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WELDING PARAMETERS AND THEIR EFFECT ON COLUMN STRENGTH

by

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CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

This thesis presents a study on the influence of different welding parameters on the magnitude and distribution of residual stresses in flame-cut plates 24" x 2" made of A36 steel. The residual stress diagrams obtained after complete sectioning and after slicing are related to the original conditions of fabrication and manufacturing.

These welded flame-cut plates have been used as parent plates of a built-up section 24 H 428, and the strength of this heavy section is analyzed. The differences observed in column strength of this simulated section 24 H 428, built-up with flanges of 24" x 2" flame-cut center-welded plates and a web of 20" x 1 1/2" flame-cut edge-welded plate, is correlated to the different heat inputs caused by the different welding parameters. Conclusions are drawn with respect to the effect of the different welding parameters on the strength of the column.

A special investigation has been made on the different plates in order to find the variation of the mechanical properties through the thickness and at different locations across the 24" x 2" plates. The mechanical properties were determined by means of tension tests on the small size specimens. The results are discussed and compared with the pattern of residual stress obtained previously.

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1. INTRODUCTION

Thermal stresses due to different sources of heat have been investigated both analytically and experimentally during the past fifty years. First the derivation of the temperature distribution in plates during welding and cutting held the attention of several investigators.(1,2) After having assumed erroneously an elastic behavior of the formation of residual stresses during the process of welding or during cooling after rolling, it was recognized(3) that the residual stresses resulting after cooling were due to plastic deformations. Physical and analytical explanation of the formation of residual stresses due to different thermal effects have been developed more recently.(4,5,6) Much attention was paid to the existence and to the possible effect of residual stresses on the strength of structural members. An important analytical and experimental contribution to the solution of this problem and in particular of the effect on column strength(7) was made at Lehigh University through various research projects over the past two decades.

The scope of the study described in this thesis was to investigate the effect of different welding parameters on the magnitude and distribution of residual stresses. The experiments were carried out on 6 flame-cut plates 24" x 2" and one flame-cut plate 20" x 1 1/2" made of A36 steel. The welding parameters were chosen to meet certain requirements. The welding parameters were based on the AWS recommendations,(8).

and the variations of the parameters were adopted such that they stayed within the limits of variation inherent to any fabrication process, and for which the influence of welding conditions would be of considerable interest. However, one plate was kept "as-manufactured" for the purpose of comparison, and another was annealed. The main reason for this procedure was to investigate if the heat-treating process would lead to a significant reduction of the magnitude of the residual stresses. A stress relieving process by thermal treatment may be of particular interest in certain cases.

The second aspect was to investigate the influence of the welding conditions on the strength of a simulated welded section built-up from the investigated plates. It has already been shown(9) that the residual stress distribution obtained for a welded section is more or less the same as it would be for individual parent plates composing the section. The strength of structural members can be predicted, knowing the magnitude and the distribution of residual stress in individual welded plates. This aspect of the investigation is of considerable interest. Nowadays heavy welded columns of different shapes are being used to an increasing extent in steel structures, and for technical and economical reasons column tests cannot be performed on such heavy sections as was done in the past with lighter sections. Little information has been available on residual stress and the strength of heavy columns and in spite of the intensive utilization of these heavy shapes in construction, the design recommendations developed for light and medium shapes are nevertheless applied when designing heavy sections.

High tensile residual stresses are created in the vicinity of heat sources. Since little information has been available on the mechanical properties of the heat-affected parent material and the weld material, this has lead to a great uncertainty as to how residual stresses can exceed the yield point of the non heat-affected parent material. The third part of the thesis describes the investigation on the variation of mechanical properties through the thickness and across the width of several flame-cut center-welded plates.

2. RESIDUAL STRESS SPECIMENS PREPARATION

The tests were conducted as a part of an intensive investigation concerned with the study of the magnitude and distribution of residual stresses in thick welded plates, and with the purpose of relating this phase of the investigation towards the strength of the compression members.

The manufacture and fabrication of the thick flame-cut and universal-mill plates made of A36 steel were observed. Information collected during the manufacture and fabrication of these test specimens, starting from the rolling of the component plates and up to the final welding or flame-cutting, was recorded.(10)

This phase of the investigation is concerned mainly with 24" x 2" and 20" x 1 1/2" A36 flame-cut plates. The six specimens of 24" x 2" flame-cut plates, see Fig. 1, were reduced to the required sizes by simultaneously flame-cutting both longitudinal edges of a 26" x 2" universal-mill plate. The 20" x 1 1/2" flame-cut plate was obtained by flame-cutting the edges of a 22" x 1 1/2" universal-mill plate. The machine used was a standard burning machine equipped with two torches to burn both edges at the same time. Air burning tips (#3, style 263) were used with propane fuel at 316 psi and oxygen at 55 psi. The flame-cutting speed was set on this burning machine at 10 ipm. Temperature measurements were taken by drawing lines on the plate surface with Tempelstick temperature crayons. Results obtained for the temperature distribution across the width can be found in Ref. 10. Five 24" x 2" test specimens were set apart from the same parent plate as shown in Fig. 1, and the sixth specimen was taken from another flame-cut plate. Identical manufacturing conditions were used for all parent plates in order to reduce the number of parameters to a minimum. For this reason the parent plates were sampled from the same heat and subjected to the same rolling conditions and the same rolling procedures in order to minimize the effect of different lots upon the mechanical properties. This objective was essentially fulfilled, and only very small differences can be found for the mechanical and chemical properties of the two plate sizes. This is illustrated in the mill test report shown in the table 1. A previous study has shown that the variation of the magnitude and the distribution of residual stresses within the material from one lot is relatively small, but somewhat larger variation may exist between residual stress patterns from different lots.(7)

Figure 1 indicates that the residual stress specimens were located at the center of each plate specimen. For technical reasons the plate specimens were cut from the parent plate by flame-cutting. Except at both ends, the variation of residual stress along a member free of any straightening effects is small.(7) Therefore the residual stress specimen was taken from the center part of the plate in order to eliminate the end effects.

Some of the plate specimens were center-welded, and when the electrode reached the center part of the plate specimen the thermal state was quasi-stationary; consequently, no sensible variation of longitudinal residual stresses due to the welding was expected in this part. This assumption has been always satisfactorily observed by different experimenters.(1,4,7)

The plate specimens designated CW-1, CW-2, CW-3, CW-4, CW-5 (CW for center-welded, and AM for as-manufactured) were prepared to contain the welds. For all these specimens, two V-shaped grooves identical to those shown in the detail A of Fig. 1 were made. The welds were deposited by a semi-automatic welding machine Lincoln ML-2 1/2. The type of electrode conformed to the AWS class E 7018. Table 2 shows the mechanical properties of the as-welded electrode as required by the AWS specifications AW 5.1-64T. The shielding was accomplished by enveloping the arc created between the plate and the electrode of 5/32" diameter wire with a granular 780 flux type. The details concerning the welding parameters are discussed further in Section 3.1. In order to delete the effect of the cold bending on the distribution and magnitude of the residual stress, no straightening of the plates at any stage of the fabrication was allowed.

3. EFFECT OF WELDING PARAMETERS ON THE MAGNITUDE AND DISTRIBUTION OF RESIDUAL STRESS

3.1 Welding Parameters

Five plate specimens of 24" x 2", welded with different welding parameters as described in table 3 were used in this investigation. One plate 24" x 2" was left unwelded, in order to give the initial condition of distribution and magnitude of residual stress. A flame-cut plate 20" x 1 1/2" was included in this study. The results of the residual stress measurements are needed for the investigation of the column behavior of a simulated built-up section.

The different welding parameters involved are the following:

- Number of passes and speed of welding,
- Temperature of pre-heating,
- Effect of a local and uniform pre-heating,
- Effect of a post-heating.

The above listed welding parameters were prepared in cooperation with the fabricator. In order to study only the effect of these welding parameters on the magnitude and distribution of the residual stress, it was endeavored to keep the material properties similar for all plate specimens, by the observation of the same manufacturing and fabrication conditions; in particular, the welds in each plate specimen were deposited according to the same welding sequence.

The specimen CW-1 was selected to conform to the requirements of the AWS specifications. CW-2 was adopted to show the difference which may have appeared in the case of a different number of passes, whereas CW-3 was proposed to study the effect of a higher pre-heating temperature on the magnitude of residual stress. The influence of a local pre-heating at a temperature of 400°F, in the vicinity of the grooves, is given by the specimen CW-4. The specimen CW-5 was stress relieved by heat treating. The specimen CW-5 was brought to a temperature of 1200°F and maintained at that temperature for 2 hours, then the specimen was cooled down in the furnace at a temperature of 600°F. Finally the specimen reached room temperature by air cooling.

The criteria which guided the choice were to stay as close as possible to practical welding conditions; in particular, the temperature of pre-heating was selected in terms of an economical criterion. The specimen CW-5 was included in this investigation to study whether the stress-relieving by heat-treatment reduces subsequently the magnitude of the residual stress, and to investigate if an appreciable change of the yield point of the weld and the parent material occur.

The data recorded from the condition of fabrication at the plant are contained in data sheets No. 1 to No. 5. The temperature of pre-heating and welding at the surface of the plate were taken with a thermo-couple as shown in Fig. 2. Slight modifications appear between the selection of welding conditions as expressed in Table 1 and the technical working conditions. It has been noticed, that the V-shaped grooves were at a higher temperature than any other part of the plate during the pre-heating. Figure 3 illustrates the typical set-up for pre-heating. The maximum temperature observed was 50°F. The drastic condition imposed in the theoretical choice in the case of a local pre-heating was not possible to realize in practice. The edges of the plate specimen were at a temperature of 150°F and the gradient of temperature between the edges and the center part of the plate was not as severe as expected, due to the thermal transmission properties of the steel. In case of the plate specimen CW-2 the speed of welding was set up higher than proposed to satisfy the technical restraint of the automatic welding machine.

3.2 Nature of Residual Stresses

The welded specimens were not free of residual stresses prior to welding. The study is intended to show also the variation of the strength under different welding conditions, and thus consideration must be given to residual stresses existing in the parent plates before welding. Residual stresses are initiated in the material during the different stages of manufacture and fabrication conditions. Prior to welding, the pattern of residual stresses is the result of a complex state of superimposition of different distributions and magnitudes of residual stress.

First the plates were rolled to the required sizes of 26" x 2", and the resulting residual stresses were due to the cooling after the hot rolling. No measurements were made on this plate 26" x 2", but to give an idea of the magnitude and the distribution of residual stresses after this first operation, results of measurement made on a 24" x 2" plate of A36 steel, which belong to the same series of plates ordered for the project for use in a different phase, is shown in Fig. 4. The edges show compressive residual stresses with a maximum of -20 ksi, which are balanced in the center part of the plate by tensile residual stresses, whose maximum is +10 ksi.

Next, the flame-cutting operation reduces the sizes of the universal-mill plate to a 24" x 2" flame-cut plate, the resulting pattern of residual stresses is indicated in Fig. 5. It can be seen that the previous distribution of residual stresses has been completely changed by the flame cutting procedure. The edges are now in tension due to the heat input, (as a general rule the part of the plate cooling most slowly will be left in residual tension), whereas the center part of the plate is now in compression.

Only these two types of residual stresses existed in the plate prior to welding. Special care was brought to the fabrication operations in order not to include any other stresses due to cold-bending or any processes of cold-straightening. The distribution and the magnitude of residual stresses as reported in Fig. 5 can be assumed identical for all flame-cut specimens concerned in this study. The assumption made earlier that the distribution of cooling stresses and flame-cutting stresses is uniform for all residual stresses specimens prior to welding, seems to be reasonable because of the care in observing the same manufacture and fabrication procedures for all specimens.(11)

3.3 Results of Residual Stresses Measurement

The longitudinal residual stresses were determined by the sectioning method described elsewhere.(12) Only longitudinal stresses have been measured, because of their prevailing effect on the load carrying capacity of steel columns. First, the residual stress specimen was cut into elements of different thickness depending upon the stress gradient expected. From this procedure, referred as the complete sectioning, the magnitude and distribution of residual stresses on the large surface of the plates was determined. Figures 5 through 11 present, for each plate specimen, the results of the measurements, and also the sectioning detail. Then, the isostress diagrams as presented in Figs. 12 through 16 have been obtained from the superimposition of the residual stresses after sectioning, and the residual stresses variation across an element determined by slicing the element into small strips.(13) In the part of the plate affected by a local heat input such as produced by a flame-cutting or a welding operation, the variation of longitudinal residual stresses across the thickness of the plate was experimentally found very important. During the investigation the stresses released by the slicing procedure have been observed to vary between +6 ksi at the edges and -5 ksi at the center part of the thickness of the plate for an element located at the flame-cut edges and between +9 ksi at the edge and -7 ksi at the mid-thickness of the plate for a strip containing the weld. In the part of the plate not drastically influenced by the external heat input, the difference is between -2 ksi and 2 ksi at the mid section.

Results are shown in Fig. 11 for the residual stress measurements on the 24" x 2" universal-mill plate, referred to as UM-2, which was center-welded with approximately the same welding parameters as the specimen CW-1.(10) These results have been incorporated into this study to see the effect of the welding upon the magnitude and the distribution of residual stresses of two plates of same dimension but with different manufacturing procedure, that is, universal-mill or flame cut-plates. As pointed out previously, the pattern of residual stresses in a universal-mill plate, Fig. 4, and in a flame-cut plate Fig. 5, differs considerably. The purpose of this comparison is to find whether the preliminary state of residual stresses at the weld location as any influence on the magnitude of the maximum tensile residual stress due to the welding.

Table 4 summarizes the magnitude of residual stresses for the different plate specimens investigated. Specimens UM-1 and UM-2 referring to Figs. 4 and 11 are included. The data which are summarized in this table give information about the level of residual stresses at the edges and at the weld location of the plates, where the highest magnitudes of residual stresses are expected.

3.4 Discussion of the Results

Different patterns of residual stress have already existed in the plate specimens prior to welding, and these are known. First, there are the residual stresses which remain after cooling from the rolling, on which are superimposed the residual stresses due to the flame-cutting.

As seen previously all plates were rolled and flame-cut to the specified sizes, and the pattern and magnitude of residual stresses given in Fig. 5 can be assumed for all plate specimens before welding.

During the welding operation, there are two heat inputs, which explain the modification in magnitude and pattern of residual stresses; that is, the heat input due to the pre-heating or post-heating, and the heat input created by the welding procedure itself.

The symmetry observed in the distribution of residual stresses in the flame-cut plate, Fig. 5, is explained by the fact that the flame-cut edges have been burnt simultaneously. Furthermore, both surfaces of the flame-cut plate have an almost identical magnitude and distribution of residual stresses, which seems to indicate that the 2 inch thickness of the plate is not important enough to show quantitative discrepancies between both patterns of residual stresses. In other words, with this experimental result in mind and for a first approximation, the analytical problem of temperature distribution in a flame-cut plate can be also considered as a two-dimensional problem, in which the heat input per unit thickness is constant. The non-symmetrical pattern of residual stresses after welding, see Figs. 6 up to 9, is due to the sequence of weld passes adopted. In addition to the weld region, where a major modification in magnitude and distribution of residual stresses occurs, changes take place also at the edges of the plate under the double influence of the pre-heating and of the heat transmission effect during welding. Because of the welds deposited on one side of the plate, significant differences are noticed in the magnitude and distribution of residual stresses on both surfaces of the plate.

When comparing Fig. 11 with Figs. 6, 7, 8, 9 together it can be pointed out that whatever the pre-heating and welding condition, and whatever the pattern of residual stresses prior to welding, the tensile stress in the weld material reaches the yield point of this material. The previous observation is also clearly shown, by comparing the minimum requirement of the yield stress of the as-welded electrode material E7018 indicated in Table 2 with the maximum tensile stresses given in lines 5 and 6 of Table 4.

Due to the high gradient of cooling temperature in the vicinity of a local heat input, such as flame-cutting or welding the mechanical properties of the parent material will change. The tensile residual stresses in the parent material, resulting from a heat source, exhibit a higher yield stress than that of the non-heat-affected parent material. This fact appears more clearly in Figs. 12 through 16 than in Table 4 which did not include the residual stress variation through the thickness of the plate which is obtained by the slicing procedure as explained above.

The residual stresses in the surface which is welded undergoes a major modification compared with the initial pattern existing prior to welding. The variation of residual stresses through the thickness after welding is found to be nearly 10 ksi, which is substantially greater than those found in thinner plates.(14)

The isostress diagrams show the influence of the welding effect. It can be noticed in the case of the specimen CW-2, Fig. 14, that a greater penetration of the weld is due to the lower speed of welding.

The specimen CW-3, pre-heated at 400°F, does not show a significant modification of the magnitude and distribution of residual stresses, compared to the specimen CW-1, (Fig. 15 and Fig. 13). The raising of the pre-heating temperature from 200°F to 400°F does not provide a real benefit as far as the magnitude and distribution of residual stresses is concerned.

The heat-treated specimen CW-5, Fig. 10, which has been annealed, has residual stresses of such small magnitude, that the sectioning method used is not sufficiently accurate to be sure that the pattern shown in Fig. 10 is valid since the magnitudes are of the same value as the possible errors of measurement.

The differences observed in the residual stresses diagrams for specimens CW-1, CW-2, CW-3, CW-4 are small, see Figs. 6, 7, 8, 9 respectively, but the influence of the welding condition will be emphasized in Section 4 by considering their effect on the strength of the column.

4. EFFECT OF WELDING PARAMETERS ON THE STRENGTH OF A SIMULATED BUILT-UP SECTION 24H428

4.1 Introduction

Since the recognition of the importance of the effect of residual stresses on compression members, a great deal of research has been spent on the strength of structural members, both experimentally and analytically. Based upon the concept of the tangent modulus load and the theoretical ultimate strength analysis, a significant contribution for predicting the load carrying capacity of rolled sections was done in the past. More recently, the same approaches have been used successfully for predicting the strength of the welded built-up columns.(15,16) However the problem is more complex, and more involved than the determination of the strength of rolled sections, because of the great number of parameters implied.

- Manufacture of the section (universal-mill, or flame-cut plates),
- Geometry of the section,
- Geometry of the component plates,
- Welding conditions,
- Type of steel.

In the past, a rather good agreement has been found experimentally between predictions by the tangent modulus concept and tests results.(16) As discussed below, the necessary simplifications introduced by the theoretical concept of composing the section from separate plates does not warrant the use of the more refined prediction of the ultimate load analysis. Furthermore, a comparison of column strength for built-up sections composed of plates center-welded with different welding parameters was a major purpose of this investigation. Therefore, this investigation studied the tangent modulus load-carrying capacity of the simulated flame-cut welded column 24H428, built-up with different investigated center-welded plates.

Intensive testing on heavy welded columns can be performed only at great expense, and findings established in the past have to be taken into consideration. Extensive experimental investigations of residual stresses distribution in rolled and welded built-up section have been conducted by different investigators. From their studies(5,16,17) it has been found that a welded built-up shape may be considered separately as the component plates with welds, provided that the sizes of the parent plates, as well as the heat inputs, are nearly the same. As a first step, from the knowledge of the residual stress distribution in the component welded plates, the complete pattern of residual stresses in a built-up section may be deduced, see Fig. 17. With this as basis, the residual stress distribution and magnitude in the structural shape is used in the prediction of its behavior under compressive load.

Such an approach has been used here to study the effect of the welding parameters on the strength of a welded built-up section 24H428, see Fig. 17. This shape was simulated from the different plate specimens mentioned above. This welded section built-up from 2 flanges of 24" x 2" and a web of 20" x 1 1/2", was successively composed from the separate plate specimens which were investigated, and for which residual stress patterns were discussed earlier in Sect. 3. The reason for selecting this section is that the corresponding shape is available in the current research project, and therefore correlation between the results obtained for the parent plates themselves and the corresponding welded section can be made later.

No measurement on the simulated edge-welded plate corresponding to the web of the 24H428 shape has been performed. A plate supplied with such welding preparation was not included in the research project material. Figures 18 and 19 present the results of the procedure which has been followed to determine the distribution and magnitude of residual stresses. From the experimental pattern of the initial stresses existing in a flame-cut plate 20" x 1 1/2", Fig. 18a, the residual stress modification created by the welds deposited at the four edges of the plate has been computed, and compared with the experimental results available for a similar edge-welded flame-cut plate 9" x 1 1/2".(18) The temperature distribution has been evaluated from the study made by Rosenthal,(1) the coefficient of heat losses has been chosen to be 85% which gives a good agreement with the result experimentally found for the plate 9" x 1 1/2". In other words 85% of the heat generated is effective in causing thermal stresses in the plate 20" x 1 1/2" in order to obtain values comparable to those found experimentally. The others variables, amperage, voltage, speed of welding were taken from prior experience,(10) the thermal properties of the plate were adopted as to those suggested in Ref. 17. Figure 19 shows the residual stress distribution assumed in the web plate, and developed from the results of

Fig. 18b by adding the residual stresses due to slicing, as obtained from the data collected in similar plates.

A numerical method utilizing a digital computer was used to compute the tangent modulus load, taking into account the measured residual stresses distribution, and material properties discussed above. Two sets of non dimensionalized tangent modulus column curves (P/P_y versus λ) have been computed for both axes of the simulated section. The first set of curves correspond to the average of σ_r for the magnitude and distribution measurements of both surfaces of the plate obtained after complete sectioning as shown in Figs. 6 through 11; the second set of curves was computed for the actual variation of residual stresses through the section of the plate as indicated by the Figs. 13 through 16.

The numerical computation was accomplished by dividing the section into a number of finite area meshes, Fig. 20. The computation was based upon the following assumptions:

- Plane sections remain plane before and after the loading application.
- The stress-strain relationship in any fiber is an ideal elastic-perfectly-plastic diagram.
- The residual stresses distribution is symmetrical with respect to both axes. The experimental residual stresses diagrams were replaced by a symmetrical one obtained by averaging the distribution of the left and right parts of

the plate.

- The geometrical properties of the section are constant along the beam.
- The column is assumed perfectly straight.

4.2 Analysis of Results

A comparison between Figs. 21 and 22, or 23 and 24 indicates that the influence of residual stress is more pronounced for columns bent in the weak axis, than in the strong axis. This result is to be expected, from theoretical predictions.(19)

A closer look into Figs. 21 and 23 reveals that no sensible variation due to effect of the welding conditions is discernible in the tangent modulus curves with respect to the strong axis bending. The greatest difference in magnitude of residual stresses in component plates occurs mainly at the edges of the plate, and thus their influences upon the tangent modulus load with respect to the strong axis bending are less pronounced as it would be for the weak axis bending.

The variation of residual stresses released across the thickness of the plate due to the slicing procedure is of a large magnitude, only in the region locally affected by a steep cooling temperature gradient as seen in Sect. 3.3. Except for these areas this variation through the thickness of the plate is not important. Consequently for columns composed of wide plates, the tangent modulus curves computed from the average of the surface readings of the residual stress distributions and from the complete stress distribution through the thickness do not show a distinct difference, as would be the case for thick, relatively narrow plates. In the case where the isostress diagram is needed, it would be reasonable to slice some elements taken in the vicinity of the flame-cut edges and the weld region, with some additional strips taken from the non-heat-affected zone in order to determine the entire stress distribution.

Figures 21 and 22 indicate the great influence of the manufacturing procedure on the column strength, that is, for welded H shapes composed of universal-mill plates (plate specimen UM-2) and flame-cut plates. The existence of compressive residual stresses at the edges of a universal-mill plate is detrimental as far as column strength is considered, when compared to the welded built-up shape with flame-cut plates of the same size. The fabrication of built-up columns from flame-cut plates results in stronger columns, it is also economically feasible as well as technically possible by the use of motorized gantry-type burning machines which usually handles plates from 4 inches up to 15 inches thick and up to 160 inches wide.(20)

These figures, show clearly also the favorable effect of the stress relieving process on the strength of the column; however, such a process is expensive and, in general, impossible for large structural components. In any event, the absence of residual stress is the most favorable condition for column strength.

Examination of Figs. 22 and 24 indicates that a slight difference exists between the column curves of the shapes built-up with the plate specimens CW-1 and CW-2. The column curve for specimen CW-1 is higher than the column curve for the shape built-up from the plate specimen CW-2. In other words, the number of passes is not a critical factor in producing residual stresses. As found analytically(5) the major portion of the stresses are caused by the first pass. Also, the influence of reducing the speed of welding, which was also a welding condition imposed on the specimen CW-2, is negligible; the change expected theoretically in terms of this welding condition has proven to be very small.

Comparison of column curves in the case of the weak axis bending of the simulated built-up section with plates CW-1 and CW-3, (reflecting the difference in pre-heating temperature, that is, 200°F and 400°F), does not exhibit any significant variation (see Figs. 22 and 24). Thus, the effect of a variation in pre-heating temperature from 200°F to 400°F, has practically no influence as far as the improvement of the strength of the column is concerned. From the standpoint of stresses the indication given by this study is that, it is not worthwhile to increase the temperature of pre-heating, considering the economical factor involved, and as will be pointed out in Sect. 5.3, the mechanical properties of the material do not reveal a significant improvement.

Contrary to the two previous comparisons, the deviation in column strength between the specimens designated as CW-1 and CW-4 is more pronounced. Specimen CW-1 pre-heated uniformly differs from specimen CW-2 which was locally pre-heated. This points out the favorable effect of uniform pre-heating on column strength. Referring to the welding preparation of specimen CW-4, it was reported above that the transition of the pre-heating temperature between the local heat-affected zone at the welds and the edges of the plate was not as important as expected. This experimental information suggests that a greater variation in column strength may be expected in the case of greater differences in the pre-heating temperature between the weld area and the edges.

5. VARIATION OF MECHANICAL PROPERTIES

5.1 Tensile Test Specimen Preparation

The flame cutting or welding process leave high tensile residual stresses in the heat-affected region. These tensile stresses have a much higher magnitude than the yield point of the parent material.

A systematic investigation of the properties, through the thickness and the width of the plate, was conducted to clarify an uncertainty as to how such peak of tensile stress can be greater than the yield point of the parent material.

Values of the static yield stress, ultimate stress, percent elongation, and reduction of area, were obtained from tension tests on small size specimens taken at different location of the cross section as represented in Fig. 25. Standard test specimens with an 8 inch gage length were also made to check the results of the small sizes tension specimens. The testing procedure and technical terms adopted conform to those described in reference 21. All 2 inch gage length specimens were loaded similarly at two strain rates. Up to the onset of strain-hardening the rate of straining was set up at 0.18 ipm and in the strain-hardening range the speed of loading was raised to 0.45 ipm.

The 2 inch gage length tensile specimens were taken from the two heat affected zones and in the intermediary position. One specimen whose location is referred to as 11 in Fig. 25 contains a part of the weld.

The same distribution of the tensile test specimens, through the thickness and along the width of the cross section as indicated in Fig. 25, was kept for all 24" x 2" flame-cut plates designated as AM-1, CW-1, CW-2, CW-3, CW-4, CW-5. The reference number of a tensile specimen is composed of two digits which indicates the location of the specimen in the plate as described in Fig. 25. The numbering was adopted to help the discussion of the results, and the difference between "position" and "level" is clearly defined in Fig. 25.

5.2 Presentation of the Results

Complete information about the static yield stress, modulus of elasticity, ultimate stress reduction of area and percent elongation are given in Tables 5 through 11. The average of the different mechanical properties is also given, the weighted average has not been computed because the cross sectional area was almost similar for all specimens.

Figures 26, 27 and 28 show in a graph form and for each level, the variation of the static yield stress and the percent elongation of the 2 inch gage length tensile specimen for each plate.

5.3 Discussion of Results

The discrepancy observed between the values of the yield point of the material as given by the mill test report, Table 1, and the results of tension tests carried out on the same material as reported in Table 11, is mainly due to the effect of the strain rate.(21)

Figure 26 indicates that, for the plate specimens CW-1, CW-2, CW-3, CW-4, the weld and a part of the adjacent heat-affected base metal had a significantly higher yield point, a somewhat higher ultimate stress, a lower elongation, and reduction of area than the unaffected base metal (tension specimen 11). The tensile residual stresses obtained at the weld for all center welded plates, except for the stress relieved specimen, is around 63 ksi (Table 4); the yield stress of the material containing a part of the weld was found to be experimentally lower than the value previously given. This contradiction between the higher value of tensile residual stress and the slightly lower yield point can be explained by the fact that the tension tests were performed on a specimen which did not contain the weld entirely, whose yield point is higher as seen in Table 2.

Comparison between Table 10, which summarizes the results of the tensile tests carried out on the specimens coming from the annealed plate specimen CW-5, and Table 6 referring to a non-heat-treated plate specimen, point out the influence of the stress-relieving process on the material properties.

There is, for the stress-relieved specimen CW-5, an important decrease of the static yield stress for specimen location 11, containing the base metal and a part of the weld. Due to the stress-relieving process the base metal has a somewhat lower yield point, and higher ductility than the non-heat-treated specimen.

For the tension specimens, excluding CW-5, whose locations are 12, 22 and 32, no significant effect of the heat transmitted from the steep rate of cooling during the flame-cutting or welding process is noticed. In other words the high temperature gradient has only a local influence on the magnitude of residual stress.

The differences in mechanical properties of the parent material, for the tension specimens sampled in the vicinity of the flame-cut edges such as 13, 23 and 33 are less accentuated. Only specimens in location 33 show clearly a higher static yield point than the parent plate material. Probably, this is due mainly to the fact that the specimens were cut from a region directly influenced by the flame. This fact has been verified by observing the line markings produced by the liquid particles in fusion on the cut face. Reference 23 notes very high values of the Rockwell hardness in the area located in the immediate vicinity of the cutting flame. The difference of the Rockwell hardness through the thickness is explained by the difference of microstructure of the cut face. This confirms the high magnitude of tensile stresses found in the heat-affected area. These deviations are certainly more important than those experimentally observed. The size of the tension specimen does not give a full indication of the mechanical properties in the immediate vicinity of the flame-cut face.

Table 5, for the test results performed on specimen AM-1, does not indicate any significant variation of the mechanical properties along the width of the plate. The only difference observed, that is, a higher static yield point, holds true for tension specimens coming from the neighborhood of the flame-cut edges.

6. SUMMARY AND CONCLUSIONS

The investigation described in this thesis, has been concerned with the effect on residual stresses and column strength of the welding condition, pre-heating, post-heating, temperature, number of passes, speed of welding. The experimental work was carried out on 24" x 2" flame-cut and universal-mill plates of A36 steel. This study was a part of a major research program intended to determine the residual stresses in thick welded plates and shapes and to relate this to the load carrying capacity of compression members.

In this thesis the influence of the welding conditions is studied in two separate steps. Firstly, the evolution and differences of the magnitude and distribution of the longitudinal residual stresses have been investigated. Secondly the effect of these different patterns of residual stress on the load-carrying capacity of simulated column shapes built-up from flame-cut plates has been analyzed. Special attention is paid to the variation of mechanical properties of these specimens subjected to different heat input during their fabrication. From these investigations, the results found may be summarized as follows:

(1) The variation of residual stresses across the thickness of a plate was found to be significant in the heat affected zone, but in a region of 2" distant from the flame-cut edges and the weld area this variation is greatly reduced.

(2) Whatever the pre-heating and welding conditions of the plate, the maximum tensile residual stress created in the weld area reaches the yield point of the weld material.

(3) In those regions of the parent material subjected to a very steep gradient of cooling temperature, as in the case of cutting or welding processes, it has been found that the residual tensile stresses in those regions are equal to the yield point of the weld metal, or metal affected by flame-cutting, which is higher than the yield point of the unaffected parent material.

(4) A higher pre-heating temperature of 400°F, as compared to the normal of 200°F, has no significant effect on the formation of residual stresses and consequently no real improvement of the tangent modulus load has been observed.

(5) Local pre-heating has been found to have unfavorable effect on the tangent modulus load.

(6) The sub-critical annealing has the effect of reducing considerably the magnitude of residual stresses to a negligible value. The mechanical properties of the parent material and the weld are also affected by this heat treatment. Also a lower static yield and ultimate stress with an improvement in the ductility properties were noticed.

(7) For relatively wide and thin plates, the variation of longitudinal stresses through the thickness has almost no influence on the tangent modulus load.

(8) The tangent modulus load computed with respect to the weak axis bending is more sensitive to variations of welding conditions.

(9) The manufacture and fabrication conditions play an important role in column strength. Welded shapes made of universal-mill plates have an unfavorable column curve compared with the column curves computed for a welded built-up section made of flame-cut plates.

(10) The number of passes and the speed of welding have almost no influence on the column strength of welded built-up sections.

(11) The weld and part of the adjacent heat affected base metal, has a significantly higher yield point, and slightly higher ultimate strength, whereas the ductility properties of the material are reduced compared to those of the base metal.

(12) Meaningful differences are observed for the mechanical properties between the tension specimens cut in the vicinity of the flame-cut surface, and the tension specimens taken from the unaffected base metal.

7. TABLES AND FIGURES

Table 1 Mill Report of Mechanical and Chemical Tests

Plate No.	Yield(1) Point (ksi)	Tensile Strength (ksi)	Elongation % (2)	C %	Mn %	P %	S %	S_i %
24 x 2	39	71	29.0	.18	1.00	.012	.020	.25
20 x 1 1/2	44.4	71	36.0	.20	1.00	.008	.019	--

(1) As given by a dynamic test

(2) The gage length was 8 inches

Table 2 Typical Mechanical Properties*

Electrode Name	Tensile Strength (ksi)	Yield Point (ksi)	Elongation in 2" %
E7018	72 - 79	60 - 66	24 - 31

*Conforms to Test Requirements of AWS-A5.1 & ASTM-A233. Low figures give the minimum AWS requirements of the as-welded material.

Table 3 Welding Parameters and Residual Stress Specimens

Flame-Cut Plates, A36 Steel

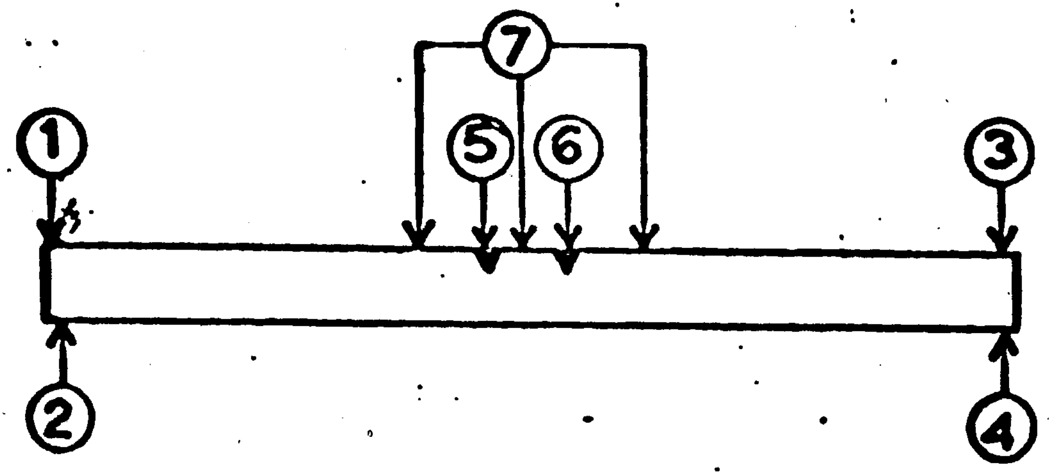
			First pass			Second pass		
Specimen number	Preheat Temp. °F	Postheat Temp. °F	Velocity imp	Current A	Voltage V	Velocity imp	Current A	Voltage V
Plates 24" x 2"								
AM-1*								
CW-1	200		16	410	32	32	410	32
CW-2	200		8	410	32			
CW-3	400 uniform		16	410	32	30	410	32
CW-4	400 local at weld	Annealing Process see Sect. 3.1	16	410	32	30	410	32
CW-5	200		16	410	32	30	410	32
Plate 20" x 1 1/2"								
H 428 FC W1*								

*Plates as-manufactured

Table 4 Residual Stresses Magnitude at Different Location Across The Plate Width

(ksi)

	Plate Specimen Name (FC)						(UM)	
Location	AM-1	CW-1	CW-2	CW-3.	CW-4	CW-5	UM-1	UM-2
1	32.1	28.0	22.4	5.4	4.1	1.6	-18.7	-24.0
2	35.1	41.3	28.1	14.5	14.5	-.1	-17.8	-15.1
3	37.2	28.1	7.4	4.1	13.4	-.8	-18.0	-21.1
4	39.1	39.5	18.2	11.0	22.9	-2.3	-18.7	-17.0
5	-.1	62.1	62.8	61.6	61.6	2.5	7.4	61.9
6	-.9	64.4	60.1	65.7	63.0	3.0	7.4	65.3
7*	-	38.2	42.8	36.2	39.1	-	-	42.3



*Values obtained by averaging the experimental results relative to the elements adjacent the elements containing the weld.

Table 5 Tention Specimen Test Results
Plate 24" x 2" (FC) - 36 Steel

Reference No.: AM-1

Tension* Specimen No.	Static Yield Stress (ksi) $\epsilon = .005$	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	32.9	24.0	65.8	65.4	46.5
21	33.6	32.2	67.4	63.2	42.8
31	32.4	27.8	66.1	64.4	44.3
12	32.5	32.1	65.9	60.2	44.6
22	33.9	27.0	69.2	63.6	42.0
32	32.4	29.9	65.9	65.4	47.2
13	36.3	28.8	67.0	63.7	43.5
23	35.0	31.6	67.7	64.7	42.9
33	37.8	28.3	65.9	69.2	42.0
Average	34.1	29.1	66.8	64.4	44.0

* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve.

***The gage length was 2 inches

Table 6 Tensions Specimen Test Results
Plate 24" x 2" (FC) - A36 Steel

Reference No.: CW-1

Tension* Specimen No.	Static Yield Stress (ksi) ε = .005	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	54.6	31.0	77.3	62.6	33.8
21	30.7	29.6	63.7	65.9	42.8
31	32.2	28.0	67.0	62.0	45.0
12	33.7	27.1	66.1	63.6	45.7
22	30.7	31.5	64.0	63.8	46.0
32	34.6	29.7	64.4	65.4	44.7
13	38.9	27.2	67.7	59.9	42.1
23	37.1	27.3	67.1	61.2	42.0
33	38.3	30.1	68.3	64.0	41.5
Average	36.8	29.1	67.3	63.2	42.6

* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

***The gage length was 2 inches

Table 7 Tension Specimen Test Results
Plate 24" x 2" (FC) - A36 Steel

Reference No.: CW-2

Tension* Specimen No.	Static Yield Stress (ksi) $\epsilon = .005$	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	52.2	27.0	76.3	53.2	28.4
21	35.7	31.6	69.7	61.5	40.3
31	34.9	27.9	66.1	62.1	43.7
12	32.5	27.7	65.5	64.5	45.5
22 22	33.7	30.2	69.0	61.6	44.9
32	34.7	28.3	65.3	61.8	44.1
13	35.0	29.0	66.8	65.0	43.8
23	34.9	28.1	66.9	62.3	45.7
33	38.9	27.8	66.7	61.1	44.0
Average	36.9	28.6	68.0	61.5	42.3

* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

***The gage length was 2 inches

Table 8 Tension Specimen Test Results Plate 24" x 2" (FC) - A36 Steel

Reference No.: CW-3

Tension* Specimen No.	Static Yield Stress (ksi) $\epsilon = .005$	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	49.6	30.0	74.3	60.5	34.0
21	34.7	29.7	70.1	63.9	43.0
31	31.9	27.4	65.9	61.6	42.5
12	32.9	29.2	65.8	61.1	43.5
22	33.9	29.7	69.5	60.6	42.0
32	33.7	27.9	67.0	56.9	45.5
13	37.6	28.3	67.8	63.5	41.5
23	35.5	28.8	67.8	63.1	39.9
33	39.4	29.7	67.3	62.3	44.9
Average	36.6	29.0	68.4	61.5	41.9

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* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

***The gage length was 2 inches

Table 9 Tension Specimen Test Results
Plate 24" x 2" (FC) - A36 Steel

Reference No.: CW-4

Tension* Specimen No.	Static Yield Stress (ksi) $\epsilon = .005$	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	51.2	28.4	75.4	60.2	35.5
21	38.1	25.9	70.3	65.2	40.5
31	33.6	29.8	67.2	64.3	42.0
12	35.2	29.7	65.9	62.7	46.0
22	35.4	28.2	70.8	62.8	41.5
32	33.2	24.3	67.1	64.5	41.4
13	36.5	23.5	68.0	62.9	44.2
23	37.1	27.8	50.6	65.1	43.5
33	41.1	27.7	68.3	62.7	38.5
Average	37.9	27.3	67.1	63.4	41.5

* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

***The gage length was 2 inches

Table 10 Tension Specimen Test Results
Plate 24" x 2" (FC) - A36 Steel

Reference No.: CW-5

Tension* Specimen No.	Static Yield Stress (ksi) $\varepsilon = .005$	Modulus of** Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length*** (%)
11	38.5	26.6	65.8	65.1	42.5
21	30.7	30.5	64.4	64.1	44.5
31	32.5	29.8	61.4	63.5	44.5
12	30.7	29.9	61.8	66.5	46.0
22	31.3	31.4	64.5	64.2	43.1
32	30.3	27.0	61.4	62.5	50.0
13	32.0	29.0	61.5	67.9	46.5
23	30.8	28.9	61.7	67.0	48.5
33	31.9	29.3	62.1	67.4	48.5
Average	32.1	29.2	62.7	65.4	46.0

---

* The numbers used in this table refer to those in Fig. 25

** The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

***The gage length was 2 inches

Table 11 Tension Specimen Test Results
Plate 24" x 2" (FC - A36 Steel

Correlation Tests
(8" gage length tension specimen)

Tension* Specimen No.	Static Yield Stress (ksi) $\varepsilon = .005$	Modulus of Elasticity E (ksi)x10^{-3}	Ultimate Stress σ_u (ksi)	Reduction of Area (%)	Elongation in Gage Length (%)
B-AM-1	33.0	27.6	69.1	62.6	33.4
B-CW-1	31.6	30.0	64.1	64.0	34.7
B-CW-2	32.4	33.0	68.0	62.5	33.3
B-CW-3	33.4	31.9	68.6	61.0	32.7
B-CW-4	33.2	31.1	68.0	60.8	31.7
B-CW-5	29.4	33.4	62.9	62.7	34.7
Average	32.1	31.2	66.8	62.3	33.4

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* The numbers used in this table refer to those in Fig. 25

**The values of E should be regarded as indicative only since they were evaluated directly from the autographically recorded curve

FIGURES

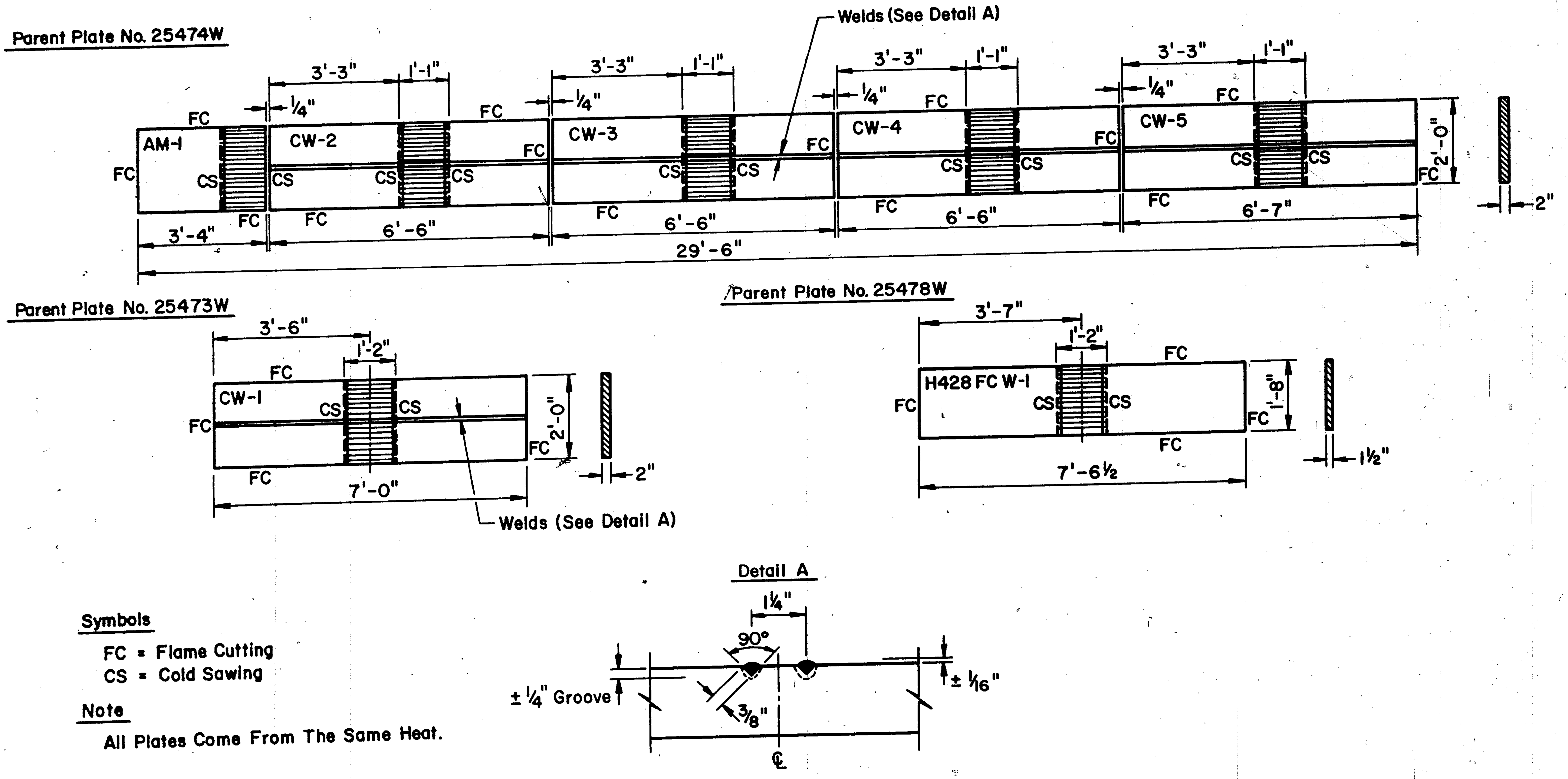


Fig. 1 Residual Stress Specimen Preparation

Fig. 2 Temperature Measurement

Fig. 3 Set-Up for Preheating

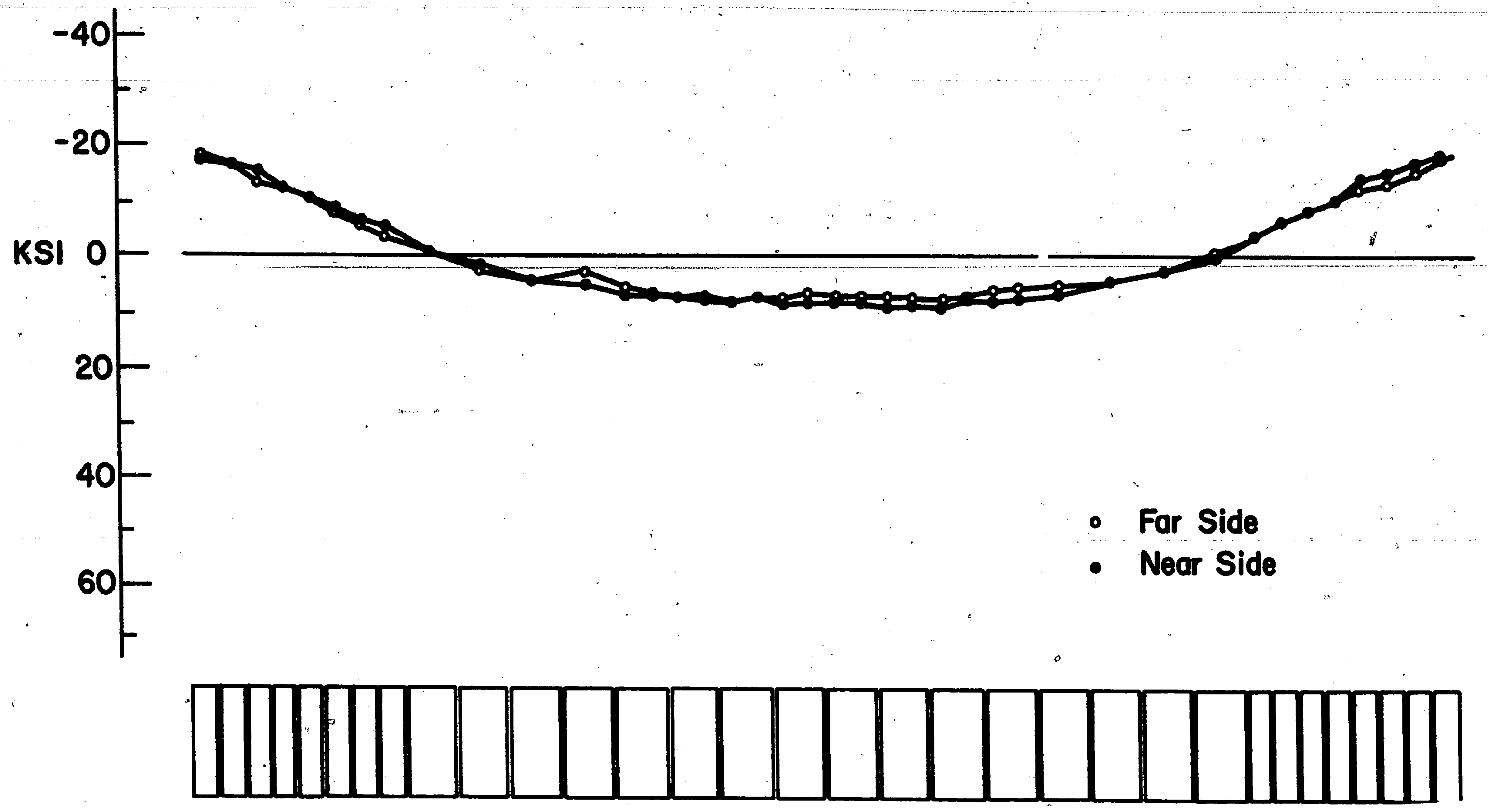


Fig. 4 Longitudinal Residual Stresses in an Universal-Mill Plate 24" x 2"

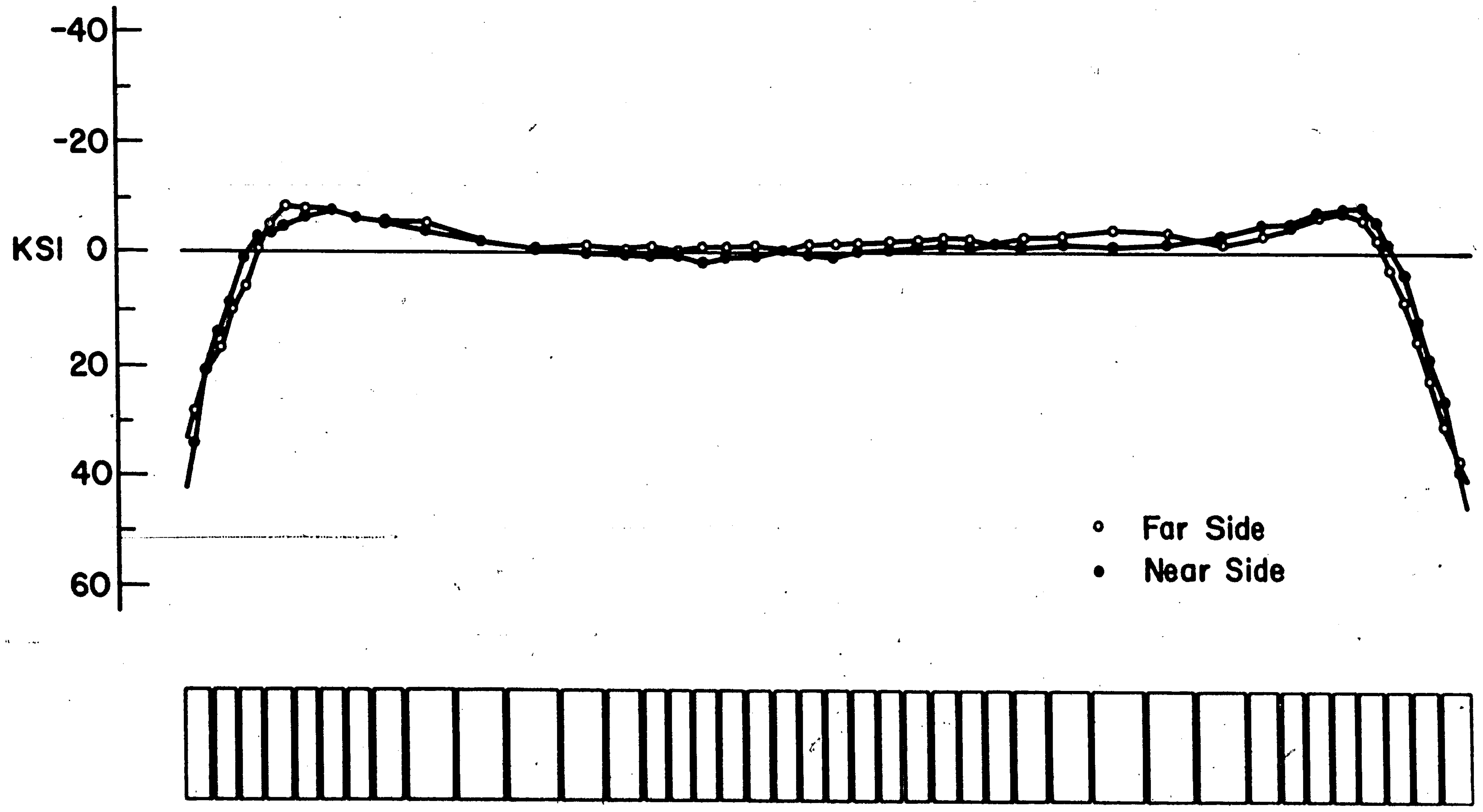


Fig. 5 Residual Stresses in a Flame Cut Plate 24" x 2"

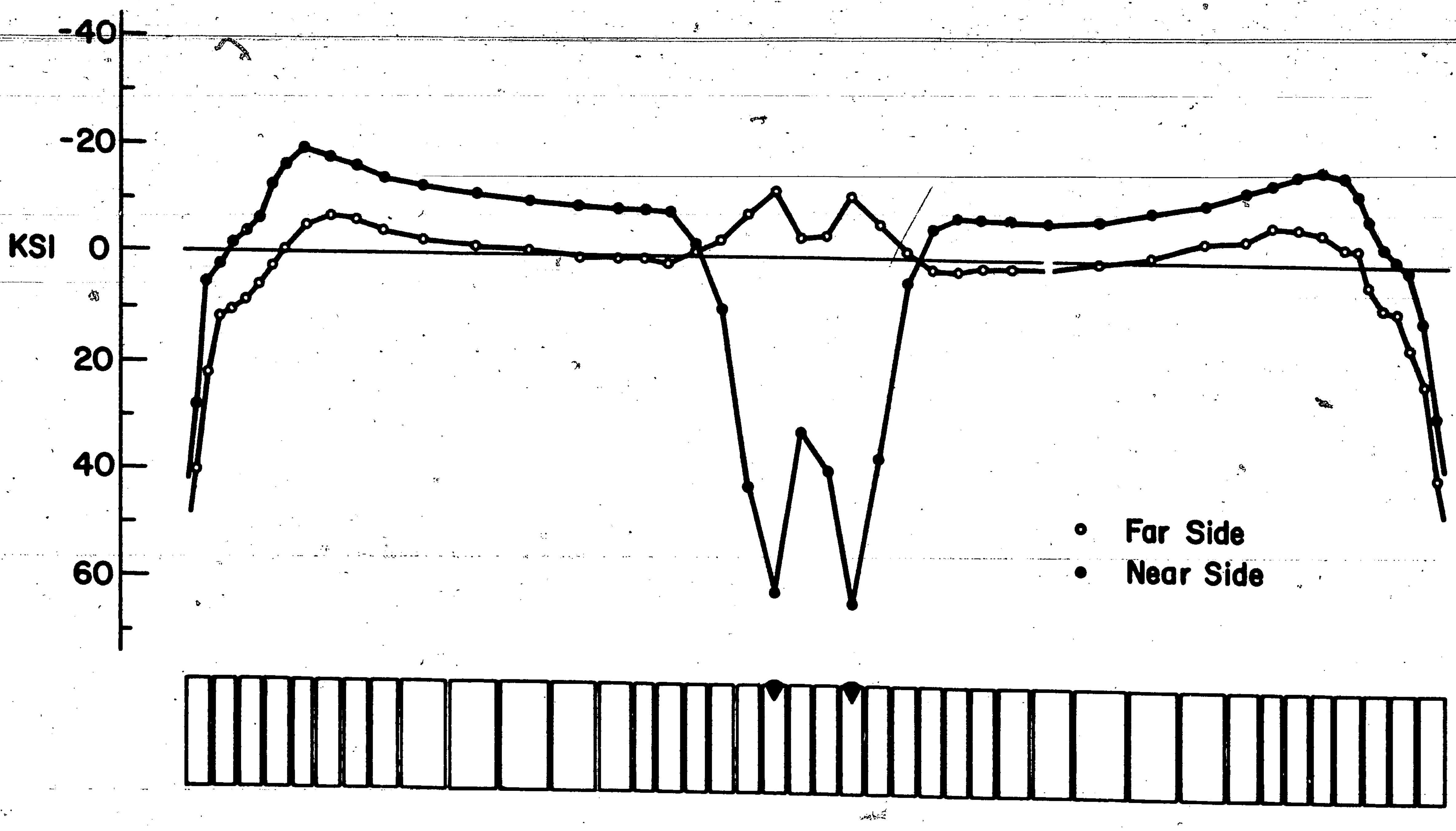


Fig. 6 Residual Stresses in a Flame-Cut Plate 24" x 2" Center Welded - Reference CW-1, (200°F Preheat, 2 Passes)

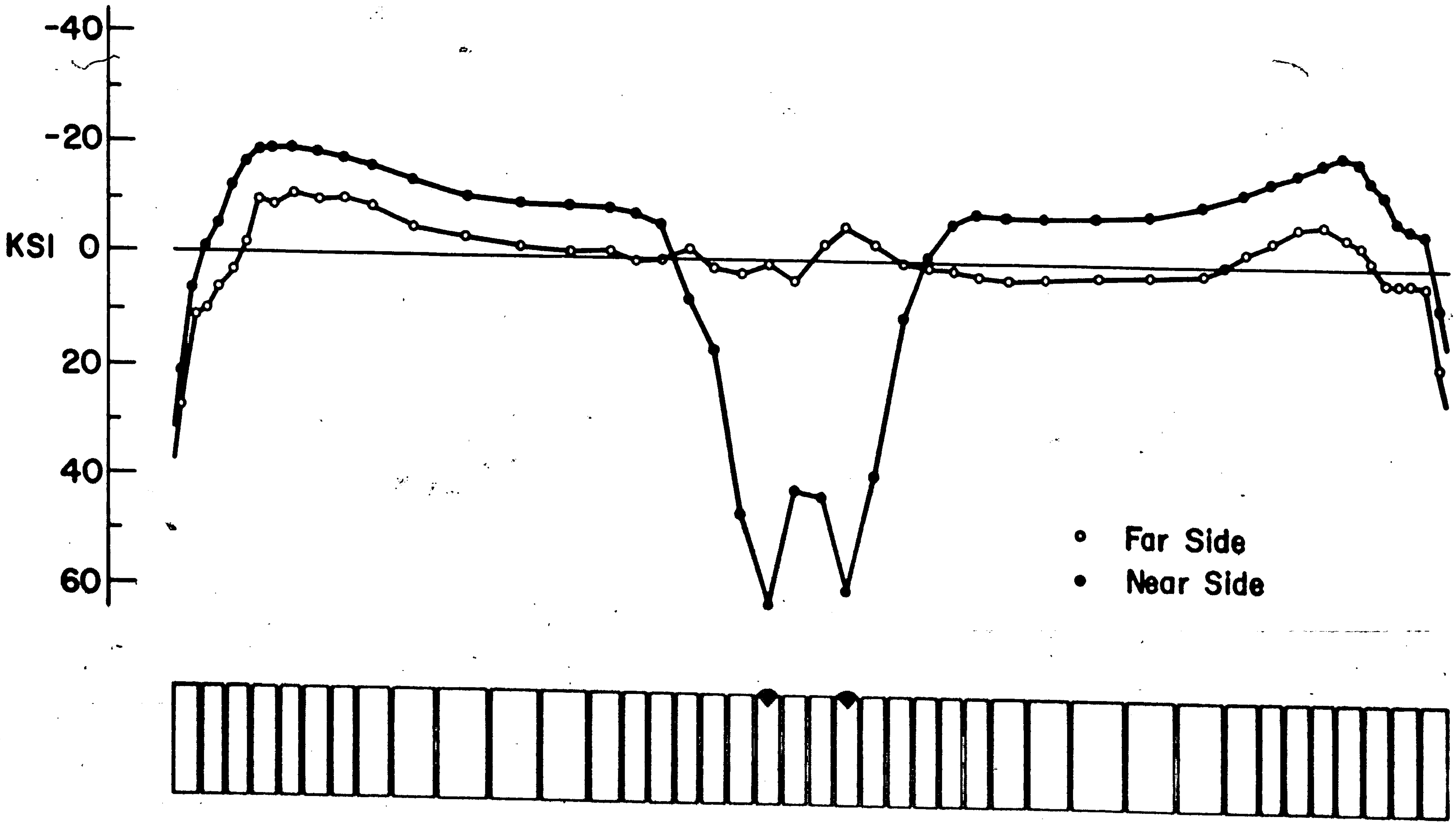


Fig. 7 Residual Stresses in a Flame Cut Plate 24" x 2" Center Welded - Reference CW-2 (200°F Preheat, 1 Pass)

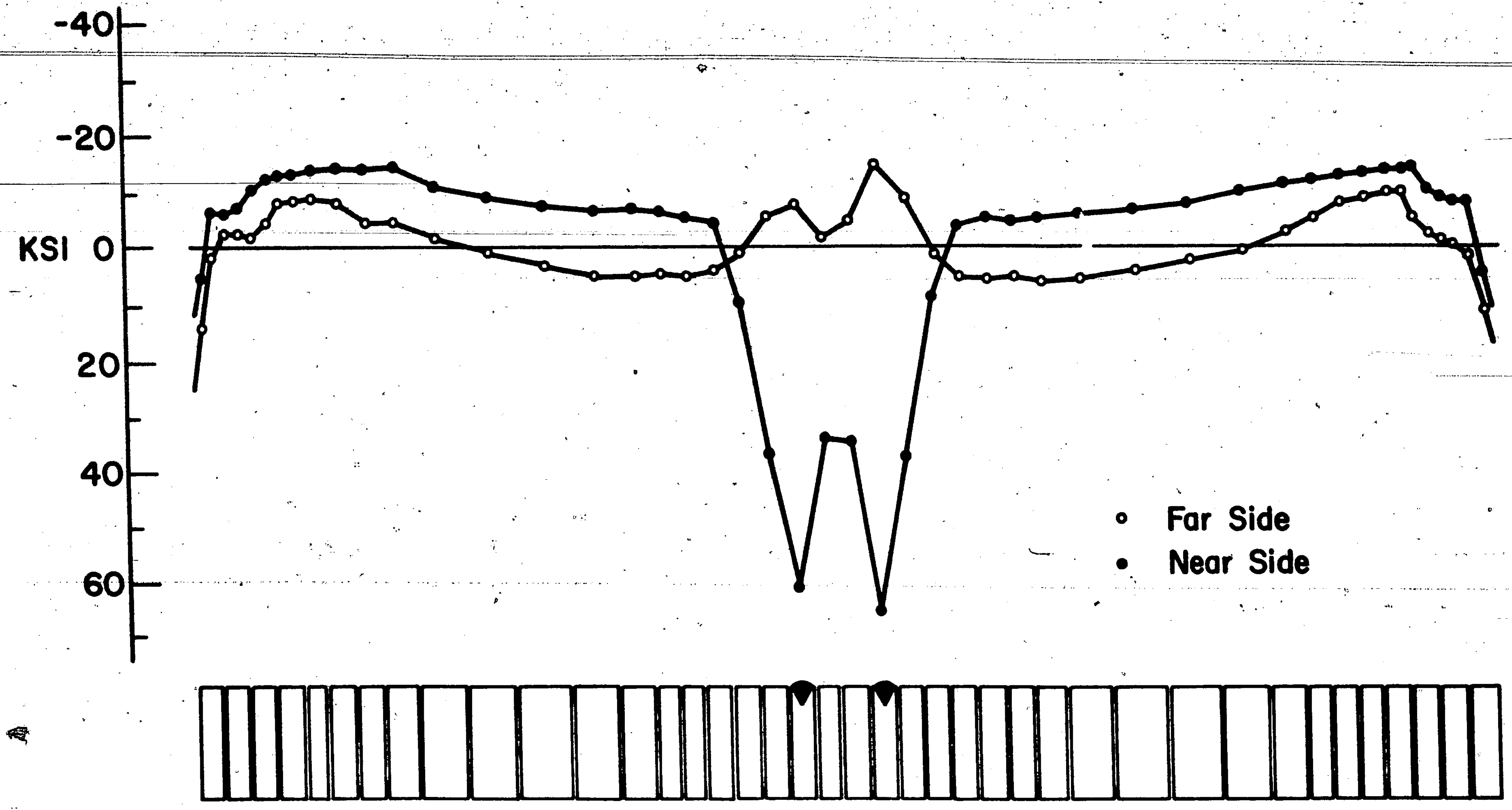


Fig. 8 Residual Stresses in a Flame-Cut Plate 24" x 2"
Center Welded - Reference CW-3 (400°F Uniform Preheat, 2 Passes)

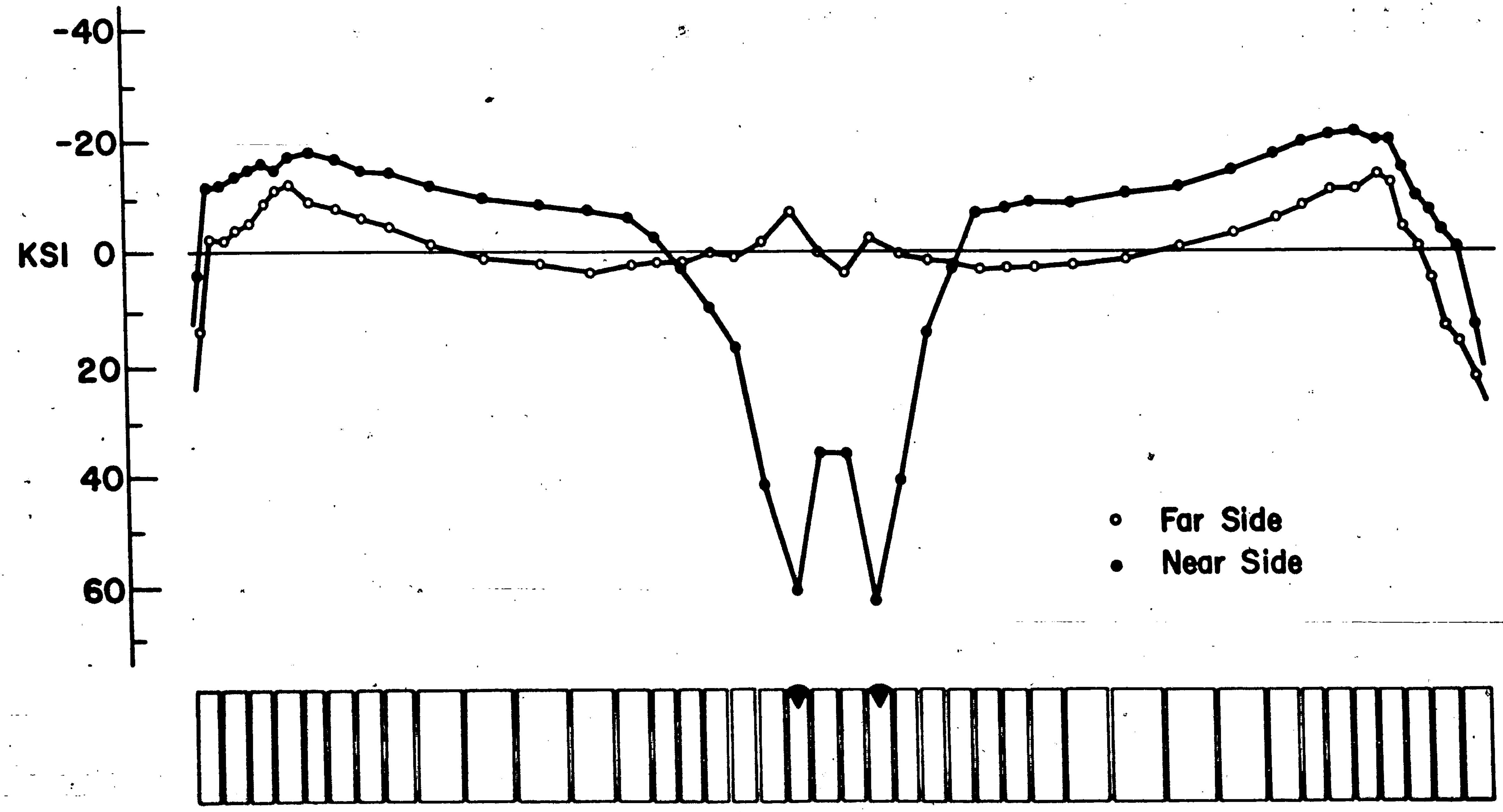


Fig. 9 Residual Stresses in a Flame-Cut Plate 24" x 2"
Center Welded - Reference CW-4 (400°F Local Preheat, 2 Passes)

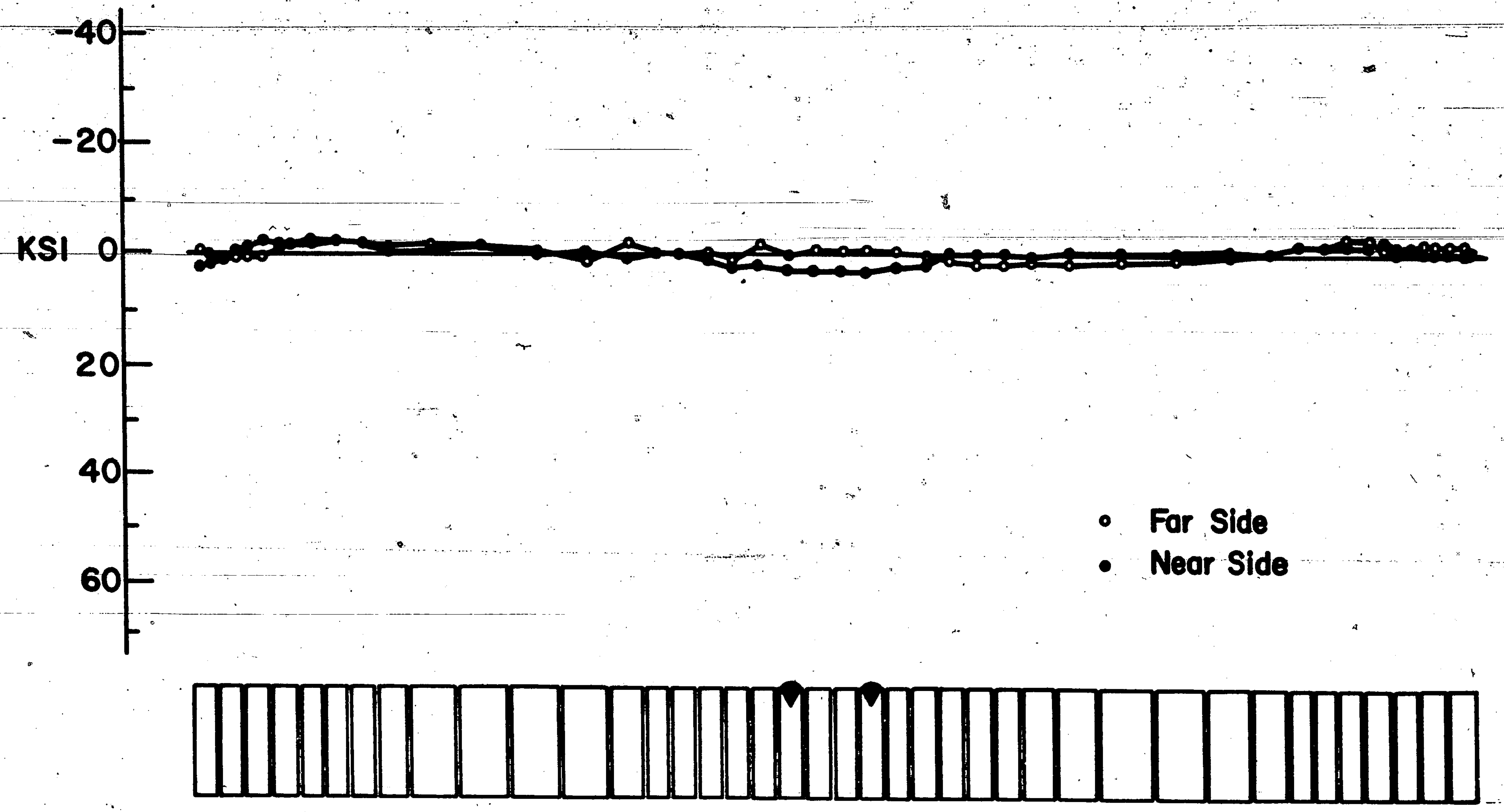


Fig. 10 Residual Stresses in a Flame-Cut Plate 24" x 2" Center Welded and Stress Relieved - Reference CW-5

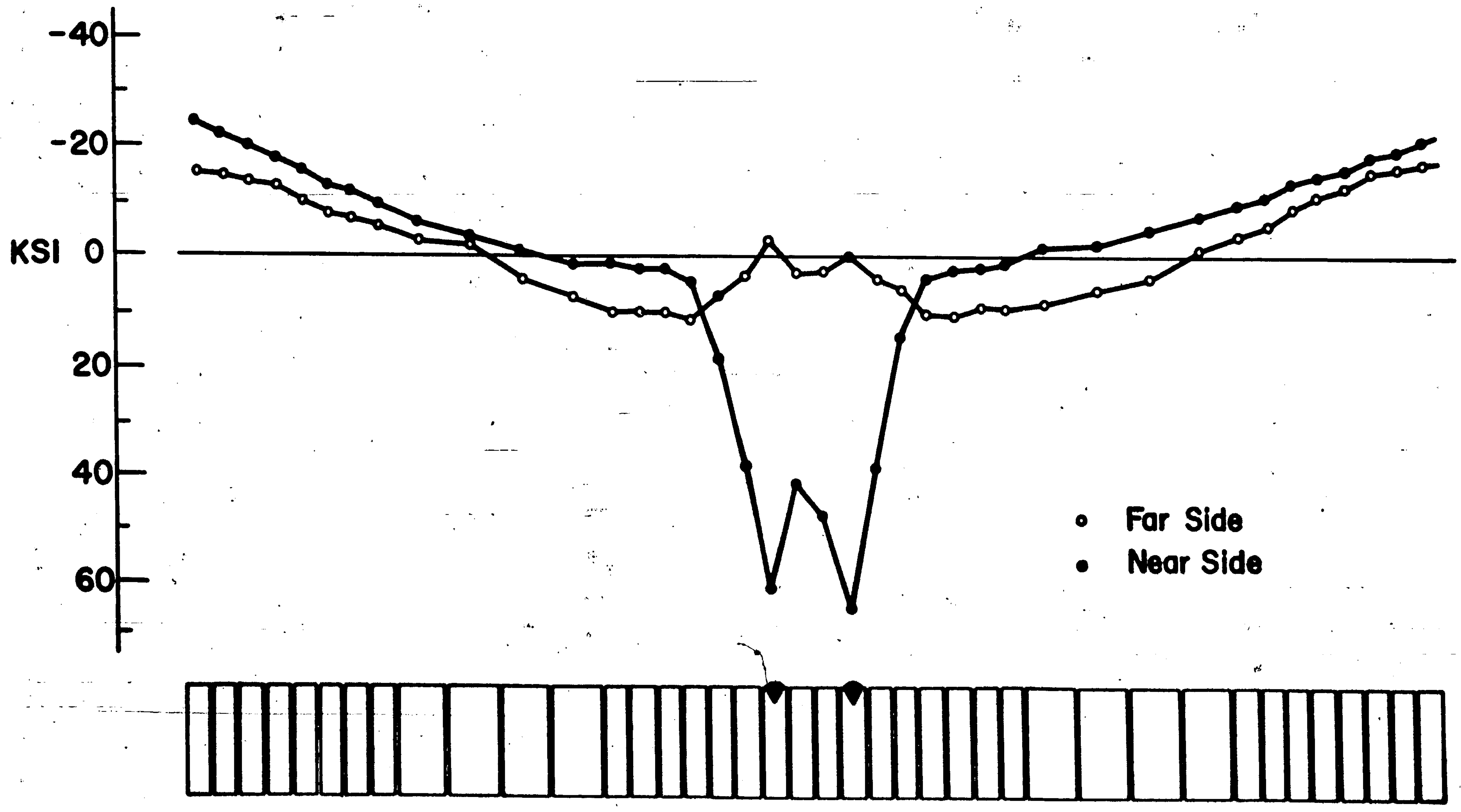


Fig. 11 Residual Stresses in a Universal-Mill Plate 24" x 2" Center Welded (200°F Preheat, 2 Passes)

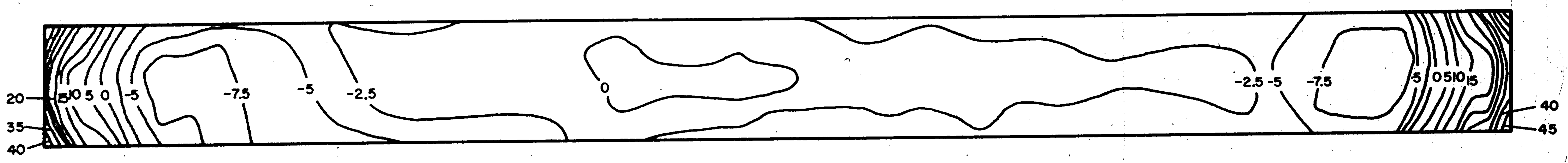


Fig. 12 Isostress Diagram of a Flame-Cut Plate 24" x 2"
Reference AM-1

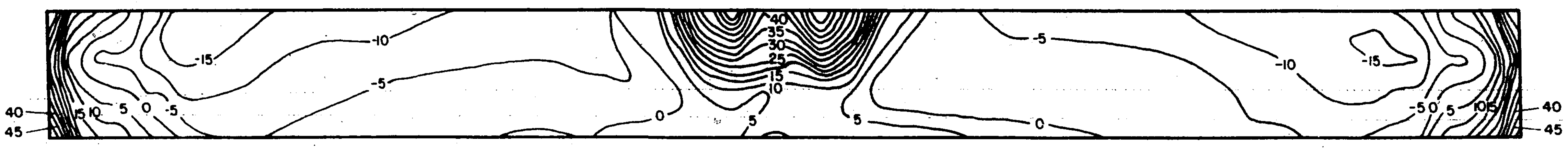


Fig. 13 Isostress Diagram of a Flame-Cut Plate 24" x 2"
Center Welded - Reference CW-1, (200°F Preheat, 2 Passes)

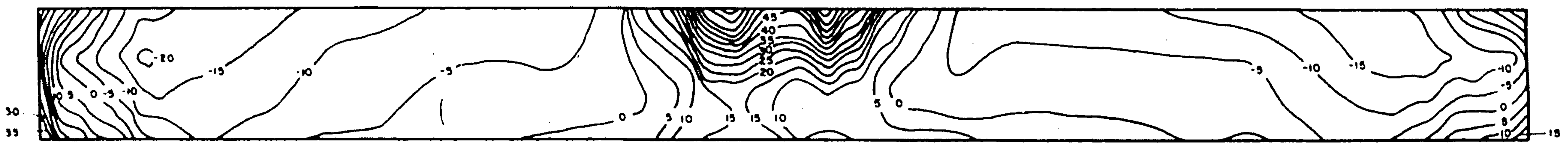


Fig. 14 Isostress Diagram of a Flame-Cut Plate 24" x 2"
Center Welded - Reference CW-2, (200°F Preheat, 1 Pass)

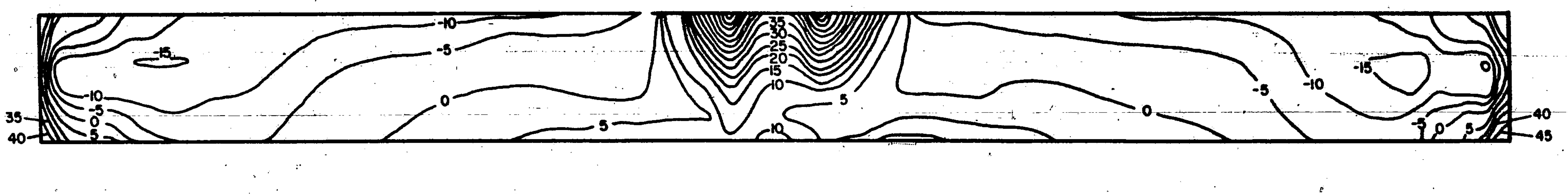


Fig. 15 Isostress Diagram of a Flame-Cut Plate 24" x 2" Center Welded - Reference CW-3, (400°F Uniform Preheat, 2 Passes)

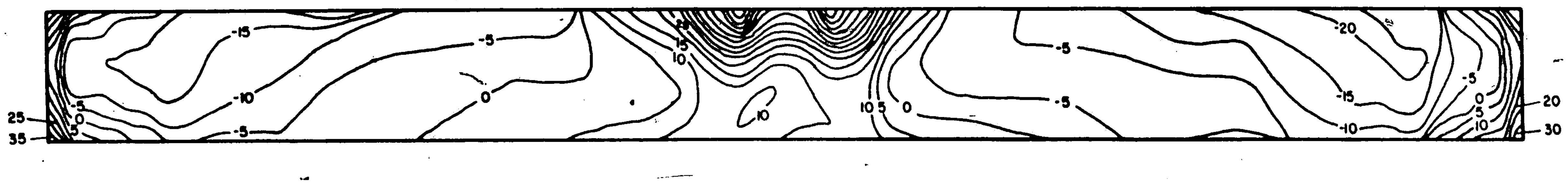
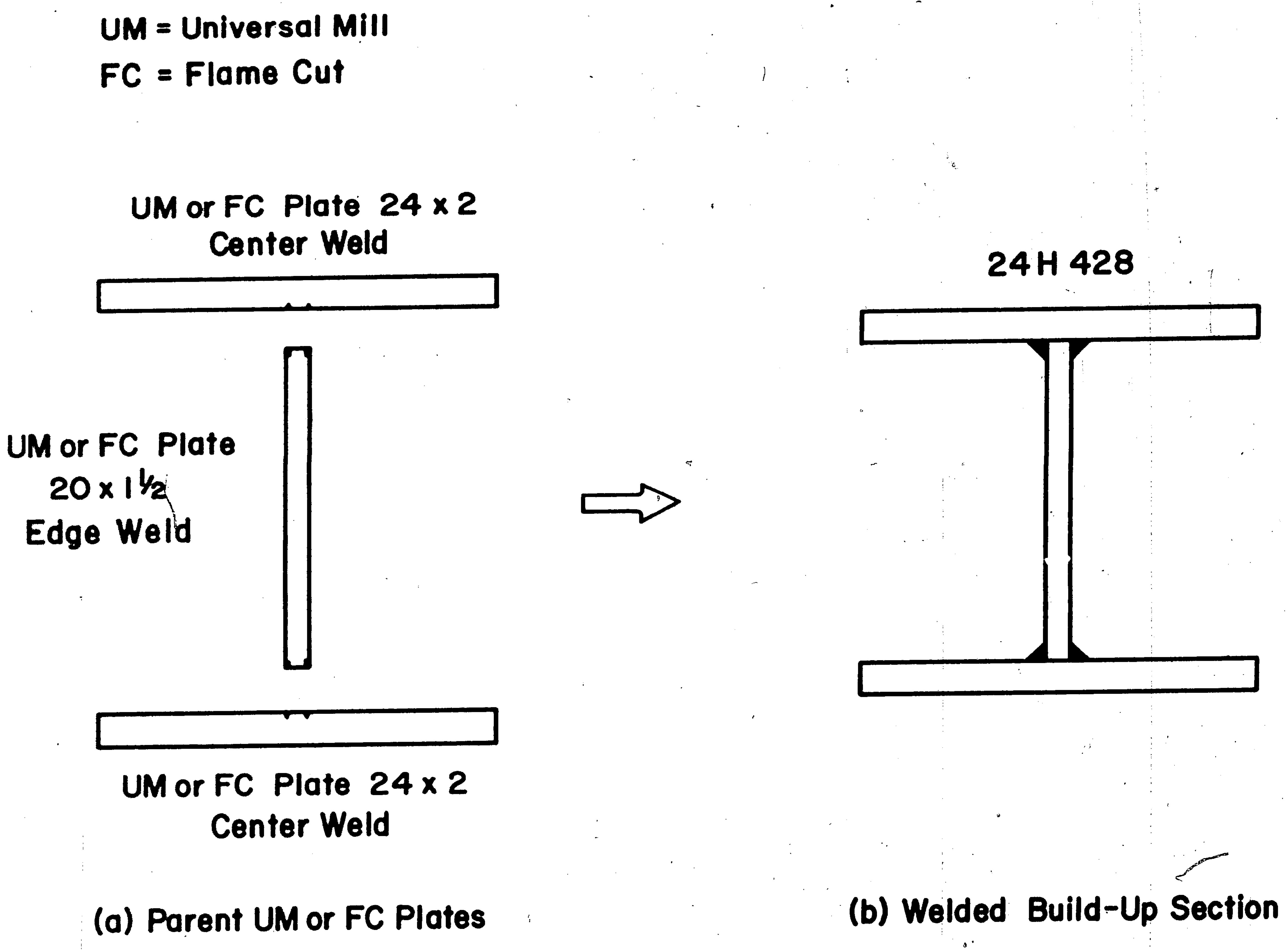


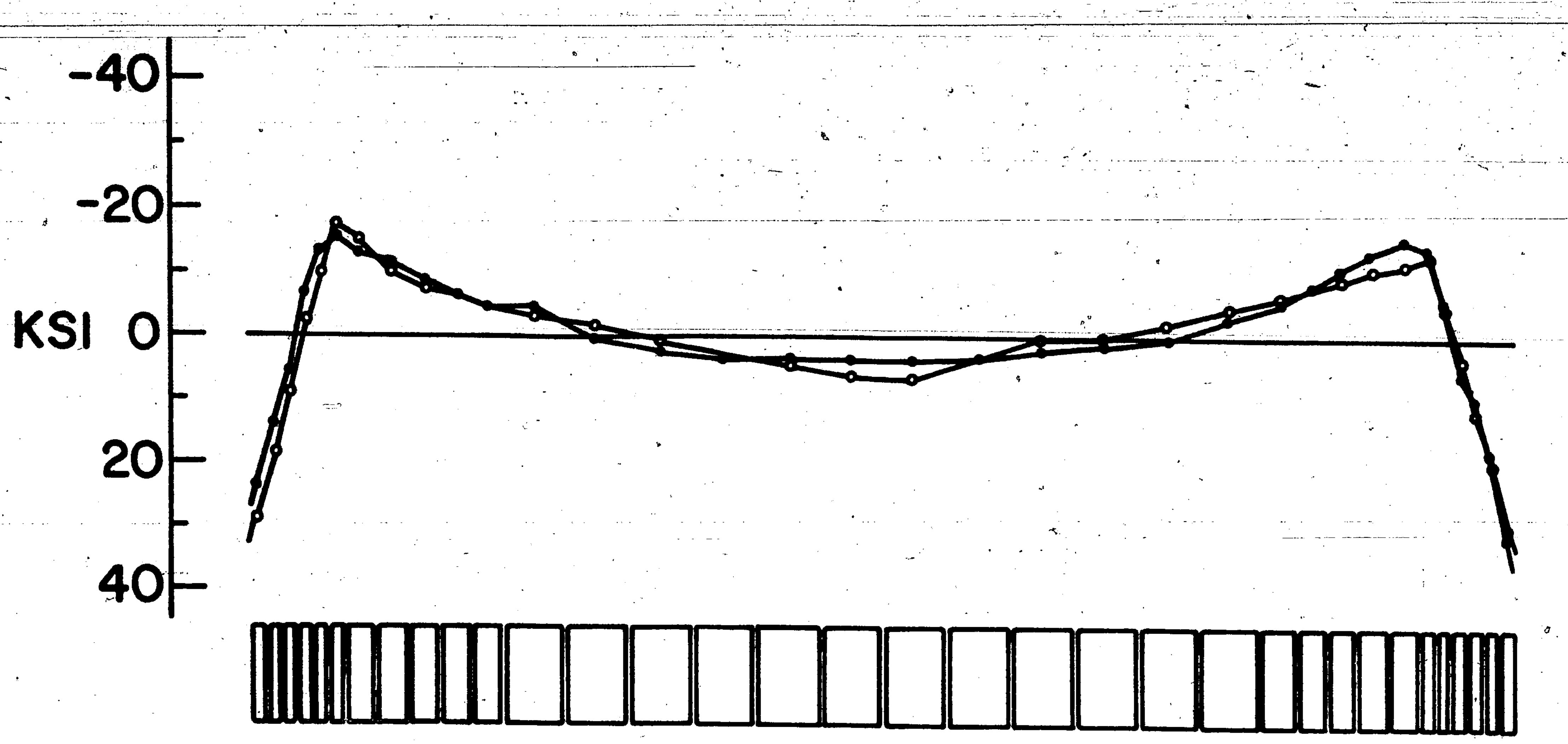
Fig. 16 Isostress Diagram of a Flame-Cut Plate 24" x 2" Center Welded - Reference CW-4 (400°F Local Preheat, 2 Passes)



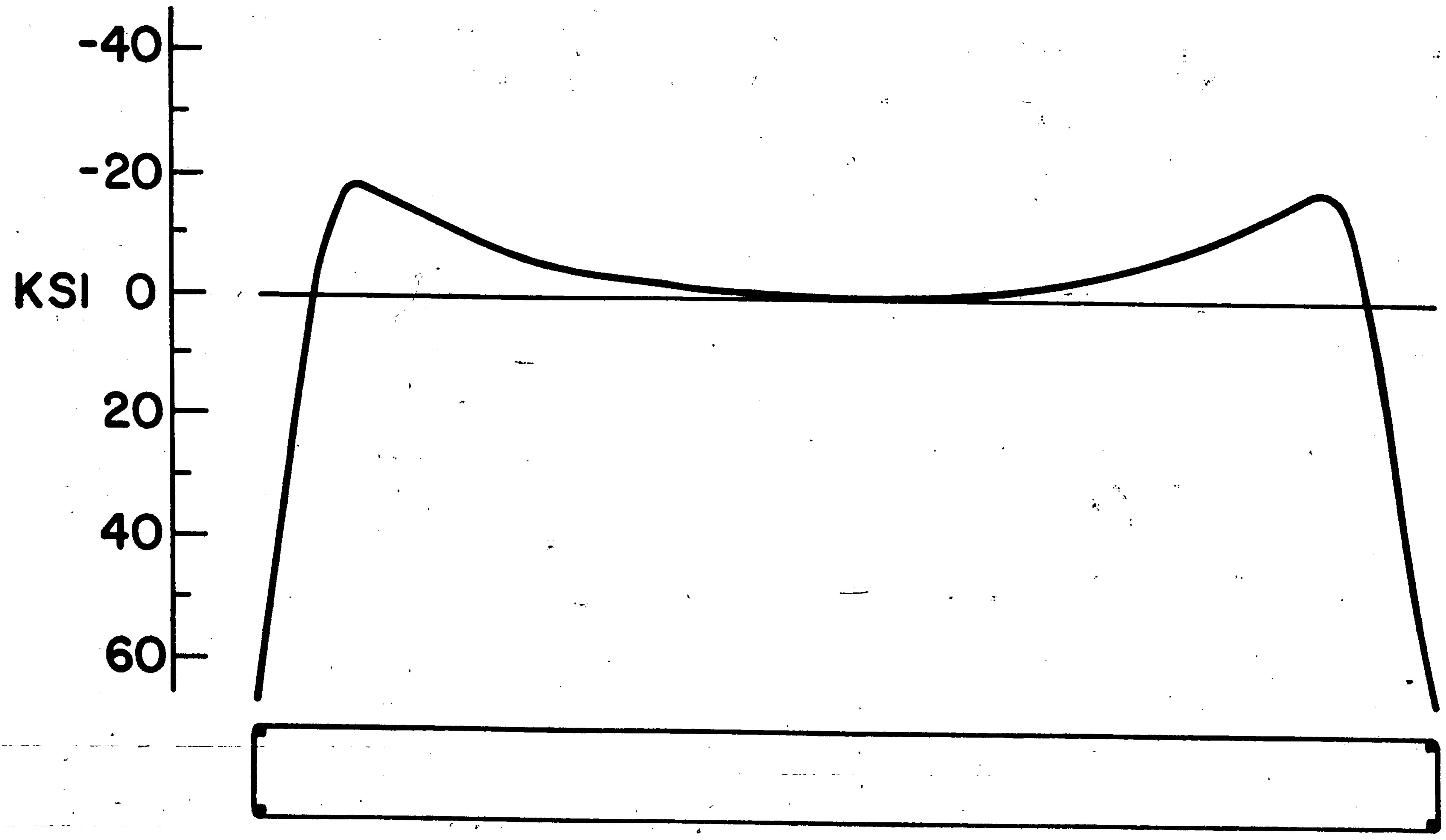
(a) Parent UM or FC Plates

(b) Welded Build-Up Section

Fig. 17 Schematic Representation of a Simulated Section Built-Up From the Plate Specimens



(a) Experimental Residual Stress For The 20 x 1½ Flame-Cut Plate



(b) Computed Residual Stress Distribution For The 20 x 1½ Flame-Cut Plate With Edge Welds

Fig. 18 Computed Residual Stresses Due to Welding in a 20" x 1 1/2" Flame-Cut Plate

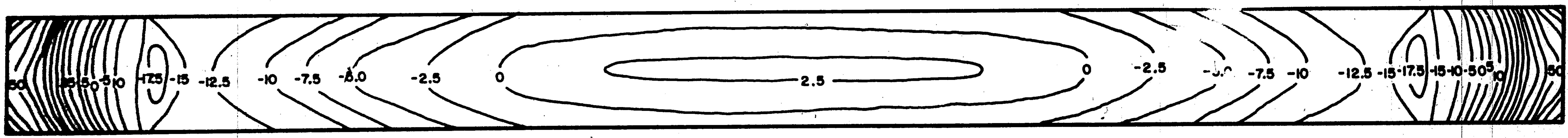


Fig. 19 Theoretical Isostress Diagram in a Edge Welded 20" x 1 1/2" Flame-Cut Plate

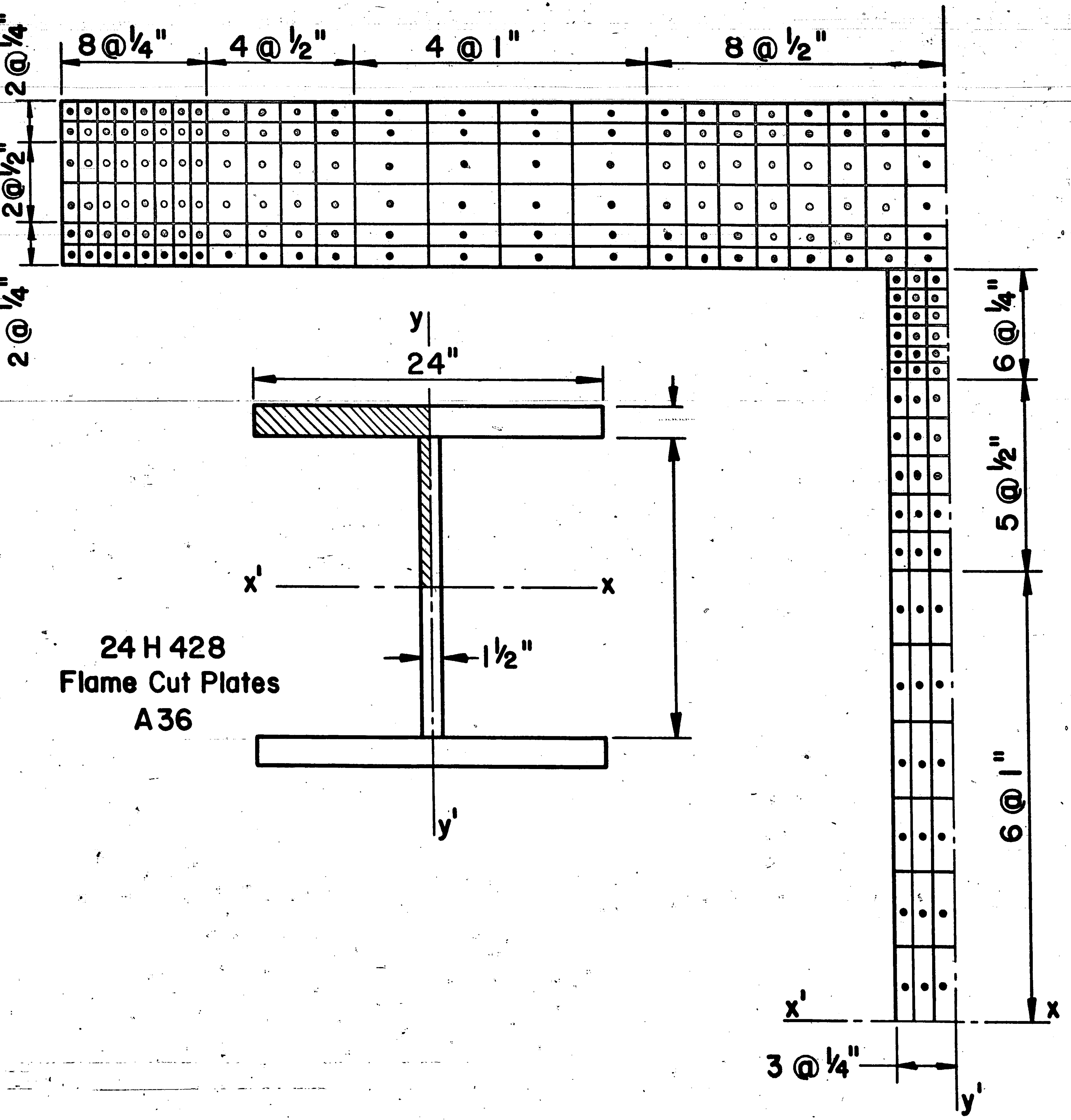


Fig. 20 Arrangement of Finite Area Elements

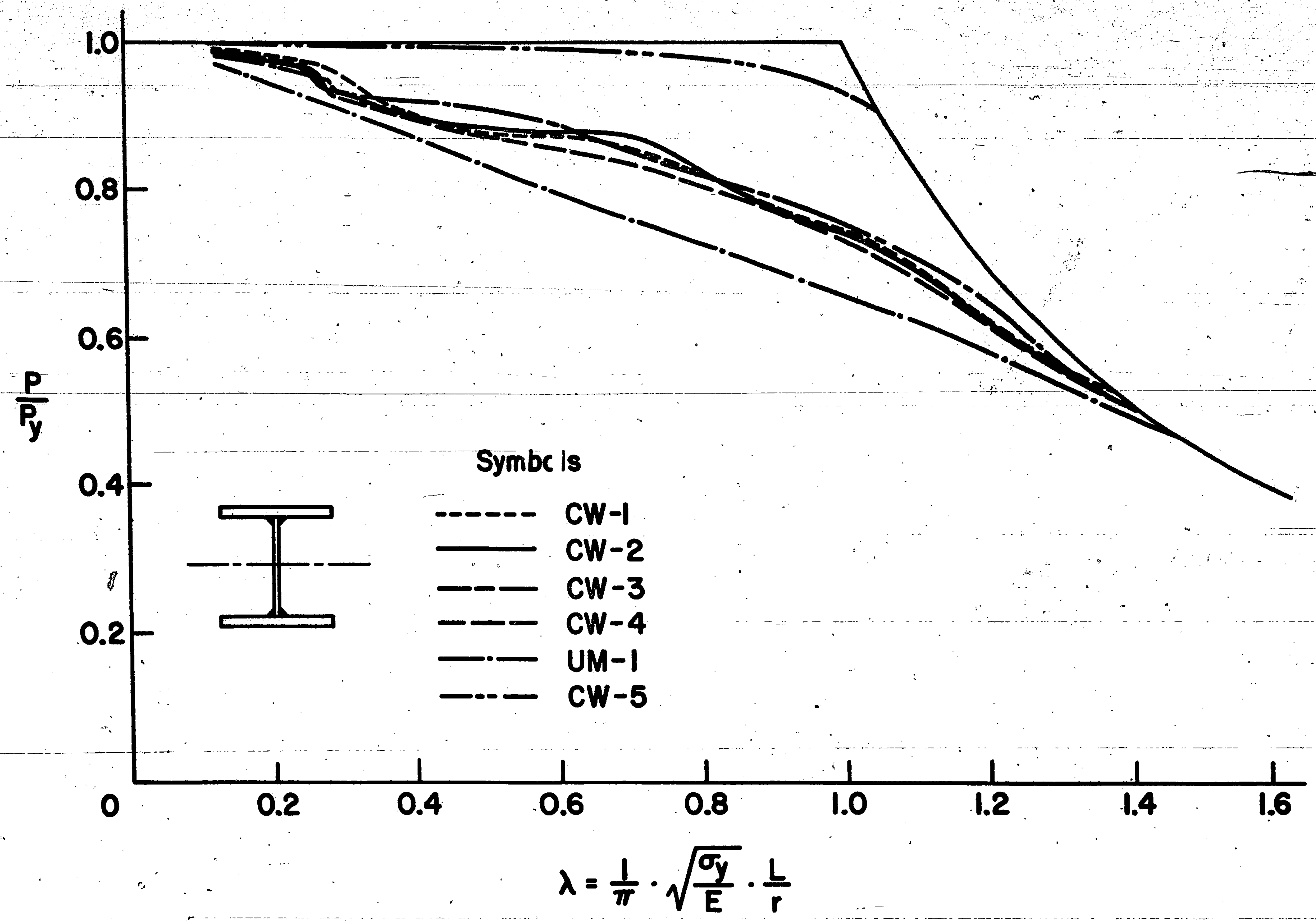


Fig. 21 Tangent Modulus Curves With Respect to the Strong Axis Bending for the Average Distribution of Residual Stresses

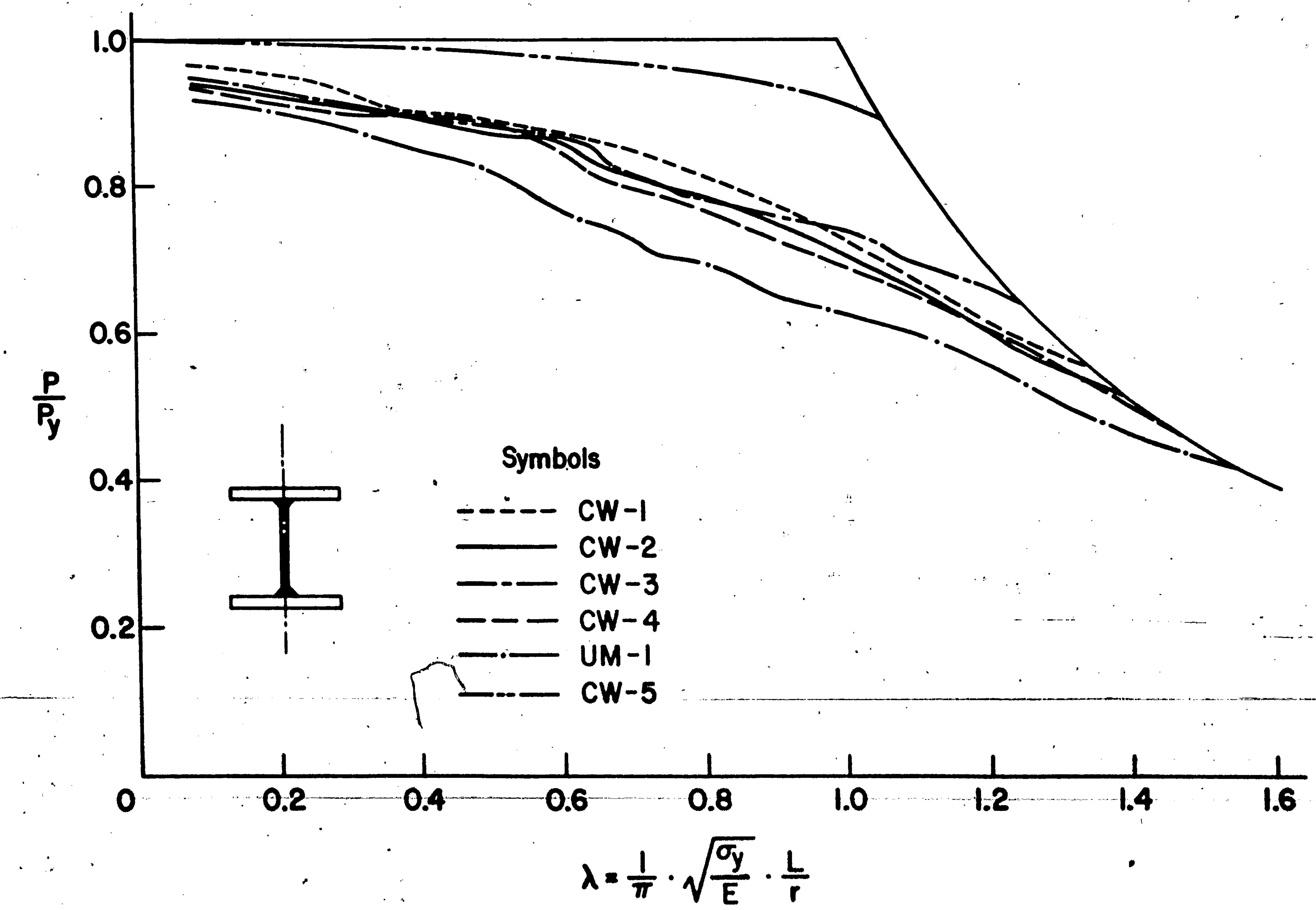


Fig. 22 Tangent Modulus Curves With Respect to the Weak Axis **Bending** for the Average Distribution of Residual Stresses

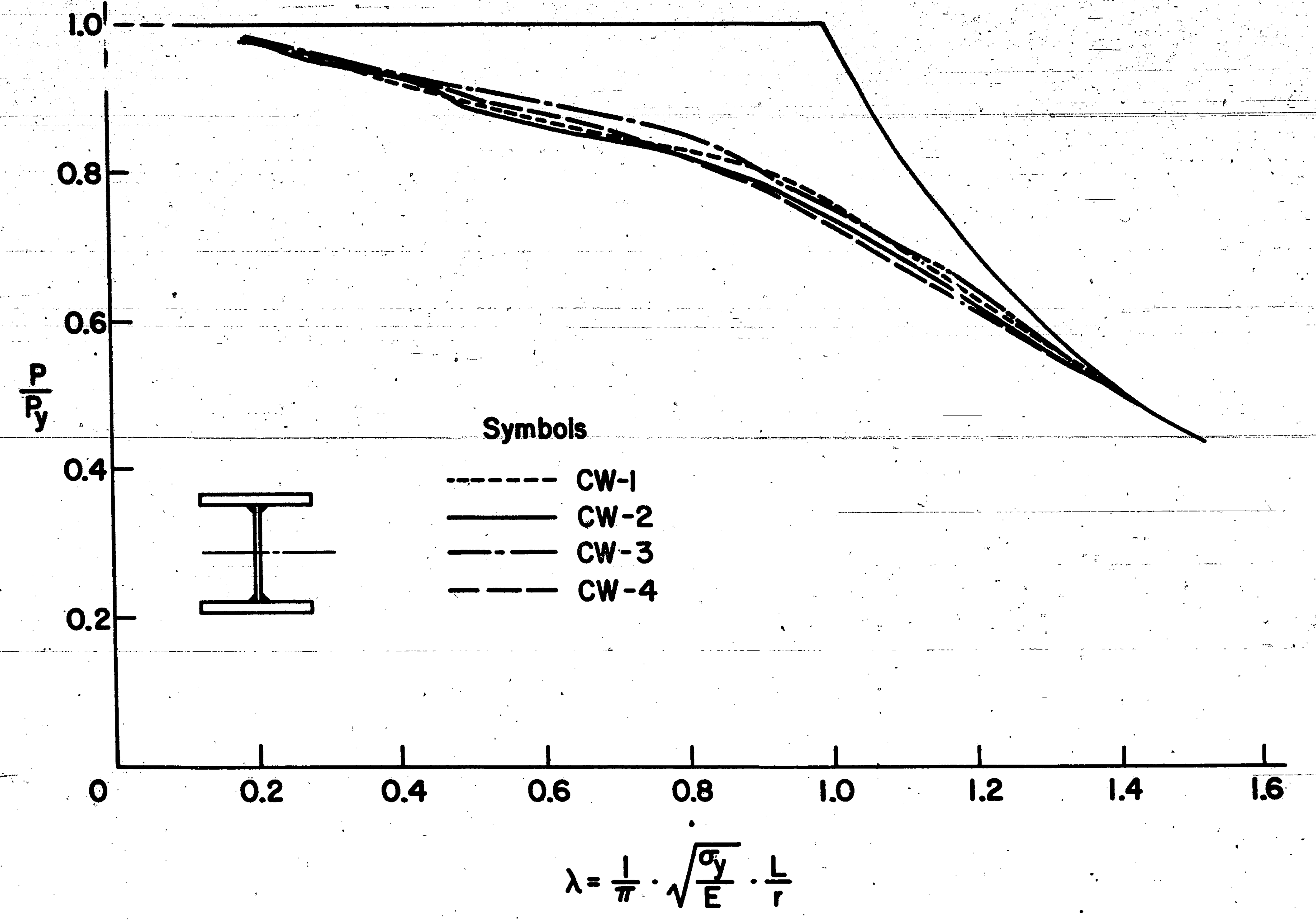


Fig. 23 Tangent Modulus Curves With Respect to the Strong Axis Bending for the Residual Stress Distribution through the Thickness

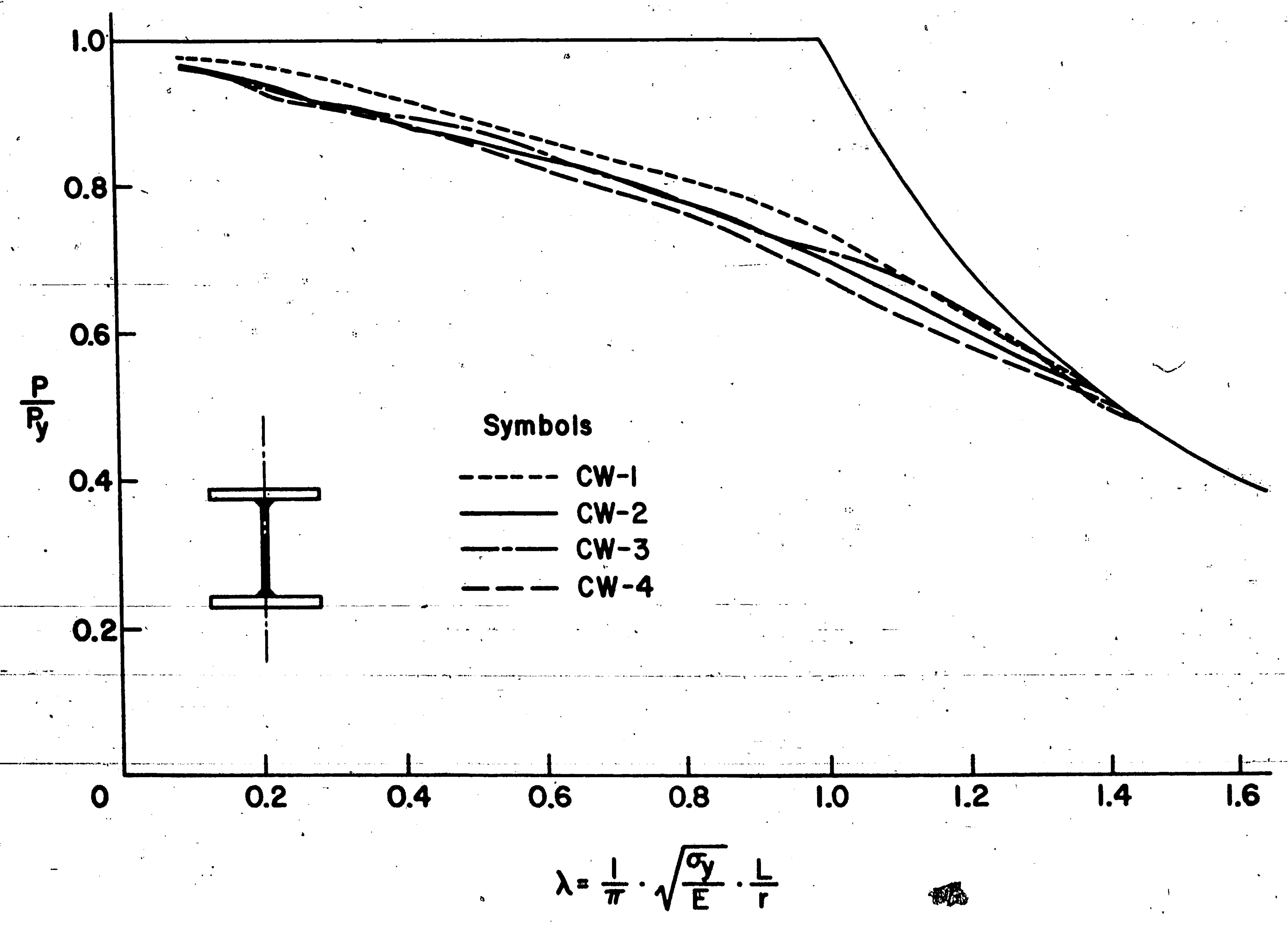
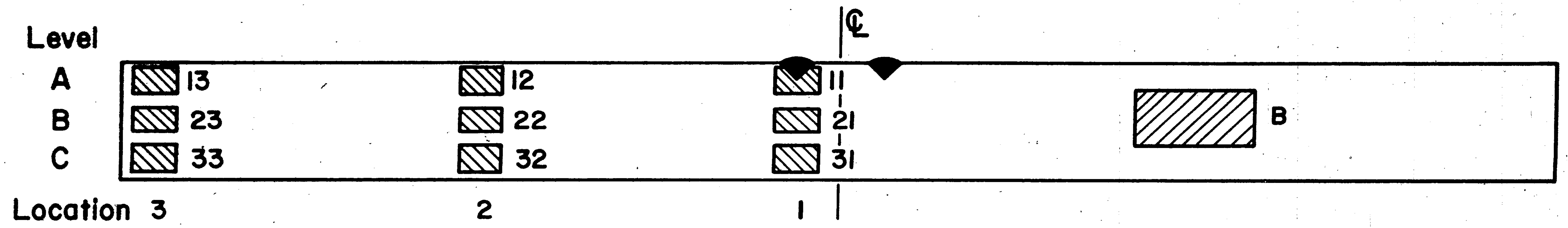
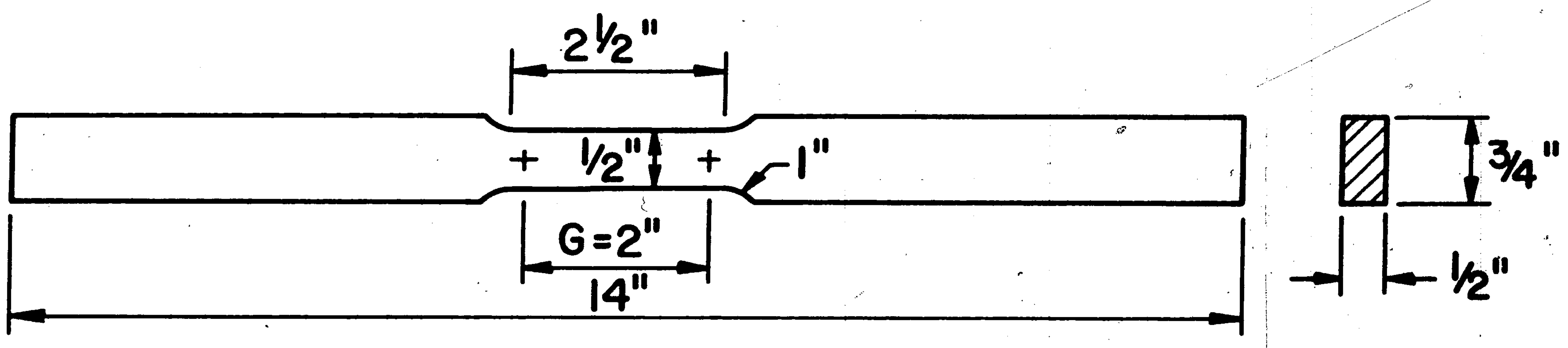


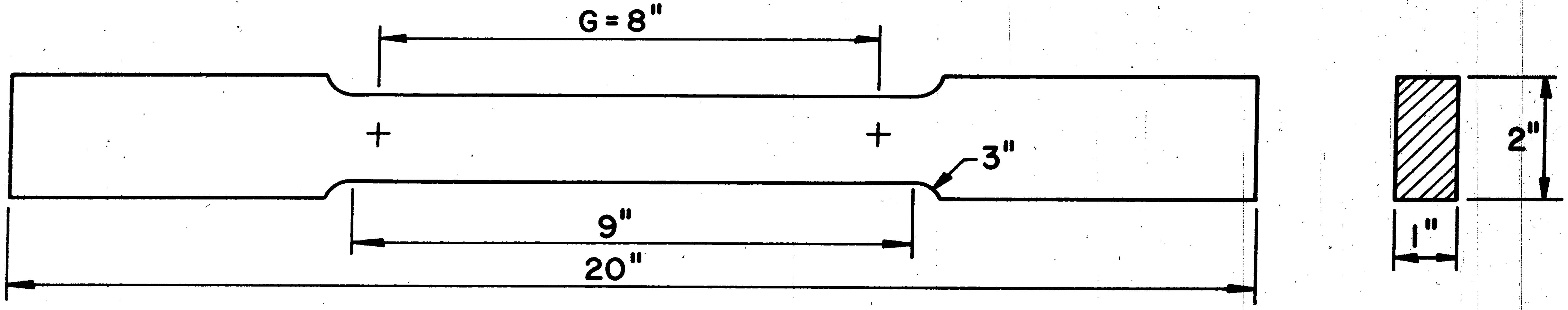
Fig. 24 Tangent Modulus Curves With Respect to the **Weak Axis Bending** for the Residual Stress Distribution Through the Thickness



(a) Location of Test Specimens Across The Width and Thickness of a 20 x 2 (FC)



(b) Standard Test Specimen With a 2" Gage Length (ASTM A570)



(c) Standard Test Specimen With a 8" Gage Length (ASTM A570) Ref. B

Fig. 25 Layout and Dimensions of the Tension Test Specimens

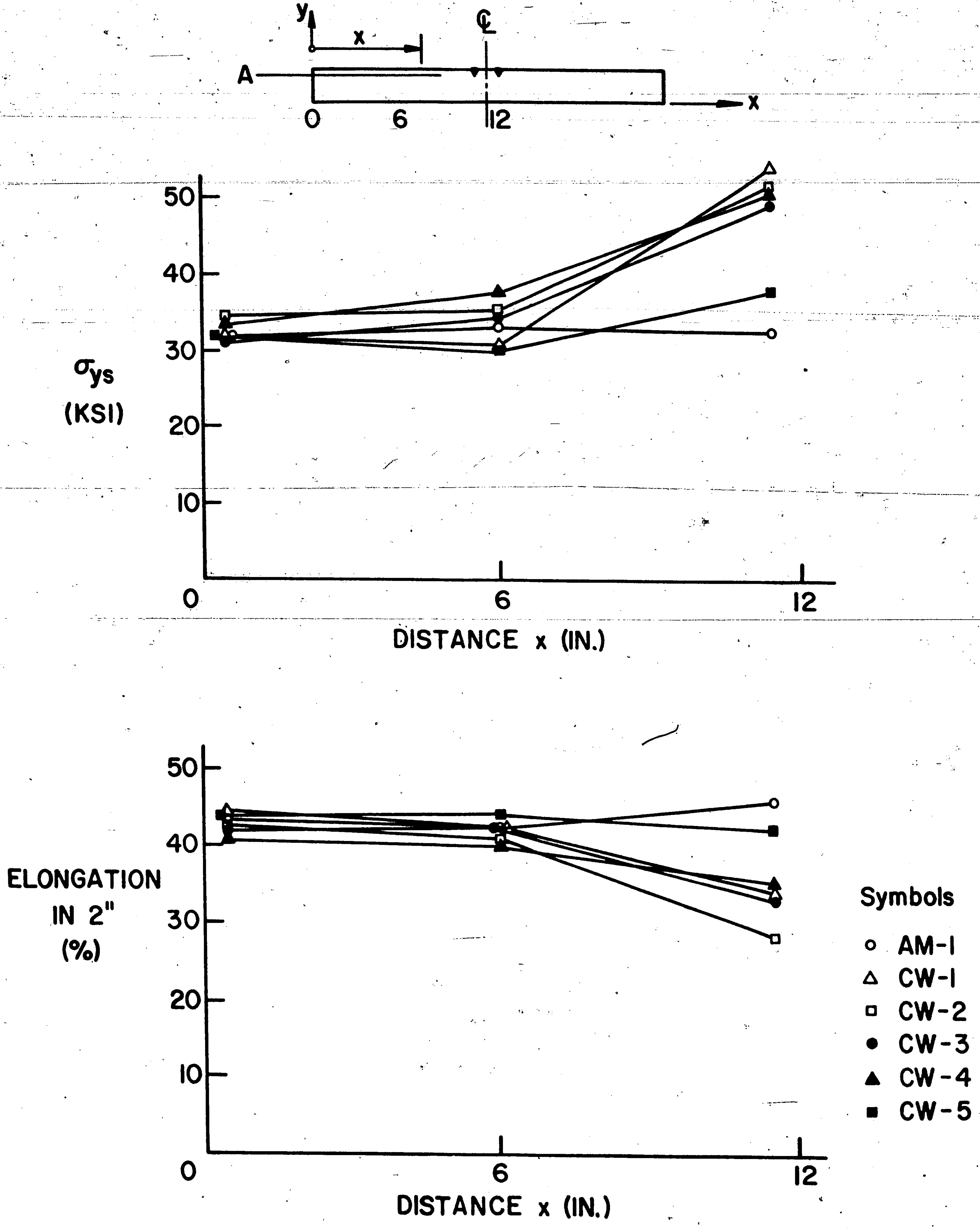


Fig. 26 Static Yield Stress and Percent Elongation Variation - Level A

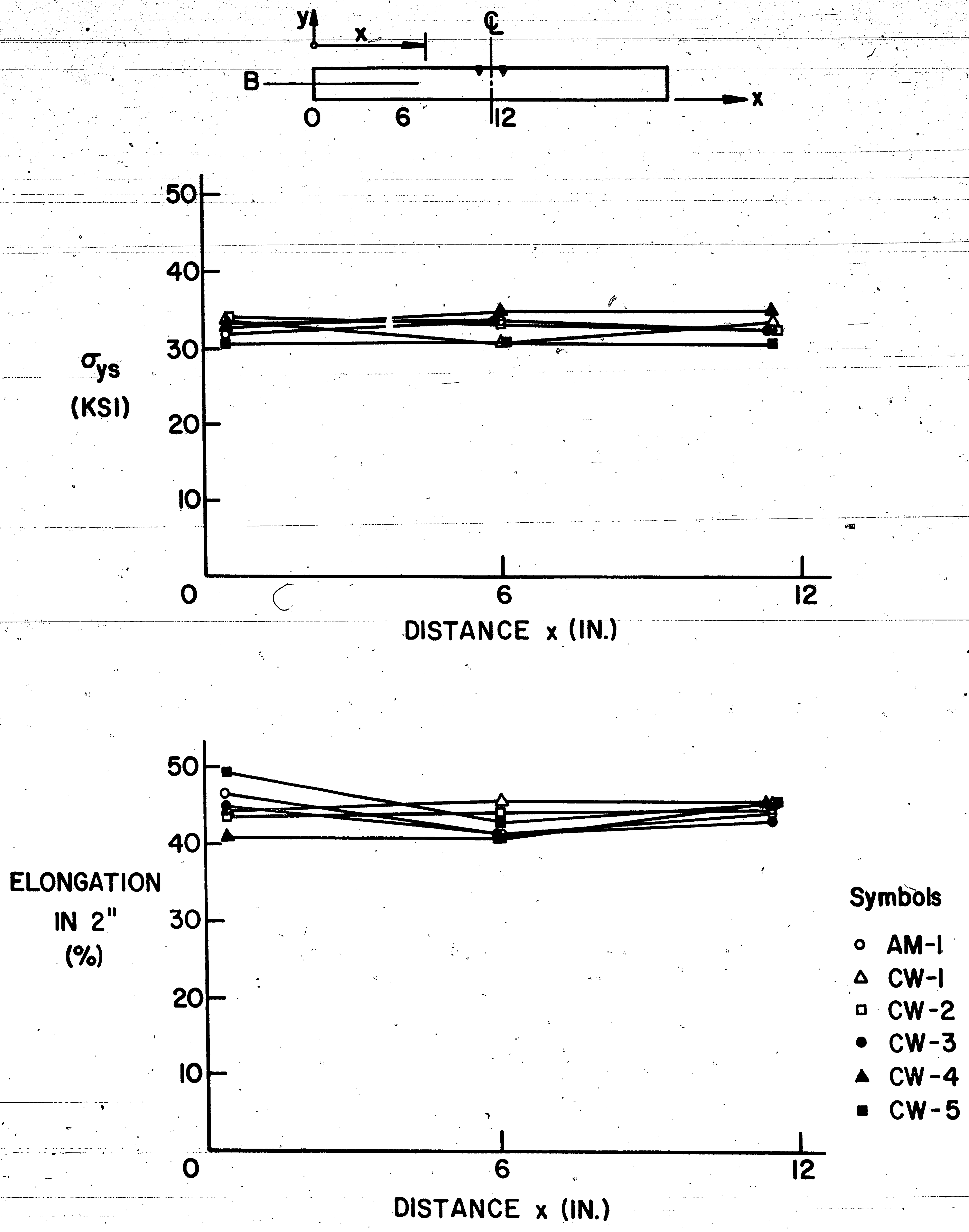


Fig. 27 Static Yield Stress and Percent Elongation Variation - Level B

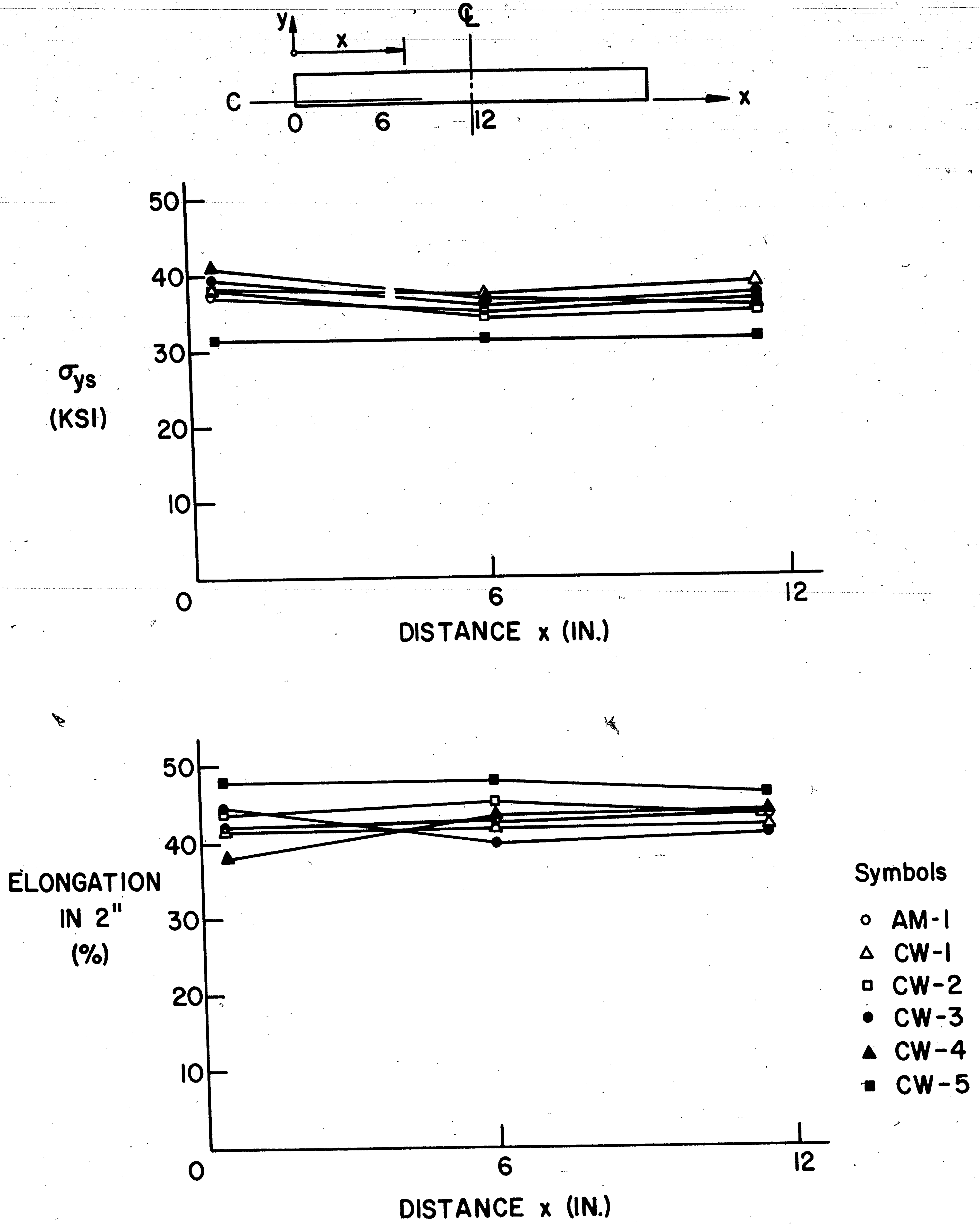


Fig. 28 Static Yield Stress and Percent Elongation Variation - Level C

DATA SHEETS

DATA SHEET NO.: 1

PLATE SIZE: 24" x 2"

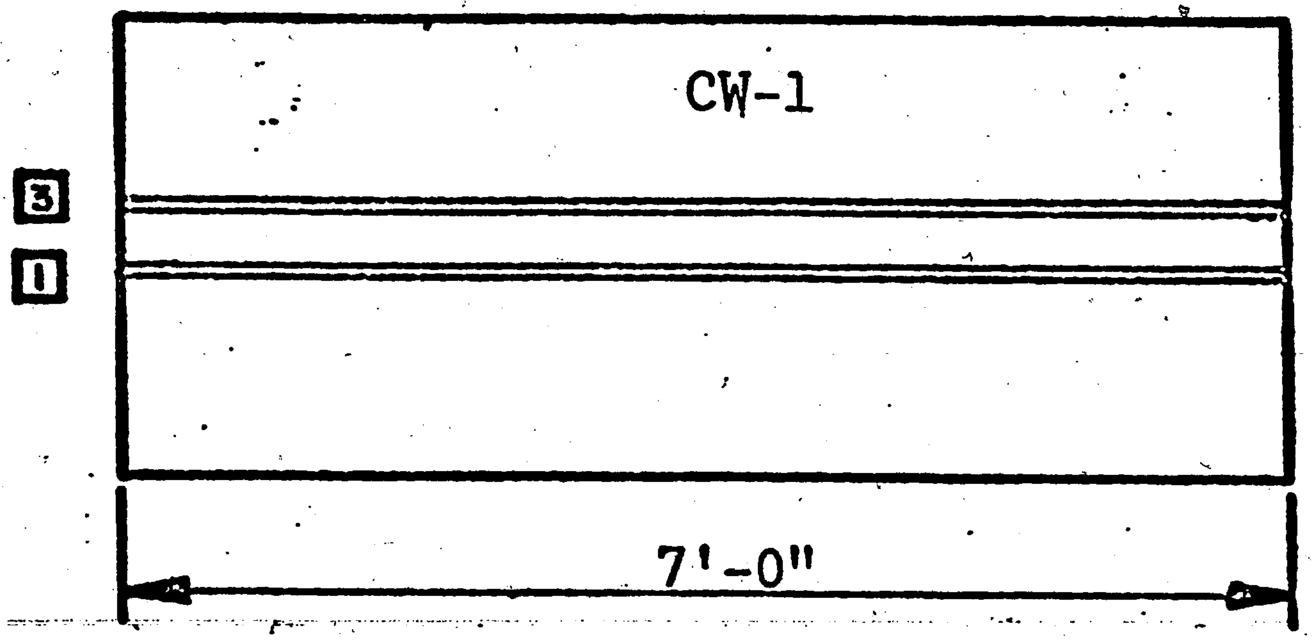
PARENT PLATE NO.: 25473W

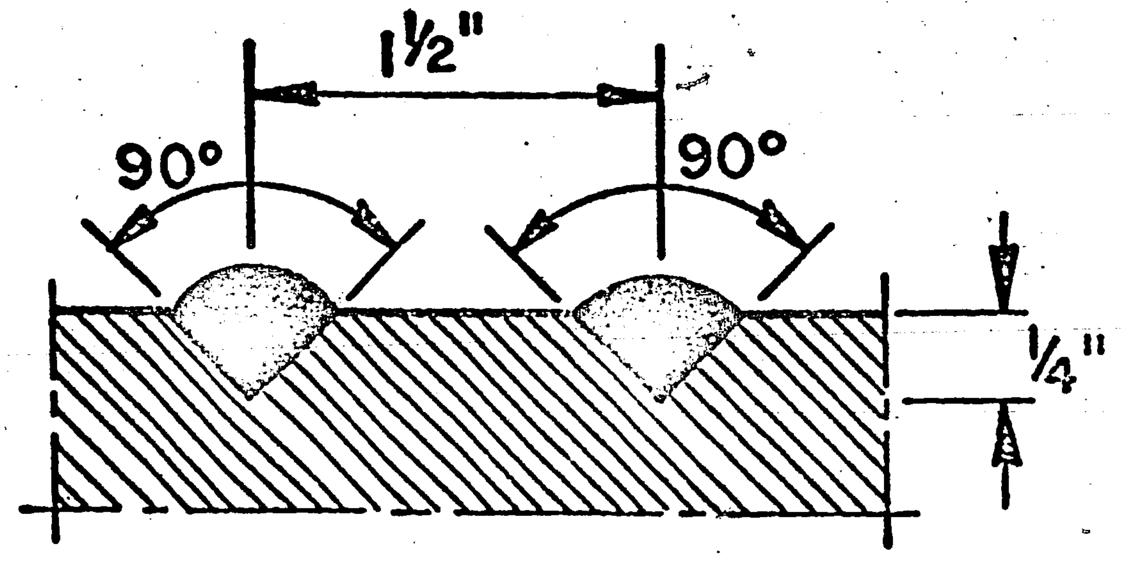
HEAT NO.: 411 W 9731

CORRESPONDING SHAPE: 24 H 428

FABRICATOR REFERENCE NO.: H 428 (FC) F-2

STEEL: ASTM A36





☐ Sequence of welding

DATA:

PASS NO.	3-4	1-2	1-2	3-4	
VOLTAGE (Volts)	33	33	33	33	
CURRENT (Amperes)	410	410	410	410	
STARTING TIME (sec.)	11:08:45	11:17:35	11:25:30	11:31:30	
STOPPING TIME (sec.)	11:13:25	11:22:10	11:28:15	11:34:10	
SPEED OF WELDING (in/min.)	18.0	18.3	30.6	31.4	

REMARKS:

Preheating temperature: 200°F

DATA SHEET NO.: 2

PLATE SIZE: 24" x 2"

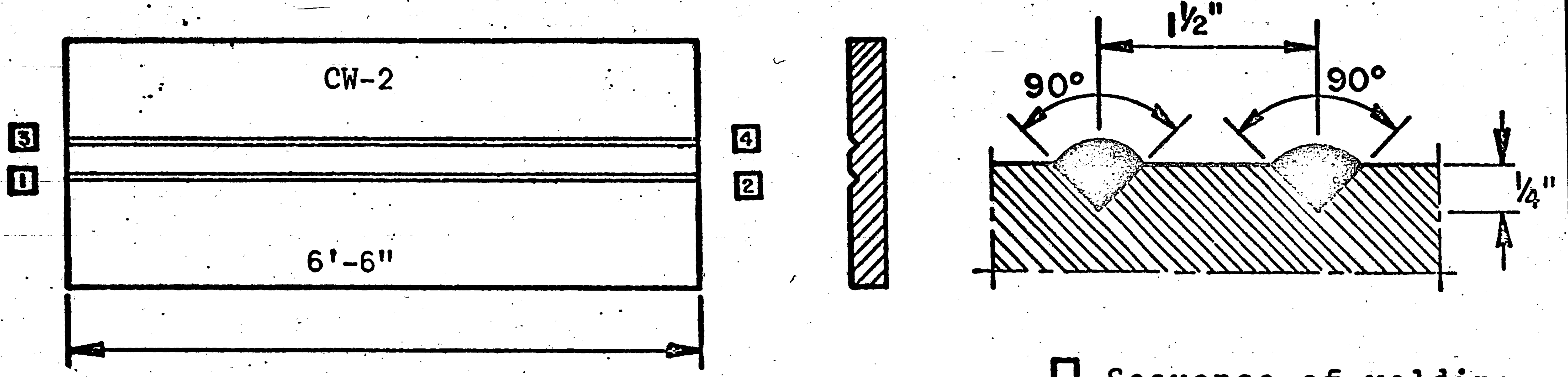
PARENT PLATE NO.: 25474W

HEAT NO.: 411 W 9731

CORRESPONDING SHAPE: 24 H 428

FABRICATOR REFERENCE NO.: H 428 (FC) F-1

STEEL: ASTM A36



☐ Sequence of welding

DATA:

PASS NO.	1-2	3-4			
VOLTAGE (Volts)	33	33			
CURRENT (Amperes)	420	420			
STARTING TIME (sec.)	11:24:27	11:36:20			
STOPPING TIME (sec.)	11:32:23	11:44:15			
SPEED OF WELDING (in/min.)	9.85	9.87			

REMARKS:

Preheating temperature unequally distributed on the surface of the plate. Close to the V-grooves a temperature within the range of 240°F and 250°F was recorded. Near the edges the temperature was within the range of 200°F and 220°F.

DATA SHEET NO.: 3

PLATE SIZE: 24" x 2"

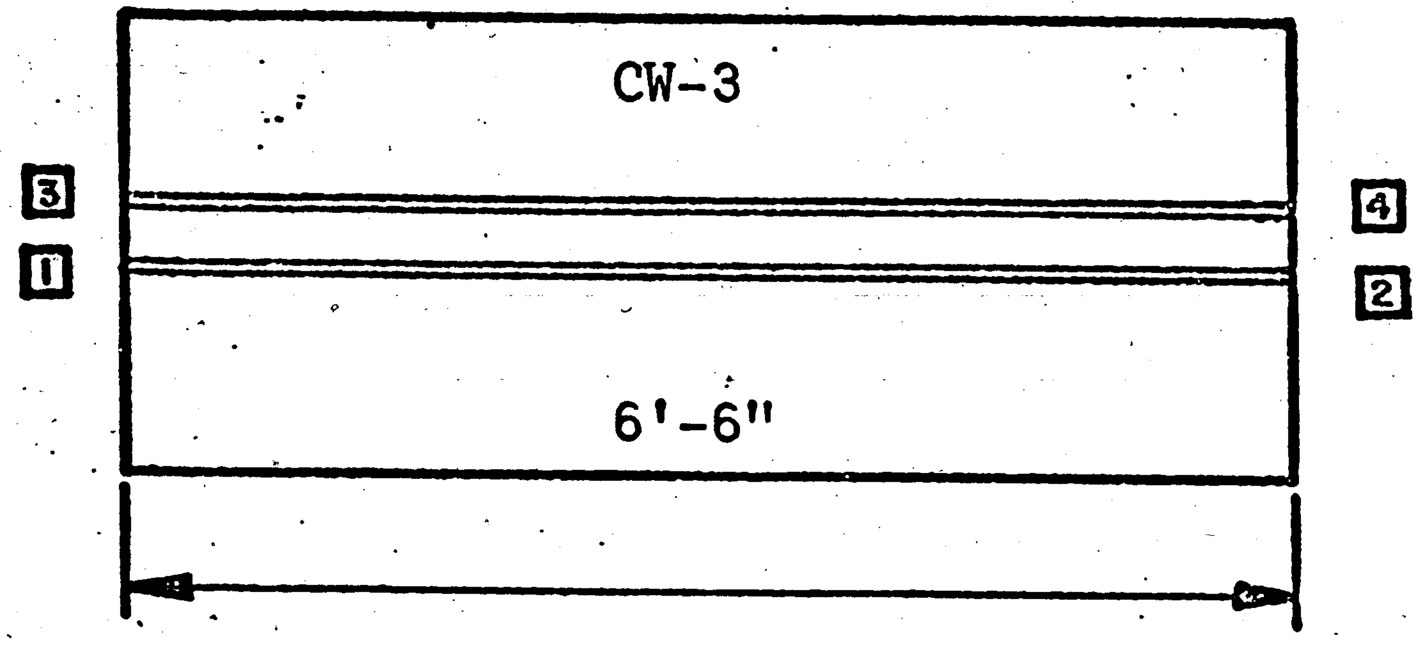
PARENT PLATE NO.: 25474W

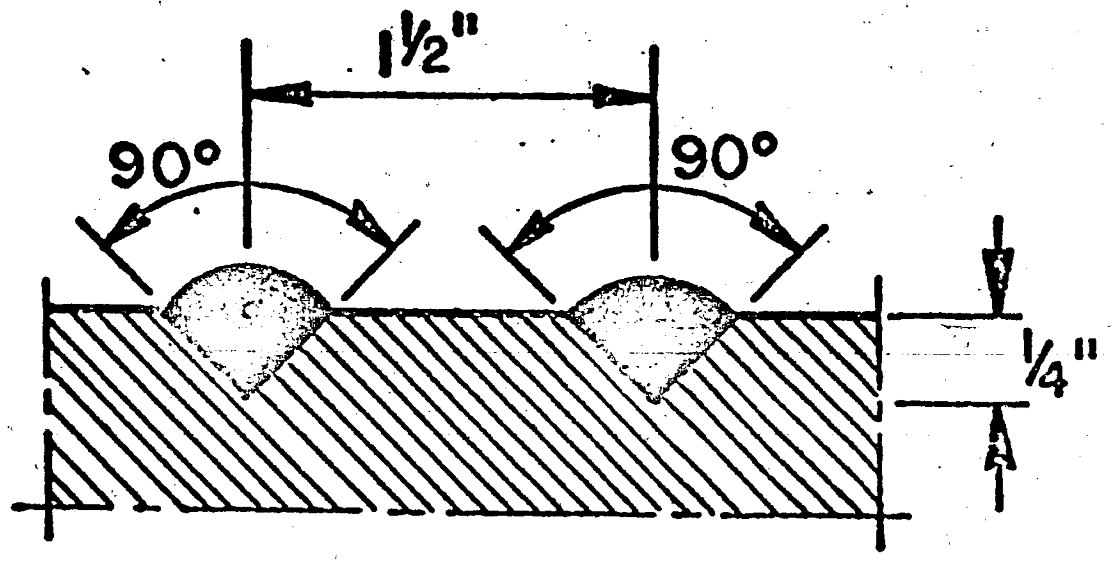
HEAT NO.: 411 W 9731

CORRESPONDING SHAPE: 24 H 428

FABRICATOR REFERENCE NO.: H 428 (FC) F-1

STEEL: ASTM A36





☐ Sequence of welding

DATA:

PASS NO.	1-2	3-4	3-4	1-2	
VOLTAGE (Volts)	32	33	33	33	
CURRENT (Amperes)	410	410	410	410	
STARTING TIME (sec.)	12:47:37	12:55:30	13:03:50	13:08:24	
STOPPING TIME (sec.)	12:52:27	13:00:17	13:06:26	13:11:00	
SPEED OF WELDING (in/min.)	16.1	15.8	30.	30.	

REMARKS:

Preheating temperature was recorded within the range of 400°F and 425°F at the surface of the plate. The temperature was obtained equally distributed by reheating the edges with a manual torch.

DATA SHEET NO.: 4

PLATE SIZE: 24" x 2"

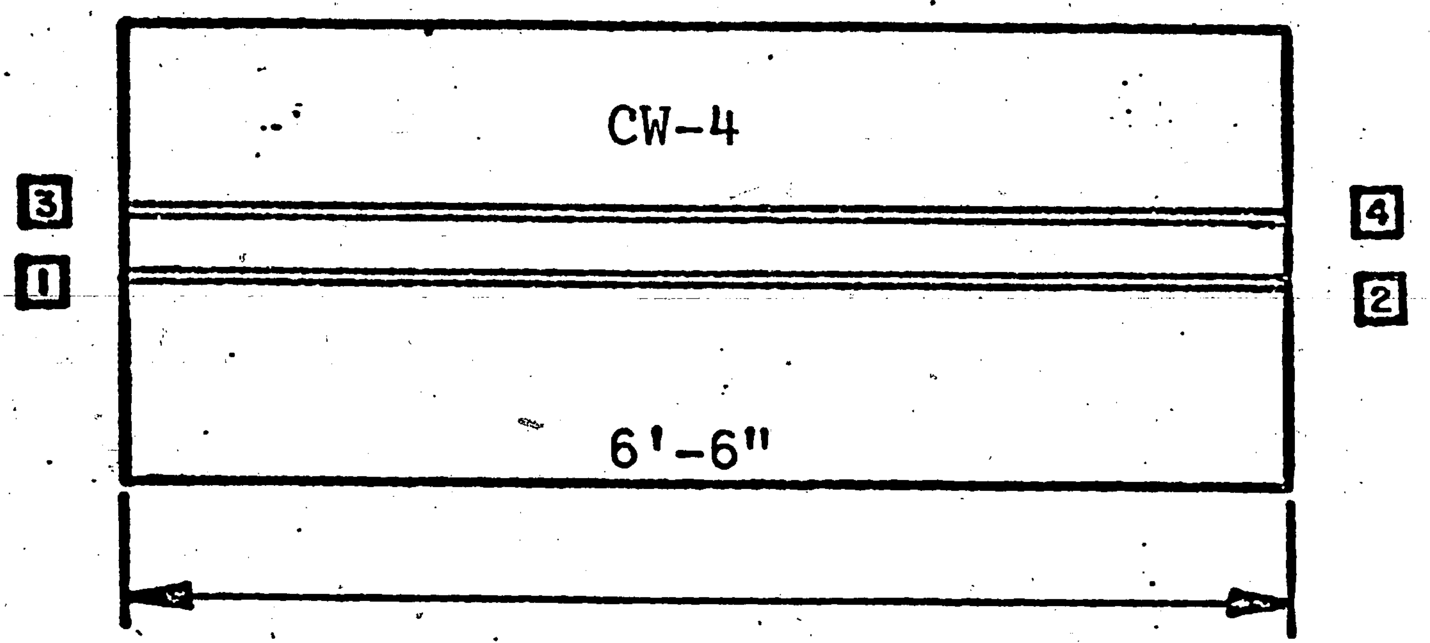
PARENT PLATE NO.: 25474W

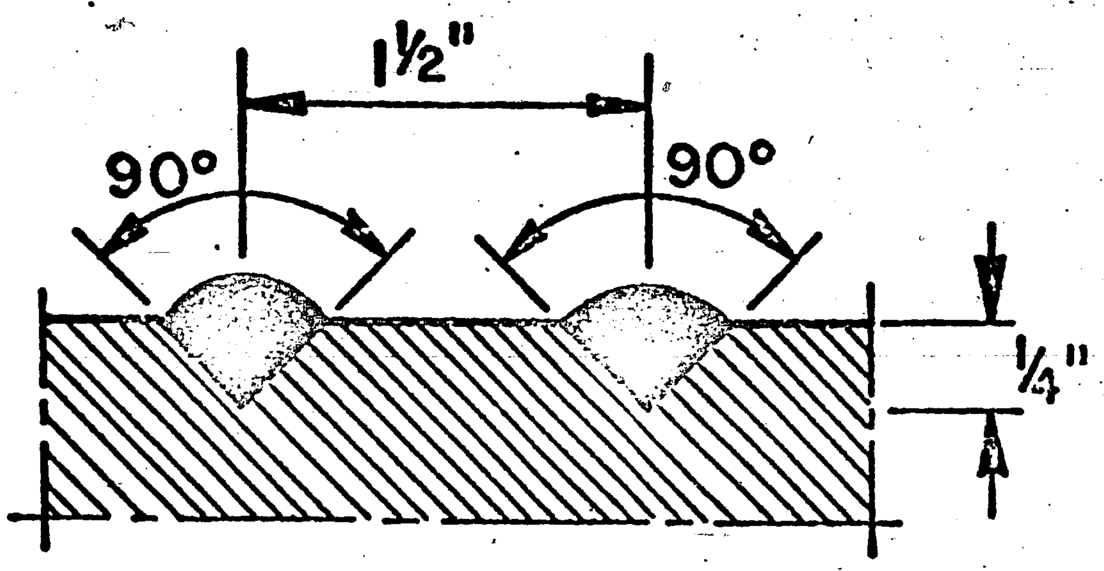
HEAT NO.: 411 W 9731

CORRESPONDING SHAPE: 24 H 428

FABRICATOR REFERENCE NO.: H 428 (FC) F-1

STEEL: ASTM A36





☐ Sequence of welding

DATA:

PASS NO.	1-2	3-4	3-4	1-2	
VOLTAGE (Volts)	33	33	33	33	
CURRENT (Amperes)	410	410	410	410	
STARTING TIME (sec.)	13:39:40	13:48:25	13:55:40	14:01:17	
STOPPING TIME (sec.)	13:44:33	13:53:16	13:58:18	14:03:55	
SPEED OF WELDING (in/min.)	15:95	16.08	29.63	29.63	

REMARKS:

The local preheating of the V-grooves was accomplished with a manual torch. Before welding the V-grooves were recroded at a 400°F temperature and the edges of the plate were at 150°F.

DATA SHEET NO.: 5

PLATE SIZE: 24" x 2"

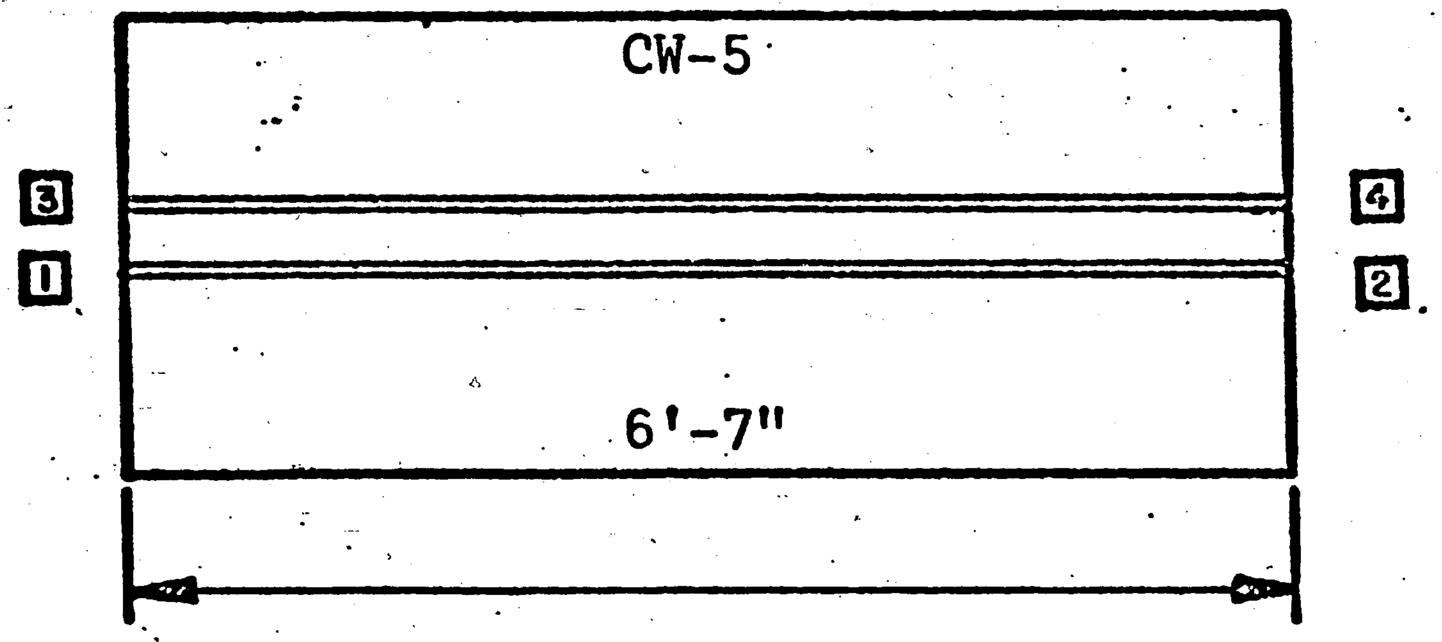
PARENT PLATE NO.: 25474 W

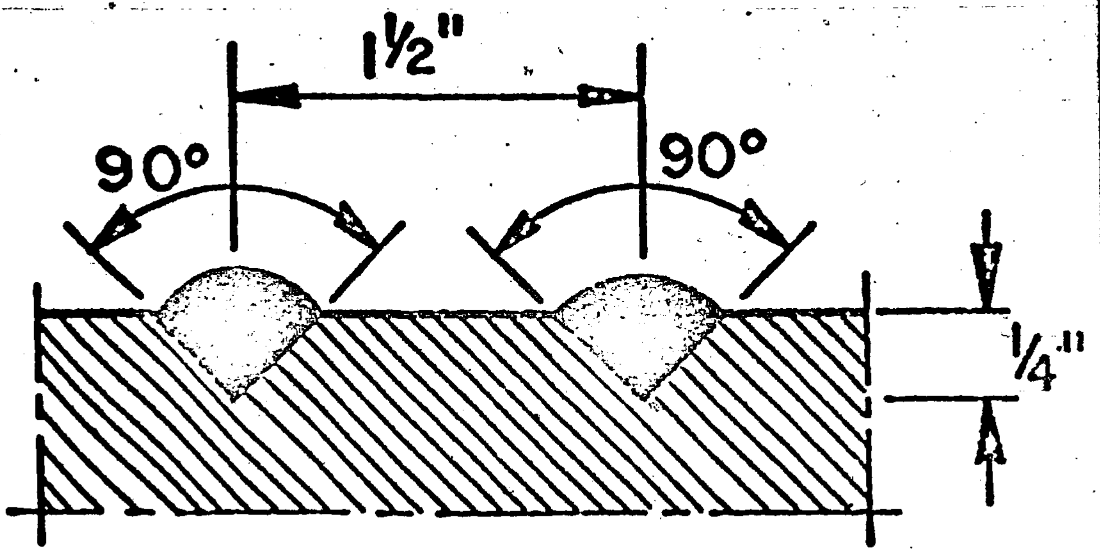
HEAT NO.: 411 W 9731

CORRESPONDING SHAPE: 24 H 428

FABRICATOR REFERENCE NO.: H 428 (FC) F-1

STEEL: ASTM A36





☐ Sequence of welding

DATA:

PASS NO.	1-2	3-4	3-4	1-2	
VOLTAGE (Volts)	33	33	32	32	
CURRENT (Amperes)	410	410	410	410	
STARTING TIME (sec.)	9:49:03	10:05:22	10:15:16	10:24:03	
STOPPING TIME (sec.)	9:54:12	10:10:29	10:18:03	10:26:53	
SPEED OF WELDING (in/min.)	15.34	15.45	28.40	27.94	

REMARKS:

Temperature recorded within the range of 200°F and 225°F; the temperature was higher in the center part of the plate.

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VITA

Jacques Brozzetti was born on February 21, 1940 in Chatillon sous Bagneux, France, the first son of Louis Brozzetti and Gisele Rigolet.

He attended high school at Jules Ferry College, Versailles where he received his two "Baccalaureats" part I and part II respectively in 1957 and 1958.

From 1960 to 1964 he attended the "Ecole Nationale Superieure des Ingenieurs des Arts et Metiers", Paris, he graduated in 1964. In 1965 he studied at the "Centre des Hautes Etudes de la Construction", Paris and graduated in 1966. The same year, he was appointed Engineer of Public Works at the Department of Public Roads and Building Construction of Oran, Algeria. In June 1968 he was appointed Research Engineer at the "Centre Industriel de la Construction Metallique", Paris.

In December 1968 he joined the research staff in the Fritz Laboratory, Department of Civil Engineering, at Lehigh University, Bethlehem, Pennsylvania. He has been associated with the project on "Residual Stresses in Thick Welded Plates" in the Structural Stability Division.