 1200°F. The second letter represents the nominal chromium-nickel type; the nickel content increasing in amount 'A' to 'X'. For example, 'F' stands for the 19 per cent Cr - 9 per cent Ni, 'K' for the 25 per cent Cr - 20 per cent Ni, and 'W' for the 12 per cent Cr - 60 per cent Ni alloy types. Numerals following the letters indicate the *maximum* carbon content of the corrosion-resistant alloys; carbon content may also be designated in the heat-resistant grades by following the letters with a numeral to indicate the *midpoint* of a ±0·10 per cent carbon range. If special elements are included in the composition, they are indicated by the addition of a letter to the symbol. Thus, 'CF-8M' is an alloy for corrosion-resistant service of the molybdenum-containing 19 per cent Cr - 9 per cent Ni type with a maximum carbon content of 0·08 per cent.

NOTE A — Wrought alloy type numbers are listed only for the convenience of those who want to determine corresponding wrought and cast grades. Because the cast alloy chemical composition ranges *are not the same* as the wrought composition ranges, buyers should use cast alloy designations for proper identification of castings.

NOTE B — Most of the standard grades listed are covered for general applications by American Society for Testing Materials Specifications A 296-49T and A 297-49T. A.S.T.M. Specifications A 217-49T, A 351-52T, A 362-52T, B 190-50 and B 207-50 also apply to some of the grades.

This indicates that silicon is five to six times as potent a ferrite-former as chromium. The above figures are not absolute equivalent factors. The total amount of all elements present as well as their ratios have a noticeable effect. For example, certain elements (chromium, tantalum, niobium, titanium, etc.) have a great affinity for carbon and the variation in carbon thus governs the amounts of the above elements left available for the promotion of ferrite.

Alloy Classification — Commercial heat-resistant alloys are classified according to composition and metallurgical structure into three broad groups (*see* Table 1):

1. Chromium-iron
2. Chromium-nickel-iron
3. Nickel-chromium-iron.

Chromium-iron Alloys: HA, HC, HD — The chromium-iron group is made up of alloys of high chromium and little or no nickel. They are predominantly ferritic in structure.

HA — This alloy is used primarily to resist corrosive effects of hot petroleum products up to about 650°C. (1200°F.).

HC and HD — These two relatively low-priced alloys are used in high sulfur-bearing atmospheres up to about 1040°C. (1900°F.) where high creep strength is not a factor. They are used in applications such as rabble arms and blades in ore-roasting furnaces, dampers, sintering bars, grates, tuyeres and salt pots where uniform temperatures are encountered.

Chromium-nickel-iron Alloys: HE, HF, HH, HK, HL, HI — The chromium-nickel-iron group comprises alloys which are essentially austenitic. These alloys are characterized by better creep strength than the chromium-iron types. They have good cold and hot ductility and resistance to oxidizing and reducing atmospheres.

HE grade has better creep resistance than HD, but not as good as the more highly alloyed grades. It can be used under conditions of fairly high sulfur atmospheres in such applications as furnace conveyers,

recuperators, roasting furnaces, and tube supports in the petroleum industry.

HH grade is one of the most widely used furnace alloys. It has good strength and surface stability at elevated temperatures in such applications as oil still tube supports, kiln parts, furnace rolls, hearths, link belts, dampers and pots. This alloy is made in two types. Type I alloy is partially ferritic and has higher ductility but lower creep strength than Type II which is fully austenitic. This is accomplished by varying the carbon-nickel-chromium ratio within the composition limits.

HF — The uses of the HF grade are parallel to those of the HH grade, but the top service temperature limit is much lower.

The HI, HK and HL grades have relatively high creep resistance and good resistance to industrial atmospheres. Because of the higher chromium contents, HI and HL may be used in atmospheres containing considerable amounts of sulfur. The uses of these alloys are similar to those of grade HH, but also include some gas turbine applications.

All these alloys have a top temperature limit of about 1100°C. (2010°F.) except HF which is used only up to about 870°C. (1600°F.).

Nickel-chromium-iron Alloys: HN, HT, HU, HW, HX — The alloys in this group are all austenitic. They have good creep strength, oxidation and carburization resistance and thermal fatigue properties. Their use in high sulfur atmospheres is not usually recommended.

They have a top operating temperature of about 1100°C. (2010°F.) and are used for muffles, carburizing retorts, trays and boxes, lead and salt pots and enameling fixtures. The HW and HX grades are also used in nitriding furnace parts.

Industries that Use Heat-resistant Alloy Castings — Industries in which heat-resistant alloy castings are used include:

Aeronautical
Atomic energy
Automotive

Brazing (copper, etc.)
Cement
Ceramic — glass, enameling, pottery
Chemical
Electrical heating
Furnace
Heating and heat-treating
Non-ferrous rolling mills
Petroleum
Power (steam)
Pulp and paper
Pyrometry
Smelting and refining
Steel mills

Basic Service Limitations — The service limitations of heat-resisting castings are established, basically, by temperature since it is evident that any structure must be made from materials with a melting point substantially higher than the operating temperature. The temperature of operation also influences quite markedly the strength of the material and it is, therefore, equally obvious that any materials selected for high temperature use must have sufficient strength at the temperature of operation to support their own weight plus any applied mechanical load and the inevitable thermal loading.

Of almost equal importance, the material must be resistant to the corrosive effects of the atmosphere in which it operates. If the casting is to be continuously subjected only to the oxidation effects of air at elevated temperatures, it is possible to predict with considerable accuracy the usefulness of any given alloy for such service. If the temperature is cyclic, there is less certainty as to the expected life, largely because of the physical characteristics, at different temperatures, of the protective oxide films. This may result in the different ' spalling ' tendencies in different alloys. Alloys containing less than a total of 50 per cent nickel plus chromium are particularly subject to this spalling effect. Should the atmosphere, instead of being air, be flue gas, somewhat shorter life at any given temperature must generally be anti-

cipated. This is particularly true in the case of sulfur-bearing flue gases.

There is, further, the effect of ' temperature differentials ' which may result in thermal fatigue and thermal shock failures. This phase of the service limitations will be dealt with in a later section devoted to the consideration of design and application.

Alloy Selection — The selection of the proper alloy for a given high temperature appilcation is not a simple matter. The following is a list of some of the factors that must be considered:

1. Anticipated service and maximum temperatures of operation.
2. Temperature cycling:
   (a) Range of temperature cycling.
   (b) Frequency of temperature cycling.
   (c) Rate of temperature change.
3. Type and size of maximum load.
4. Type of atmosphere or other corrosive conditions.
5. Abrasive or wear conditions.
6. Size and shape of part.
7. Manner of support.
8. Ease of replacement.
9. Further processing, such as welding or machining.
10. Cost.

In designing heat-resistant alloy castings the significant properties which must be considered are as follows:

1. High temperature mechanical properties:
   (a) Ultimate strength.
   (b) Creep strength.
   (c) Stress-rupture strength.
   (d) Ductility.
2. Resistance to thermal fatigue and thermal shock.
3. Room temperature mechanical properties (especially toughness).
4. Physical properties:
   (a) Thermal conductivity.
   (b) Thermal capacity.
   (c) Coefficient of thermal expansion.
   (d) Density.

5. Surface film stability as evidenced by resistance to oxidation, carburization, etc.
6. Castability.
7. Weldability and machinability.

Tables 2, 3 and 4 contain data on the room temperature mechanical properties, high temperature properties and physical properties of the standard heat-resistant alloys.

Thermal Fatigue — In many heat-resistant applications widely fluctuating or intermittent temperatures are encountered and under such conditions the castings are subjected to very high internal stresses. Thermal fatigue failures are indicated by warpage, partial or complete cracking. An example of the type of service in which thermal fatigue failures are encountered is in carburizing processes where the tray is quenched with the work.

Creep Resistance — The conventional room temperature mechanical properties cannot be used in the design of high temperature equipment. Under stress at elevated temperatures metals behave elastically as at room temperature, but also deform plastically at a very slow rate. For this reason, time becomes a critical factor. This slow deformation is known as creep and involves four factors — time, stress, temperature and deformation.

In the design of furnace parts experience indicates that a creep rate of 0·0001 per cent per hour is satisfactory for comparison of alloys. This is sometimes expressed as 1 per cent creep in 10,000 hr. It should be kept in mind that when creep is expressed in the latter terms it does not mean that this rate of creep can be expected to continue for 10,000 hr. without failure.

Creep values which are obtained from tests made under constant temperature and load conditions are not directly applicable for design use. The allowable design stress is usually about 50 per cent of the creep value under constant load and temperature (or where the parts are readily accessible for replacement) where changes of service conditions are not severe and where the stresses are moderate. Under more severe conditions where there are changes in temperature and load during service or where parts are not readily accessible, a smaller proportion, as low as 25 per cent, should be used. Wherever possible, previous service experience is used as a guide.

Stress-rupture — Stress-rupture values determined at constant temperature and under constant load are useful in approximating the life of the alloy under such conditions and also for comparing alloys which are subject to loading which might produce failure in a relatively short time.

Heat-resistant Alloy Design — In the design of high temperature components and mechanisms there are a number of factors which must be given careful consideration that are not encountered in the design of similar items which are to operate at or near room temperature. It has been noted that changes in ambient temperature and subsequent temperature differentials will result in stresses within the casting as a result of non-uniform dimensional change. These stresses will be accompanied, particularly at high temperatures, by some degree of plastic deformation. The magnitude of the stress and/or the amount of the plastic deformation will depend on the temperature differential within the casting.

It is also necessary that the designer take into consideration the thermal conductivity, the thermal capacity and the coefficient of thermal expansion of the alloys with which he is working.

It has been shown that roughly the maximum stress may be calculated as follows:

$$\sigma \max. = E\beta(\Delta t)$$

where σ is stress; E, modulus of elasticity; β, coefficient of thermal expansion; and t, temperature.

Mathematical considerations show that the actual temperature, as a function of time, temperature-differential and geometry, is dependent on the thickness of the casting

TABLE 2—ROOM TEMPERATURE MECHANICAL PROPERTIES

Property	HA	HC	HD	HE	HF	Type 1 HH	Type 2 HH	HI	HK	HL	HN	HT	HU	HW	HX
Tensile strength, p.s.i.															
As-cast	95000[2]	70000	85000	87000	85000	80000	85000	80000	75000	86000	86000	70000	70000	68000	66000
Aged	107000[3]	—	—	85000	100000	86000	92000	90000	85000	—	—	75000	73000	84000	82000
Yield strength, p.s.i.															
As-cast	65,000[2]	65000	48000	45000	45000	50000	45000	55000	50000	53000	38000	40000	40000	36000	34000
Aged	81,000[3]	—	—	65000	50000	55000	40000	70000	50000	—	—	45000	43000	52000	50000
Elongation % in 2 in.															
As-cast	23[2]	2[1]	16	10	35	25	15	8	17	19	17	10	9	8	9
Aged	21[3]	—	—	3	25	11	8	6	10	—	—	5	5	6	9
Hardness, B.H.N.															
As-cast	180[2]	190[1]	190	200	165	185	180	180	170	192	160	180	170	185	170
Aged	220[3]	—	—	270	190	200	200	200	190	—	—	200	190	205	185
Impact Charpy, ft.-lb.															
As-cast	—	—	—	10	—	—	15	—	—	—	—	4	4	—	—
Aged	32[3]	—	—	—	—	—	4[1]	—	—	—	—	5	5	—	—
Ageing treatment				24 hr. at 760°C. (1400°F.) furnace-cooled	24 hr. at 760°C. (1400°F.) furnace-cooled	24 hr. at 760°C. (1400°F.) furnace-cooled	24 hr. at 760°C. (1400°F.) furnace-cooled	24 hr. at 760°C. (1400°F.) furnace-cooled	24 hr. at 760°C. (1400°F.) air-cooled			48 hr. at 980°C. (1800°F.) air-cooled	48 hr. at 980°C. (1800°F.) air-cooled	24 hr. at 760°C. (1400°F.) furnace-cooled	48 hr. at 980°C. (1800°F.) air-cooled

1. 48 hr. at 870°C. (1600°F.) air-cooled.   2. Annealed.   3. Normalized at 980°C. (1800°F.) and tempered at 675°C. (1250°F.).

TABLE 3—ELEVATED TEMPERATURE MECHANICAL PROPERTIES

Property	HA	HC	HD	HE	HF	HH Type 1	HH Type 2	HI	HK	HL	HN[6]	HT	HU	HW	HX
Short-time strength properties:															
Tensile strength, p.s.i. at															
540°C. (1000°F.)	67000	—	—	—	—	—	—	—	—	—	—	53500	—	—	48000
650°C. (1200°F.)	44000[5]	—	—	—	57000	—	—	—	—	—	—	42400	—	—	45000
760°C. (1400°F.)	—	10500	36000	—	35000	33000	35000	—	—	50000	—	35000	40000	32000[2]	42000[3]
870°C. (1600°F.)	—	5100	23000	—	22000	18500	22000	—	23000	30400	—	18800	19600	19000	29000[4]
980°C. (1800°F.)	—	2500	15000	—	—	9000	11000	—	—	18700	—	11000	10000	10000	10,700
1095°C. (2000°F.)	—	—	—	—	—	—	—	—	—	—	—	6000	—	—	—
Yield strength (0·2% offset)															
540°C. (1000°F.)	42000	—	—	—	—	—	—	—	—	—	—	33000	—	—	21000
650°C. (1200°F.)	72000[5]	—	—	—	—	—	—	—	—	—	—	28000	—	—	20000
760°C. (1400°F.)	—	8700[1]	—	—	—	17000	18000	—	—	—	—	26000	—	23000[2]	19500[3]
870°C. (1600°F.)	—	3800[1]	—	—	—	13500	14000	—	—	—	—	15000	—	15000	17,500
980°C. (1800°F.)	—	2100[1]	—	—	—	6300	7000	—	—	—	—	8000	6200	8000	6,900
1095°C. (2000°F.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Elongation % in 2 in. at															
540°C. (1000°F.)	36[5]	—	—	—	—	—	—	—	—	—	—	6	—	—	9
650°C. (1200°F.)	—	—	—	—	16	—	—	—	—	—	—	5	—	—	8
760°C. (1400°F.)	—	65	14	—	20	18	12	—	—	—	—	10	—	—	11[3]
870°C. (1600°F.)	—	94[1]	18	—	22	30	16	—	21	—	—	26	20	—	48
980°C. (1800°F.)	—	110[1]	40	—	—	45	30	—	—	—	—	28	28	40	40
1095°C. (2000°F.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

1. 2·8 per cent Ni - 0·15 per cent N.   2. Extrapolated.   3. At 730°C. (1350°F.)   4. At 815°C. (1500°F.)   5. At 535°C. (1100°F.).

6. This is a relatively new alloy on which data are now being developed.

TABLE 3—ELEVATED TEMPERATURE MECHANICAL PROPERTIES—*Continued*

Property	HA	HC	HD	HE	HF	Type 1 HH	Type 2 HH	HI	HK	HL	HN[6]	HT	HU	HW	HX
Creep stress 0·0001%/hr. p.s.i.															
540°C. (1000°F.)	16000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
650°C. (1200°F.)	3100	—	—	—	13000	—	—	—	—	—	—	—	—	—	—
760°C. (1400°F.)	—	1300[1]	3500	3500	6000	3000	7000	6600	6800	7000	—	8000	8500	6000	6400
870°C. (1600°F.)	—	750[1]	1900	2000	3200	1700	4000	3600	4200	4300	—	4500	5000	3000	3200
980°C. (1800°F.)	—	360[1]	1000	1000	—	1100	2100	1900	2700	—	—	2000	2200	1400	1600
1095°C. (2000°F.)	—	—	—	—	—	300	800	800	1000	—	—	500	600	500[2]	600
1120°C. (2150°F.)	—	—	—	—	—	—	—	150	200	—	—	150	—	—	—
Stress to rupture, p.s.i. 100 hr. at															
540°C. (1000°F.)	37000	—	—	—	—	—	—	—	—	—	—	—	—	—	—
650°C. (1200°F.)	—	—	—	—	30000	—	35000	—	—	—	—	—	—	—	—
760°C. (1400°F.)	—	3300	10000	11000	14000	14000	14000	13000	14500	15000	—	18000	15000	10000	13000
870°C. (1600°F.)	—	1700	5000	5300	6000	6400	7500	7500	7800	9200	—	8500	8000	6000	6700
980°C. (1800°F.)	—	1000	2500	2500	—	3100	4000	4100	4500	5200	—	4500	4500	3600	3500
1095°C. (2000°F.)	—	—	—	—	—	1500	1800	1900	2500	—	—	2500	—	—	1700
1000 hr. at															
540°C. (1000°F.)	27000	—	—	—	17000	—	—	—	—	—	—	—	—	—	—
650°C. (1200°F.)	—	—	—	—	8000	6500	22000	8500	9000	—	—	12500	—	7800	—
760°C. (1400°F.)	—	2300	—	—	3800	3800	10000	4800	5000	—	—	7000	6000	4500	4000
870°C. (1600°F.)	—	1300	—	—	—	2100	4700	2600	3000	—	—	3700	2900	2600	2200
980°C. (1800°F.)	—	620	—	—	—	—	2500	1250	—	—	—	1800	—	—	900
1095°C. (2000°F.)	—	—	—	—	—	—	1200	—	—	—	—	—	—	—	—

1. 2·8 per cent Ni - 0·15 per cent N.   2. Extrapolated.   3. At 730°C. (1350°F.)   4. At 815°C. (1500°F.)   5. At 535°C. (1100°F.)
6. This is a relatively new alloy on which data are now being developed.

TABLE 4 — PHYSICAL PROPERTIES

PROPERTY	HA	HC	HD	HE	HF	Type 1 HH	Type 2 HH	HI	HK	HL	HN³	HT	HU	HW	HX
Modulus of elasticity in tension p.s.i. × 10⁻⁶ at 21°C. (70°F.)	29	29	29	25	28	28	28	27	29	29	—	24	24	25	25
Density, lb./cu. in.	0·279	0·274	0·274	0·276	0·280	0·279	0·279	—	0·280	0·279	—	0·286	0·290	0·300	—
Mean coefficient of linear thermal expansion in./in./°F.×10⁻⁶															
21 — 100°C. (70 — 212°F.)	6·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21 — 540°C. (70 — 1000°F.)	7·1	6·3	7·7	9·5	9·9	—	—	—	9·2	—	—	8·5	8·9	—	—
21 — 650°C. (70 — 1200°F.)	7·5	6·3	—	9·9	10·1	9·9	9·9	—	9·4	9·2	—	8·9	—	8·1	—
21 — 705°C. (70 — 1300°F.)	—	—	—	—	—	—	—	10·0	—	—	—	—	—	—	—
21 — 760°C. (70 — 1400°F.)	—	6·6	8·5	10·2	10·3	—	—	10·1	9·6	—	—	9·2	9·1	8·4	—
21 — 815°C. (70 — 1500°F.)	—	—	—	—	10·3	—	—	—	9·7	—	—	—	—	—	—
21 — 870°C. (70 — 1600°F.)	—	7·0	—	10·5	10·4	10·1	10·1	10·3	9·7	—	—	9·3	—	8·6	—
21 — 900°C. (70 — 1650°F.)	—	—	—	10·5	—	—	—	10·5	—	—	—	—	—	—	—
21 — 980°C. (70 — 1800°F.)	—	7·4	—	10·8	10·5	10·8	10·8	—	10·0	—	—	9·8	9·7	9·0	8·5
21 — 1010°C. (70 — 1850°F.)	—	7·6	—	—	—	—	—	10·8	10·1	10·1	—	—	—	9·2	—
21 — 1095°C. (70 — 2000°F.)	—	7·7	9·2	—	10·9	11·0	11·0	11·0	10·7	10·7	—	9·8	—	—	—
650 — 870°C. (1200 — 1600°F.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
650 — 980°C. (1200 — 1800°F.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Specific heat B.T.U./lb./°F. at 70°F.	0·11	0·12	0·12	0·14	0·12	0·12	0·12	—	0·12	0·12	—	0·11	0·11	—	—
Specific electrical resistance Microhms — cm. at 21°C. (70°F.)	70	77	81	85	80	75-85	75-85	—	90	94	—	100	105	—	—
Thermal conductivity B.T.U./hr./sq. ft./ft./°F.															
21 — 100°C. (70 — 212°F.)	15·2	12·6	12·6	—	9·0	8·2	8·2	—	8·2	8·2	—	7·7	—	—	—
21 — 540°C. (70 — 1000°F.)	17·0	17·9	17·9	—	13·4	10·9	10·9	—	10·9	10·9	—	11·4	—	—	—
21 — 815°C. (70 — 1500°F.)	—	20·3	20·3	10·0	15·0	14·3	14·3	—	11·9	11·9	—	—	—	—	—
21 — 1095°C. (70 — 2000°F.)	—	24·2	24·2	—	16·9	16·4	16·4	—	—	—	—	—	—	—	—
Melting point (approx.) °C. / °F.	1510 / 2750	1495 / 2725	1480 / 2700	1455 / 2650	1425 / 2600	1370 / 2500	1370 / 2500	—	1400 / 2550	1425 / 2600	—	1330 / 2425	1330 / 2425	1290 / 2350	1290 / 2350
Magnetic permeability	Magnetic	14·7¹ 9·9²	Magnetic	1·3-1·8	Non-magnetic	1·1-1·9	1·0-1·05	—	1·02	—	—	Partially magnetic	Partially magnetic	—	—

1. 48 hr. at 870°C. (1600°F.).
2. 2 hr. at 1150°C. (2100°F.) water-quench.
3. This alloy has just recently been produced in quantity. Data are now being developed.

wall and is nearly proportional to this thickness. It is obvious, therefore, that all designs should be made for the minimum sections which can be produced by the foundry. Parenthetically it may be said that, as wall thickness of the casting increases, it also becomes more difficult for the foundry to produce a completely sound casting.

Solutions of the basic stress equation for all geometries show that maximum articulation of the components of any device for use at elevated temperatures will result in minimum thermal stresses. It is, therefore, desirable, if not imperative, that all castings for elevated temperature service, particularly where cyclic conditions of temperature are to be encountered, be designed so that they will ' float ' rather than be held rigid. It can be shown that Δt is dependent on thermal conductivity, thermal capacity and density, and that the coefficient of thermal expansion becomes important as soon as stress calculations are involved.

To summarize, all sharp corners and changes in section are to be avoided as much as possible. Wherever possible the basic units should be broken up into a number of free-floating components. The designer must take into consideration in his stress analysis the effect of thermal expansion, and in the case of cyclic temperatures, thermal conductivity and thermal capacity.

Corrosion-resistant Alloys

Role of Individual Elements — The balance between the major elements (nickel, chromium and iron) and the minor elements (such as molybdenum, niobium, copper, silicon, etc.) is very important. They may exert a strong influence on the structure and corrosion resistance of the alloy. The castability may also be affected by this balance. For this reason, the chemical composition range for the wrought alloys may not, and in most cases does not, apply to the cast materials.

Chromium in excess of 11 per cent imparts substantial passivity to ferrous alloys. Since all of these alloys contain considerable amounts of chromium, they possess good resistance to oxidizing acids and oxidizing solutions generally.

Alloys with substantial amounts of nickel exhibit a greater amount of passivity than do the nickel-free or low-nickel alloys. This increased passivity permits the use of these alloys in a wide variety of corrosive environments including those of a reducing nature such as dilute sulfuric acid.

Alloy Classification — The corrosion-resistant alloys may be classified in four groups:

1. Chromium-iron, hardenable (Type CA).
2. Chromium-iron, non-hardenable (Types CB and CC).
3. Chromium-nickel-iron (Types CE, CF, CH and CK).
4. Nickel-chromium-iron (Type CN).

Chromium-iron, Hardenable: CA — The CA alloys (CA-15 and CA-40) fall within this group. They are martensitic in structure, hence the mechanical properties may be varied by suitable heat treatment.

These grades are used in mildly corrosive conditions in the chemical, glass and petroleum industries and in steam power plants where the favourable mechanical properties can be used to advantage.

Chromium-iron, Non-hardenable: CB, CC — Alloys CB and CC have somewhat greater resistance than CA to most corrosive environments. Typical applications are in the mining, chemical, petro-chemical and allied industries.

Chromium-nickel-iron Alloys: CE, CF, CH and CK — The addition of nickel to the chromium-iron alloys improves the ductility and impact strength and greatly enhances the corrosion resistance of the alloy in most media. CE and CH are more highly alloyed and have better strength and ductility than CC. These alloys have found extensive use in the chemical, mining, electrical power and petroleum industries, as well as in the pulp

and paper industry where they are used for resistance to sulfurous acid solutions containing sulfur dioxide.

CF, which is considered an all-purpose alloy, is used extensively in the chemical, textile, paper, dairy and food handling industries; it is also used in architectural trim. A modification of this alloy, CF-8M, containing 2 to 3 per cent molybdenum, reduces pitting corrosion frequently encountered in some industrial applications and in sea-water. Other common additions to the CF alloy are niobium, as a stabilizing element, and selenium, to improve machinability and reduce porosity.

CK is the most highly alloyed material in this group. It is used in the aircraft, chemical and pulp and paper industries, as well as some hot oil applications in the petroleum industry.

Nickel-chromium-iron: CN-7M — This alloy is used chiefly for its resistance to various concentrations of hot sulfuric acid. It is more resistant to reducing acids than the chromium-rich alloys. There are several variations of this alloy, all covered by patents.

This alloy, which is used chiefly in the chemical industry, contains copper and molybdenum. The copper is added to provide resistance to sulfuric acid and the molybdenum to resist the pitting effect of specific media such as the halogens and sulfites.

Basic Service Limitations

The basic service limitations of the corrosion-resistant alloys are determined primarily by the ability of the casting to withstand the corrosive effects of the system fluids to such an extent that the rate of loss of cross-section is acceptable. The contamination of the system fluid by the corrosion product may adversely affect the quality of the end-product; may result in clogging of small pipes and orifices; or may lower heat transfer coefficients. Of secondary importance, but

still necessary, is the consideration of strength and ductility (*see* Table 5). Selection of the proper alloy type for any given use must be made only with full and complete information, either in the form of specific data, or as pertinent background and experience on the part of the engineer.

The corrosive conditions under which a given group of alloys provide satisfactory resistance cannot be simply stated. In industrial processes a number of factors may influence the formation and maintenance of a passive surface film. Some of the important factors are concentration, temperature, aeration, velocity and contaminants in the corrosive.

Production Methods

Melting — Heat-resisting alloys are, in general, produced in the United States by two melting methods. The greatest tonnage of castings is probably made in the three-phase electric arc furnace using either acid or basic practice. If acid practice is used, the scrap, iron and nickel are charged in whole or in part prior to striking the arc. Melt-down is done as quickly as possible using the maximum voltage available from the transformer secondary. After the melt-down a boil is induced, usually by the addition of iron oxide or nickel oxide. Some foundries today, instead of using an oxide boil, are using an oxygen lance. This has the disadvantage, unless temperatures are very carefully controlled, of burning out chromium which, in acid practice, is not readily recoverable from the slag. Generally speaking, oxygen boiling of the heat-resistant alloys results in lower carbon content than is desirable and hence recarburization of the bath is often necessary.

The boil is blocked with ferro-silicon; the ferro-chrome and ferro-manganese are added; final deoxidation with calcium, aluminum or silicon is accomplished; the heat is tapped and the castings poured. If the melt size

TABLE 5 — MECHANICAL PROPERTIES OF CAST CORROSION-RESISTANT ALLOYS*

ALLOY TYPE	HEAT TREATMENT	TENSILE STRENGTH, 1000 p.s.i.	YIELD STRENGTH, 0·2% OFFSET 1000 p.s.i.	ELONGATION, IN 2 IN., %	BRINELL HARDNESS NUMBER	CHARPY IMPACT, KEYHOLE, ft.-lb.
CA-15	AC from 1800°F., temper at 1450°F.	100	75	30	185	35
	AC from 1800°F., temper at 1200°F.	115	100	22	225	20
	AC from 1800°F., temper at 1100°F.	135	115	17	260	10
	AC from 1800°F., temper at 600°F.	200	150	7	390	15
CA-40	AC from 1800°F., temper at 1400°F.	110	67	18	212	3
	AC from 1800°F., temper at 1200°F.	140	113	14	267	4
	AC from 1800°F., temper at 1100°F.	150	125	10	310	2
	AC from 1800°F., temper at 600°F.	220	165	1	470	1
CB-30	Anneal 1450°F., FC to 1000°F., AC	95	60	15	195	2
CC-50	(Under 1% Ni) as-cast	70	65	2	212	2
	(Over 2% Ni, 0·15% N min.) as-cast	95	60	15	193	45
	(Over 2% Ni, 0·15% N min.) AC from 1900°F.	97	65	18	210	—
CE-30	As-cast	95	60	15	170	—
	WQ from 1950° to 2050°F.	97	63	18	170	—
CF-8	WQ from 1950° to 2050°F.	77	37	55	140	75
CF-20	WQ from above 2000°F.	77	36	50	163	60
CF-8M, CF-12M	WQ from 1950° to 2100°F.	80	42	50	156-170	70
CF-8C	WQ from 1950° to 2050°F.	77	38	39	149	30
CF-16F	WQ from above 2000°F.	77	40	52	150	75
CH-20	WQ from above 2000°F.	88	50	38	190	30
CK-20	WQ from above 2100°F.	76	38	37	144	50
CN-7M	WQ from above 1950°-2050°F.	69	31	48	130	70

*Representative room temperature properties; not specification values.

permits, tapping is usually done into a bull ladle and the smaller flasks are poured with hand shanks from the bull ladle. No standardized slag treatment is used, though some melters maintain an optimum slag fluidity by the judicious use of lime.

Basic arc melting is practised by a number of foundries and almost invariably the single slag method is used. Basic melting has the advantage of better chromium and manganese recovery, but the disadvantage of being somewhat slower, and there is the feeling among foundrymen that basic heats are somewhat less fluid than those produced by acid practice. Deoxidation is accomplished in the same way by either method.

The other principal method of producing heat-resistant alloy castings is by the use of high-frequency induction furnaces. Here no attempt is made to control chemistry or slag except through the additions to the melt. The furnaces are usually lined with a magnesia-alumina mixture, or in some cases with gannister, and are used as a neutral lining. At present no one is utilizing either the oxide boil or the oxygen lance on the heat-resisting alloys in induction furnaces.

It should be pointed out that there have been a large quantity of satisfactory heat-resistant alloy castings made in the past using open-hearth furnaces. This practice has practically been discontinued in the United States except in such rare instances where a casting must be made which is too large for the electric furnaces available. It should be mentioned that satisfactory castings have been made by one of the authors utilizing reduction by aluminothermic reactions.

The melting of the cast corrosion-resistant alloys is today done almost exclusively in induction furnaces. Since there is little, if any, refining possible when melting by this method, extreme care must be taken in the selection of the charge materials, particularly since the trend is toward lower carbon contents. Carefully selected scrap, Armco iron or its equivalent, and very low carbon ferrochrome must be used. It has been suggested that less care would be necessary if oxygen blowing were practised. Unfortunately, this technique does not lend itself well to induction furnace practices and only one foundry in the United States follows this practice as a routine procedure.

Where melting practices other than the high-frequency induction furnace methods are used (as in the case of metal quantities too great for the induction furnaces or in the absence of such equipment) arc furnace melting, following essentially the practice for heat-resistant castings, is utilized. In arc-melting practice today the use of the oxygen lance on corrosion-resistant alloy casting melts is almost universally practised. Care should be taken to insure complete deoxidation.

Molding — Molding practice is essentially the same for both heat-resistant and corrosion-resistant alloy castings. Until recently molding materials were almost universally of the synthetic sand type. In the early days of this industry a number of producers used core, or dry sand molds exclusively. With better synthetics green sand practice was found to be not only cheaper but in many cases more satisfactory. Very careful preparation of the sand is necessary in order to insure uniformity and permeability. In general the backing sands are coarse and ' open ' while the facing sands are somewhat finer, are hard-rammed and are often skin-dried. Moisture contents should be kept at a minimum consistent with satisfactory ramming. A typical facing sand analysis for general work is as follows:

Sand (AFA40)	1125 lb.
Organic binder	$4\frac{1}{2}$ qt.
Bentonite	$40\frac{1}{2}$ qt.
Moisture	$3\frac{1}{2}$ per cent

The erosive effect of the molten metal is great and care must be taken both in the ramming procedure and in the design of the ingates to avoid sand cutting. Pouring temperatures should be kept at an absolute minimum not only to prevent cutting of the mold and burning in of the sand, but to avoid excessive shrinkage and grain size in the casting itself. The liquid-to-solid volumetric contraction is high and good practice requires either special feeding or heavy chilling at points of significant section change. While chilling is more expensive, it is to be preferred because of the tendency of risers to create excessive grain size at the points of feeding.

In very recent years the 'C' process, or shell molding method, has gained favour with a number of producers where repetitive

castings of moderate size (up to about 10 lb.) are to be made. This process involves the production of mold halves by applying a thin layer (or 'shell') of a mixture of sand and a thermosetting plastic onto a highly polished, heated metal pattern. After the plastic has 'set', the pattern is stripped, the two halves are cemented together and the 'shell' is backed-up with molding sand, insulation such as sil-o-cel, or metal shot depending on the cooling rate desired.

Others are working quite successfully on the use of true ceramic molds, or on sand bonded with ceramic, rather than organic binders. These methods have the advantage of producing better finish and closer dimensional tolerances than are readily attained by more conventional methods. They also have the advantage of preventing wash of mold material in the mold cavity, which creates non-metallic inclusions in the castings.

Evaluation Criteria and Test Methods

In general, castings purchased are based on either confidence in the integrity of the producer or on formal specifications. Unfortunately, specifications often are unrealsitic. This does not necessarily mean that they are too strict. It is entirely possible that specifications may be unduly restrictive and still result in the acceptance of castings which are unsuitable for the purpose intended. There can, of course, be no quarrel with radiographic testing providing that the standards are thoroughly understood and are suitable for the application. There can be no quarrel with analytical specifications which are within the composition limits established by groups such as ASTM[1], API[2], or ACI[3]. Mechanical property tests, however, are often most misleading. In the case

of castings, the samples are usually made from heavy keel-block castings which have no relation geometrically to the casting itself and which in most cases will have markedly different grain size distribution and, hence, ductility. Further, the mechanical properties in the case of heat-resistant alloys will have little to do with the actual service conditions and may be difficult, if not impossible, to interpret since, as pointed out above, the physical properties may well be of greater importance, particularly where cyclic heating is involved.

In the case of corrosion-resistant alloys the room temperature mechanical properties may mean but little, while corrosion resistance, grain size, machinability or weldability may be the controlling factors. A number of standard corrosion tests are used in the corrosion-resistant alloys, the most important being the Huey and Strauss tests. The one most commonly specified is the Huey test which involves subjecting a sample of the casting to boiling 65 per cent nitric acid for several periods of 48 hr. each. Positive reaction to this test indicates carbides in the grain boundaries, which in turn really only indicates whether or not the sample was properly heat-treated. Certainly care must be taken in the interpretation of results, though admittedly some test is required and the Huey test has been largely accepted. It can be assumed, however, that properly heat-treated material of the correct analysis will successfully pass any of the tests.

Economics

Heat and corrosion-resistant alloy castings must justify their use from the standpoint of economics. Important as is the price per pound, the expected life must be taken into consideration when economic analyses are being made. In the case of the heat-resisting alloys, furnace downtime, which may be as much as two weeks while a muffle is being

1. ASTM — American Society for Testing Materials.
2. API — American Petroleum Institute.
3. ACI — Alloy Casting Institute.

changed, can result in loss of production far more costly than the alloy involved. The same is true in chemical equipment, and in this case there is the added possibility of product contamination which the use of the corrosion-resistant alloys may well eliminate. In the selection of the alloy to be specified, thought must be given to such factors as equipment life, cost of downtime in production loss, labor cost of replacement, effect of product contamination, weldability, and many other factors.

With rare exception, the use of the heat-resisting alloys at temperatures above 1000°F. is always justified. The use of corrosion-resistant alloy castings is a ' must ' in the food and pharmaceutical industries and has been shown to be economically desirable in a great many other fields as evidenced by the increase in the use of stainless steels in the United States.

Acknowledgements

PAPERS DISCUSSED

MR. J. F. SEWELL (Samuel Fox & Co. Ltd., Stocksbridge)

Hundred-ton U.T.S. 4 per cent Ni-Cr-Mo for aircraft master rods has to be made to closely controlled limits to obtain satisfactory impact properties, but many difficulties are experienced through overheating in processes subsequent to steel-making. Has the use of the case-hardening variety of this steel, just oil-hardened and tempered, been considered for this application ?

While sympathizing with the plea that the aircraft industry should not be subjected to pressure to employ inferior quality steels the implication that steels termed substitutes are inferior is most unfortunate. It should also be stressed that low-alloy steels do not necessarily have inferior properties. Alloy conservation is essential if the world expansion of alloy steel production in the next few years is to take place.

MR. R. A. P. MISRA (Indian Wild-Barfield Ltd., Bombay)

It has been stated with some sense of an apology that more alloy steels are not used in railways because of their lack of availability in India. It should be realized that replacement of carbon steels by alloy steels must be justified on technical and economic grounds.

Mr. Cadambe appears to think that special alloy steels will not be available in India due to their small demand. Until recently the demand for aircraft alloy steels has been small. The electric furnace which can produce small casts of high-alloy steels will meet the situation.

Regarding hardening of aero-crankshafts nitriding is much preferable to induction-hardening which is only suitable for lightly stressed crankshafts such as those required for tractors and diesel engines. Only one German aero-engine has used induction-hardening of journals. An induction-hardened journal has discontinuities at the end of the hardened portion where maximum stress occurs and failures are common on highly stressed components. Induction-hardened surfaces also have residual

tensile stresses which reduce their effective fatigue stress.

DR. B. R. NIJHAWAN (Dy. Director, National Metallurgical Laboratory)

In India, grain-controlled steels are rarely available in sections in which they will be required for connecting rods and so on. In fact, I think it comes down to this that the Indian railways use silicon-manganese spring steels and virtually use no other alloy steels at all except when a big job comes up, like a major bridge project. I feel that Prof. O'Neill's paper could be studied with great profit by the Railway Board.

MR. E. H. BUCKNALL (Director)

In connection with the next paper Mr. McFarlane probably will be interested to know that at the National Metallurgical Laboratory we have been trying to extend the range of usable silicon steels beyond 4 per cent by carrying out all the cold-working operations hot, but so far without very great success. I think the possibility of a 100-times' increase in resistance giving a 10-times' increase in lamination thickness is just beyond the realm of all physical possibility. I do not like to be directive about the matter, but I think a 4-times' increase in resistance giving double thickness in lamination is just within the realm of possibility and no more.

Regarding Mr. Cadambe's paper that in England, apart from the engine, the engine mountings, the underframe part, wing attachments, etc., are made in alloy steels, usually in the form of forgings. Incidentally, I wonder whether it is generally realized by people flying in Dakota aircraft that in the Pratt-Whiteney double-wasp engine the cylinder wall thickness is 0·11 in. Quite a number of accidents have, in fact, involved tensile failure of the cylinder wall.

MR. R. A. P. MISRA (Indian Wild-Barfield, Bombay)

Mr. Sundaracharlu may have left the impression that 'Carbodrip' gas-carburizing fluid may have to be imported. I am pleased to inform him that arrangements have now been made to manufacture this material from indigenous raw materials and supplies can be guaranteed.

DR. B. R. NIJHAWAN (Dy. Director, National Metallurgical Laboratory)

The third paper by Mr. Cadambe on the Application of Alloy Steels to Aircraft Industry in which Mr. Cadambe asked a question as to how he came in the picture. I would like to reply him on his behalf that he comes in the picture because before joining the N.P.L. he was a designer in the aircraft industry itself and I suppose his interest in the aircraft field has not lagged since joining the Council of Scientific & Industrial Research. He has given a very able survey of the aircraft material in relation to the metallurgical improvements that happened in that end and which could be achieved. The next paper on the Application of Stainless Steel in Nuclear Technology is a very important paper in the sense that it is the only paper which has dealt with the use of alloy steels for the nuclear technology fields, fields which are going to stay — specially structural materials for nuclear reactor's components which are going to form the most difficult field for research and development in different countries for the metallurgists, depending on the raw materials situation and the chemical engineering developments and technical personnel in each country. The subject is going to hold a very prominent figure so far as the metallurgists are concerned.

The last paper by Sutton and Geiger on Heat and Corrosion-resistant Alloy Castings of the United States is a very masterly survey of the situation which prevails in that country today.