NAVY DEPARTMENT - OFFICE OF RESEARCH AND INVENTIONS

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DIVISION OF PHYSICAL METALLURGY - WELDING SECTION

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THE EVALUATION OF PREHEAT AND POST-HEAT-TREATMENT OF WELDS ON THIN SECTIONS OF STEEL NE 8630

By

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NRL Problem M-59

ABSTRACT

Three methods are in current use for obtaining adequate ductility in aircraft steels such as NE 8630. A study of these methods showed that welding both with and without preheat produced a low ductility acicular structure in the heat-affected zone and that both isothermal postheat and torch "stress relief" treatments resuled in more desirable microstructures and excellent ductility.

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INTRODUCTION

(A) Authorization

1. This investigation was authorized by the Bureau of Aeronautics Project Order No. 492/43 of 4 January 1943, Reference TED No. N.R.L. 2535.

(B) Statement of the Problem

2. During the war aircraft manufacturers used a considerable amount of NE 8630 alloy steel for structures ultimately fabricated by either metallic-arc or gas welding. The three methods of heat-treatment specified by Navy Aeronautical Specification PH-11 for producing satisfactory properties in the weld area of medium alloy steels are: (1) preheating followed by stress relieving after welding, (2) preheating and controlled cooling after welding (isothermal postheat-treatment) and (3) normalizing after welding. Opinions have been expressed by some in the aircraft industry that post-heat-treatment was of little value in improving the physical properties of the heat-affected zone and that preheating prior to welding was sufficient. Consequently, it was the object of this investigation to compare the effectiveness of (1) welding with and without preheat, (2) isothermal postheat-treatment, and (3) torch "stress relief" treatment in producing satisfactory properties in the weld heat-affected zone of steel NE 8630.

(C) Known Facts Bearing on the Problem

3. In welding alloy steels of the air-hardening type, low ductility and cracking can be expected when martensite occurs in the heat-affected zone. It has been known for some time that low ductility and cracking may be minimized by preheat, post-heat-treatment, or some combination of the two. However, a survey of the literature on the weldability of NE 8630 and SAE 4130 steels and the effect of post-heat-treatment on the properties of weld heat-affected zones in these steels indicated that there still remains some justifiable doubt as to the necessity for post-heat-treatment after welding when these steels are used.

4. A previous investigation, NRL Report No. M-2242 of May 1944 on the effect of isothermal postheat-treatment on the properties of weld heat-affected zones, showed that the proper choice of preheat and postheat temperatures, in most instances, made possible the welding of medium alloy steels in the heat-treated condition without loss of ductility.

(D) Materials

5. The material used for the main part of this investigation consisted of NE 8630 alloy steel sheets, plates, and tubes. Sheet and plate thicknesses were as follows: 0.028 inch, 0.063 inch, 0.125 inch and 0.250 inch. Tube sizes ranged from 0.028 inch to 0.120 inch in wall thickness and from 1/2 inch to 1-1/2 inches in outside diameter. Chemical compositions are given in Table I.

TEST METHODS AND RESULTS

(A) Procedure

6. The ductility of the heat-affected zone is largely dependent upon the cooling rate and the post-heat-treatment, two factors which determine the resulting transformation products. A prediction of the transformation products may be had from a consideration of the time-temperature relationships for the various weld cooling conditions together with the continuous cooling transformation diagram. It is to be noted that little information is to be gained from superimposing continuous cooling curves on an isothermal transformation diagram. The continuous cooling transformation diagram (Plate 4) for steel NE 8630 was determined with a high speed dilatometer as described in NRL Report No. M-2340 (2). Unfortunately, the austenitizing temperature used in establishing the continuous cooling transformation diagram was only 1600°F because of practical limitations on the furnace of the high speed dilatometer; whereas, the austenitizing temperature involved in arc welding is probably in the neighborhood of 2500°F. This temperature difference would be expected to result in longer times for transformation than indicated by the curve as presented in Plates 5 and 6.

7. The longitudinal bead weld bend test was selected as the most suitable weldability test specimen for studying the properties of the heat-affected zone. The test specimens were prepared by depositing a 3 inch bead weld along the center line of a 3 by 6 inch sheet specimen with the weld parallel to the 6 inch dimension (Plate 1). Welds were made with automatic welding equipment using Murex-Alternex mild steel electrode (AWS - ASTM, Grade E6013) and Airco 190 alloy steel electrodes. Details of the welding technique used are listed in Table II. Records were made of the welding currents and arc voltages by means of Esterline-Angus recording meters in order to establish the average heat-input used for welding each specimen. The majority of the welds were made with mild steel electrodes since they more consistently produced weld deposits with greater ductility than the heat-affected zone.

8. A jig was used to support the specimen and thermocouple during the welding and heat-treating operations. In the preheat and post-heat-treatments, temperatures were satisfactorily maintained by an oxy-acetylene torch. For measuring the temperature of the heat-affected zone during welding and post-heat-treatment operations, chromel-alumel thermocouple wires were flash welded to each bead weld bend test specimen in the heat-affected zone on the side of the specimen opposite from the weld (Plate 2). It proved satisfactory to weld the wires to the surface of the 0.028 inch and 0.063 inch specimens; however, for the thicker specimens it was necessary to drill holes in order to place the junction closer to the weld bead. Cooling from 1800°F to 200°F was recorded with a Leeds and Northrup "Speedomax".

9. Bend ductility at the location of the thermocouple was measured using the jig illustrated in Plate 3 by bending the specimen to failure or to the capacity of the jig and taking the angle at which failure occurred in the heat-affected zone as the index of weldability. If the failure initiated in the bead weld, or if the weld and heat-affected zone failed simultaneously, the test was regarded as an unsatisfactory indication of the ductility in the heat-affected zone in the base metal and, therefore, was discarded. A test specimen was considered to fail when a crack of 1/8 inch length was observed in the base metal.

(B) Discussion of Results

The effect of various cooling conditions on the microstructure and ductility of the heat-affected zones of a number of welds was investigated for the various thicknesses of NE 8630 steel sheet. Cooling curves for specimens (1) with no preheat, (2) with 400°F preheat and (3) with 600°F preheat were determined and their relationship to the continuous cooling transformation curves is shown on Plate 6.

To compare the effect of the various weld cooling programs on the ductility of the heat-affected zone, one sheet specimen (0.063 inch) was used. The bend angles of the 0.063 inch thick plate after having been subjected to weld cooling programs involving no preheat, 400°F preheat and 600°F preheat were 63°, 77° and 92° of bend respectively. In order to study the progress of transformation upon continuous cooling from the no preheat condition, specimens were quenched at regular intervals as cooling proceeded and the corresponding ductility was recorded on the cooling curve (Plate 6). To facilitate interpretation of these data, changes in ductility upon continuous cooling were plotted against quenching temperature (Plate 7). It is to be noted that there is fair agreement between the sharp rise in ductility and the end of transformation as indicated by the continuous cooling transformation diagram.

The effect of isothermal postheating was investigated by making bead weld tests on 0.063 inch specimens. "Isothermal postheat" is a special welding technique in which cooling is interrupted at some predetermined level and the temperature maintained for a definite length of time, after which the weld is allowed to air cool. The procedure was similar to that described in Reference (1) with the exception that the specimens were not preheated, a more drastic technique than called for by current specifications. After the weld was completed, the heat-affected zone was allowed to cool to postheat temperature before additional heat was applied. The postheat temperature was then carefully maintained for various time intervals, after which the specimens were allowed to cool in air from the postheat temperature. The Ae_1 critical temperature was selected as the reference point for the initial time for both the cooling and postheating periods. The time-temperature relationship and ductility resulting from the isothermal postheat-treatment may be seen in Plate 8. It is to be noted that the time necessary for maximum improvement in ductility (180°) was in close agreement with the completion of isothermal transformation. Thus, the data obtained substantiated the findings of a previous report of this laboratory (1) that within a definite contour corresponding to the end of isothermal transformation there exists an optimum ductility.

The effect of "stress relieving" was investigated by making longitudinal bead weld bend tests on 0.063 inch specimens. As in the case of isothermal postheat-treatment, no preheat was used. After the weld was completed and allowed to cool to room temperature, the specimen was reheated with an oxy-acetylene torch to some elevated temperature, held at temperature for a certain time, and finally cooled in air. The ductility resulting from the various "stress relief" treatments investigated (Plate 9) indicates that again a definite time-temperature relationship exists for optimum ductility. From the relatively low temperatures and short times involved, it is apparent that the term "stress relieving" as here applied is a misnomer. The process of torch "stress relieving" at 800°F for 3 minutes, for example, is to all practical purposes little more than a tempering treatment of the transformation products.

The relatively low angle of bend observed in the preheated specimen as compared to that of the post-heat-treated specimen indicates the presence of a brittle transformation product. A joint consideration of the transformation diagram together with the experimentally determined cooling curves indicates the transformation product to be bainite in the case of both the preheated and unpreheated specimens. In considering whether or not martensite may be present, it is to be noted that (1) the relative position of the cooling curves and the transformation diagram (Plate 6) indicate that transformation to bainite was completed and (2) the constant bend angle at temperatures below 800°F (Plate 7) indicate that no further transformation took place below 800°F, a temperature over 100°F above the Ms. Thus, the brittle performance of the specimen may be attributed to bainite. However, in the event that the higher austenitizing temperatures associated with welding materially lengthen the required time for transformation, then the possibility of martensite is to be considered. Examination of the microstructure for the purpose of confirming the above analysis was inconclusive due to the difficulty of establishing the presence of small quantities of martensite in a structure that was predominantly lower bainite (Plates 10 and 11).

CONCLUSIONS

The cooling rates in welds made on thin sections of NE 8630 steel are sufficiently rapid to permit the formation of an acicular structure as indicated by micro examination and low bend ductility. Thus, post-heat-treatment of welds is necessary if an optimum ductility in the heat-affected zone is to be obtained.

The ductility obtained in steel NE 8630 using the post-heat-treatments under investigation indicated that either the isothermal post-heat-treatment or the torch "stress relief" treatment is equally satisfactory for the purpose intended.

REFERENCES

1. NRL Report No. M-2242 "Investigation of Controlled Postheating for Welding of Medium Alloy and Aircraft Steels", M. A. Pugacz, G. J. Siegel and J. O. Mack.

2. NRL Report No. M-2340 "A High Speed Dilatometer and the Transformation Behavior of Six Steels", A. L. Christenson, E. C. Nelson and C. E. Jackson.

TABLE I

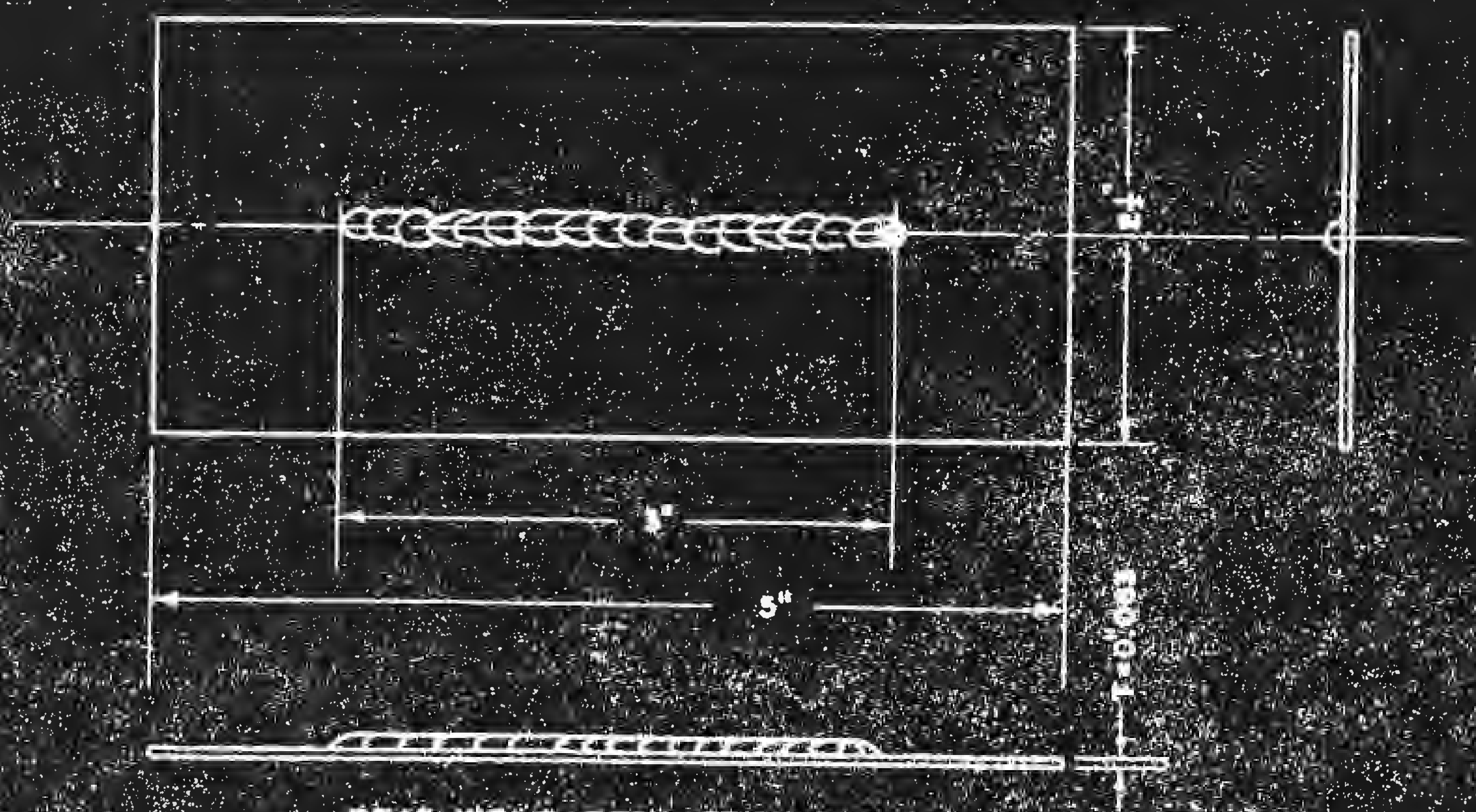
CHEMICAL COMPOSITIONS OF STEELS USED

Steel	Thickness (Inches)	Per Cent C	Mn	Si	Ni	Cr	Mo
NE 8630	0.250	.30	.91	.32	.61	.52	.17
NE 8630	0.125	.32	.84	.33	.56	.48	.16
NE 8630	0.063	.33	.78	.31	.38	.54	.21
NE 8630	0.028	.33	.78	.19	.42	.53	.19
SAE 4130	0.250	.29	.58	.29	.31	.85	.18
SAE 4130	0.125	.33	.43	.34	.14	.91	.23
SAE 4130	0.063	.31	.48	.20	.18	.93	.23
SAE 4130	0.028	.30	.44	.23	.11	.93	.22

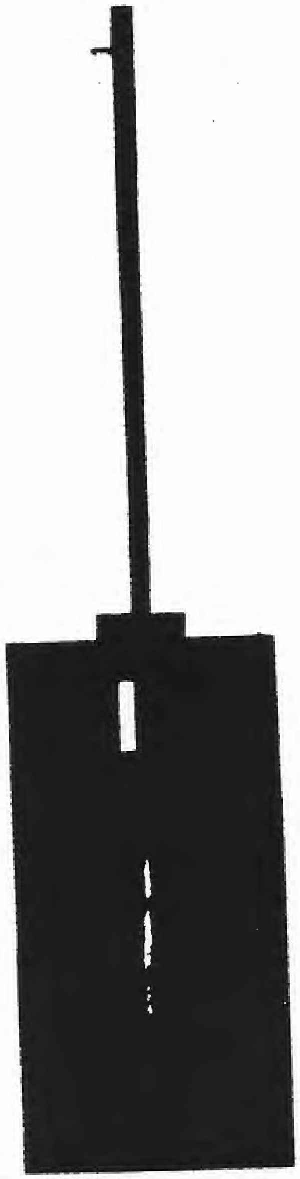
TABLE II

WELDING TECHNIQUES USED FOR BEAD WELDS

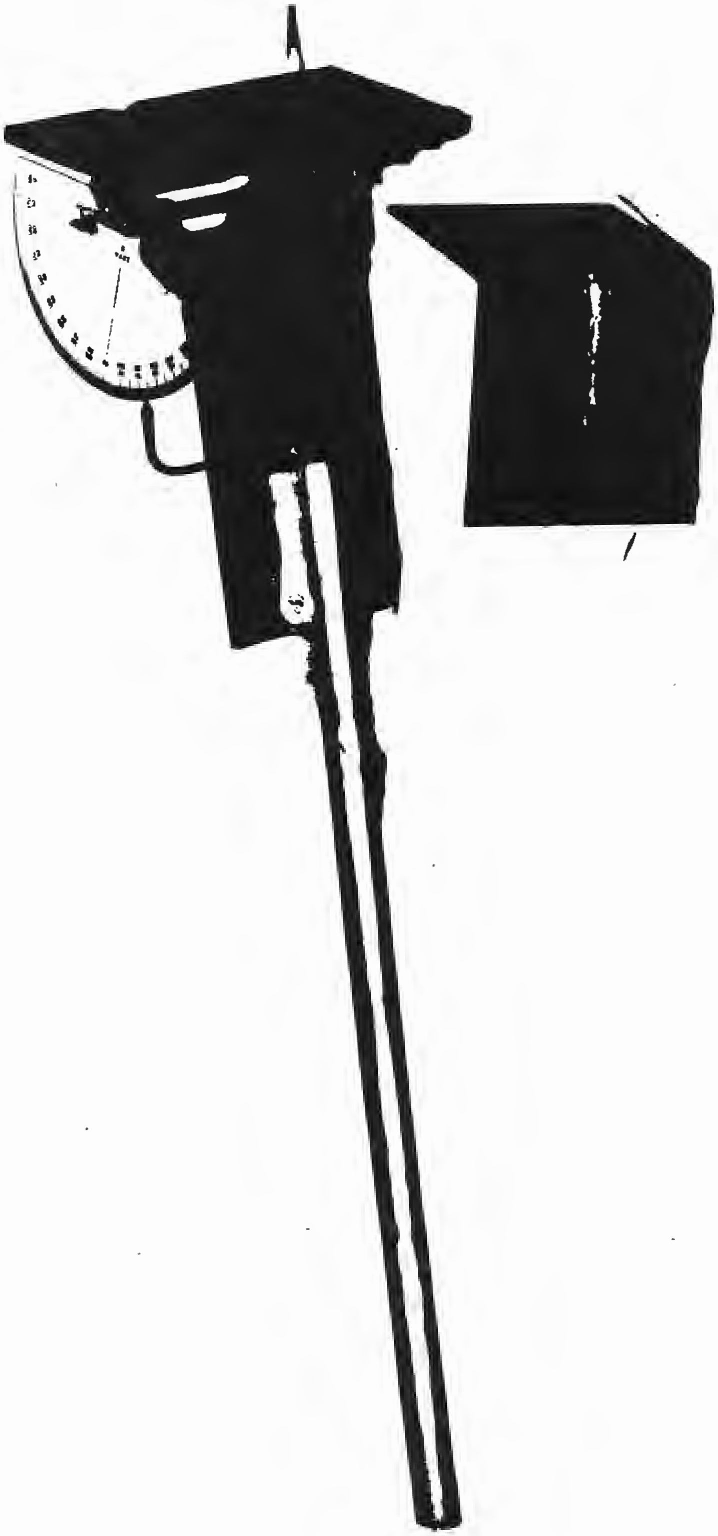
Sheet Thickness (inches)	Welding Current (amperes)	Arc Voltage (volts)	Speed of Travel (in./min)	Avg. Heat Input (Joules/in)	Electrode Diameter (inches)
0.125	90/100	19/21	12	9500	1/8
0.063	70/80	18/20	16	5200	1/8
0.028	40/50	17/19	18	2700	3/32



BEAD WELD BEND SPECIMEN

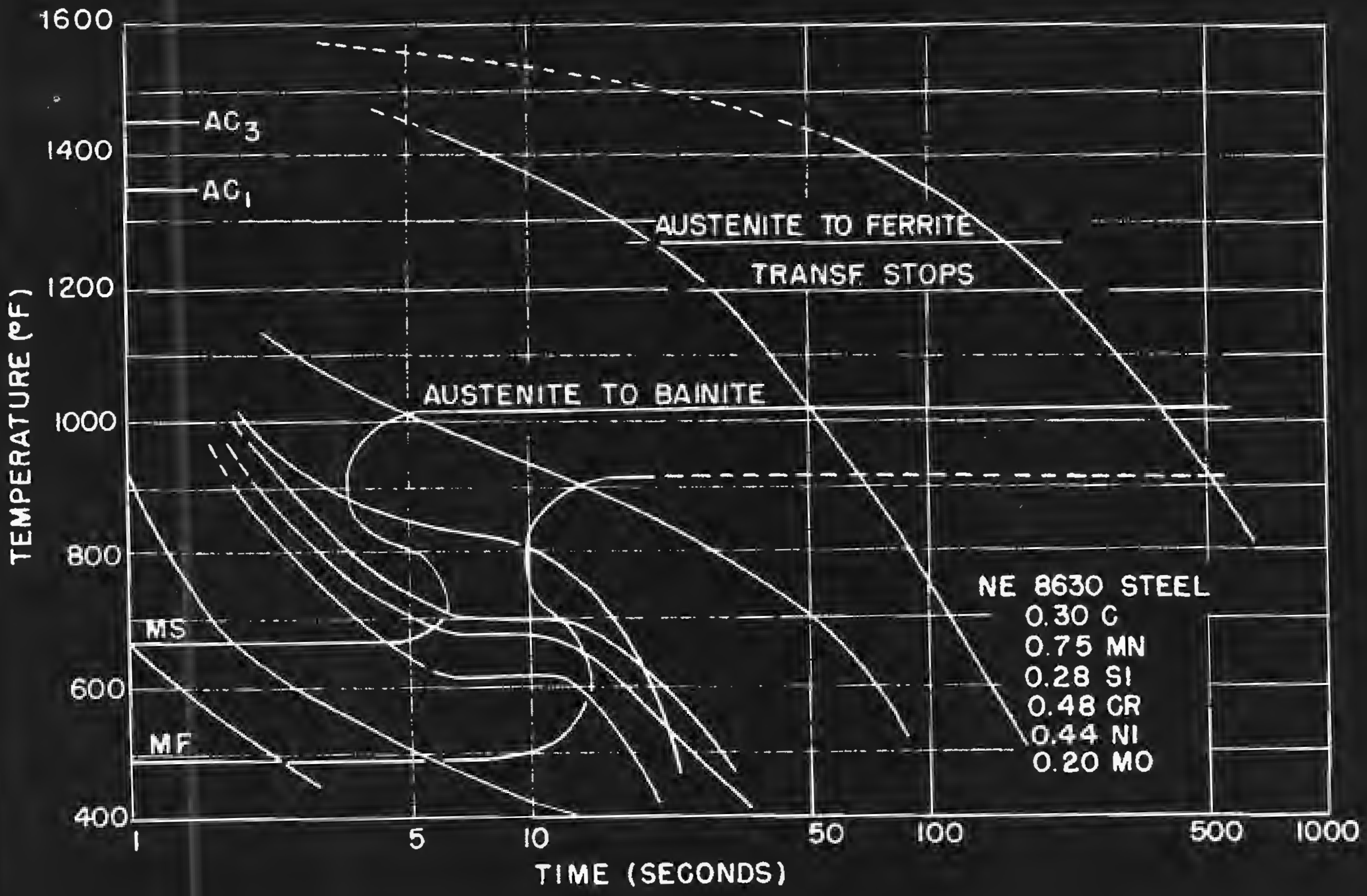


PHOTOGRAPH SHOWING THERMOCOUPLE LOCATION



BEND JIG

PLATE 3



CONTINUOUS COOLING TRANSFORMATION DIAGRAM

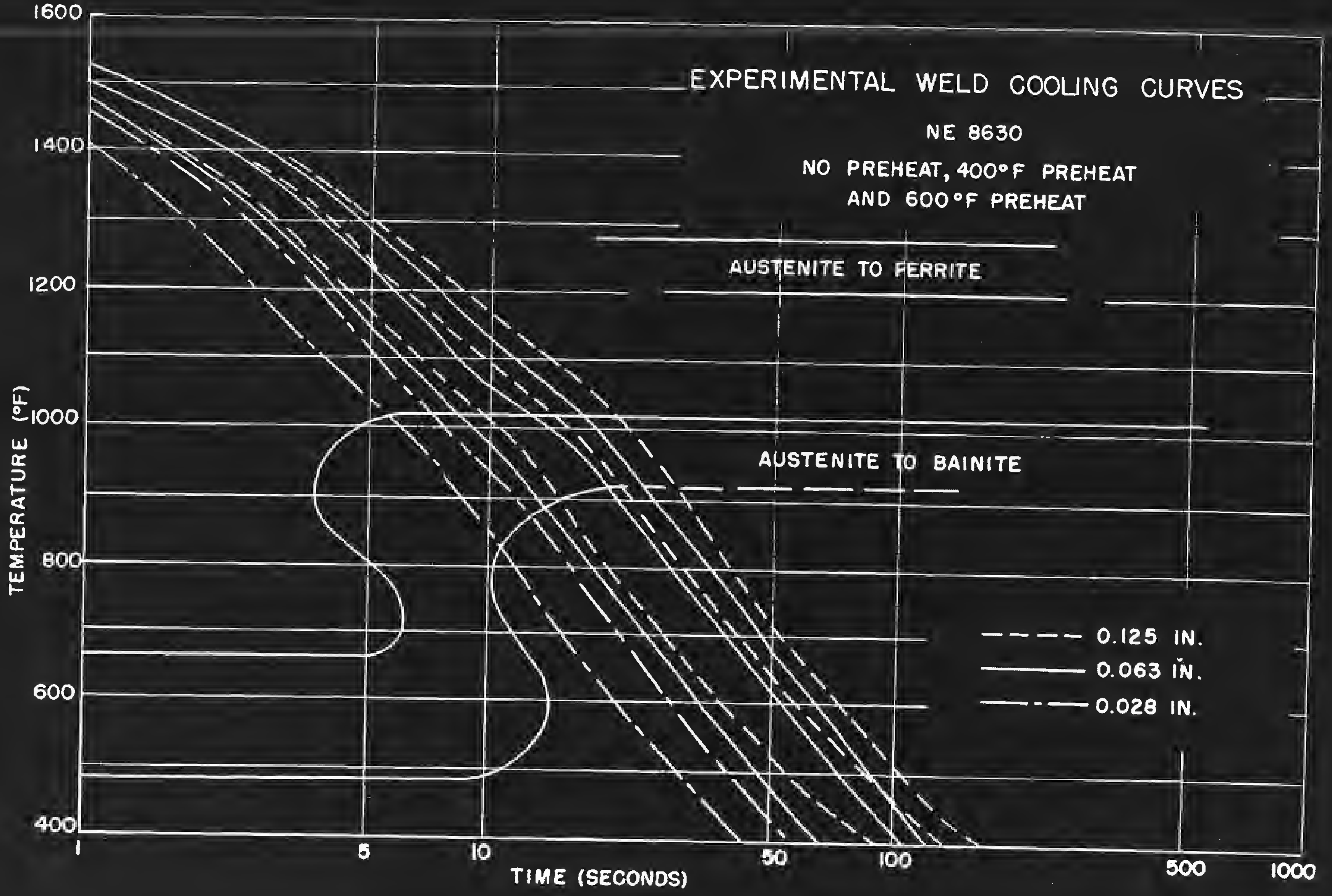


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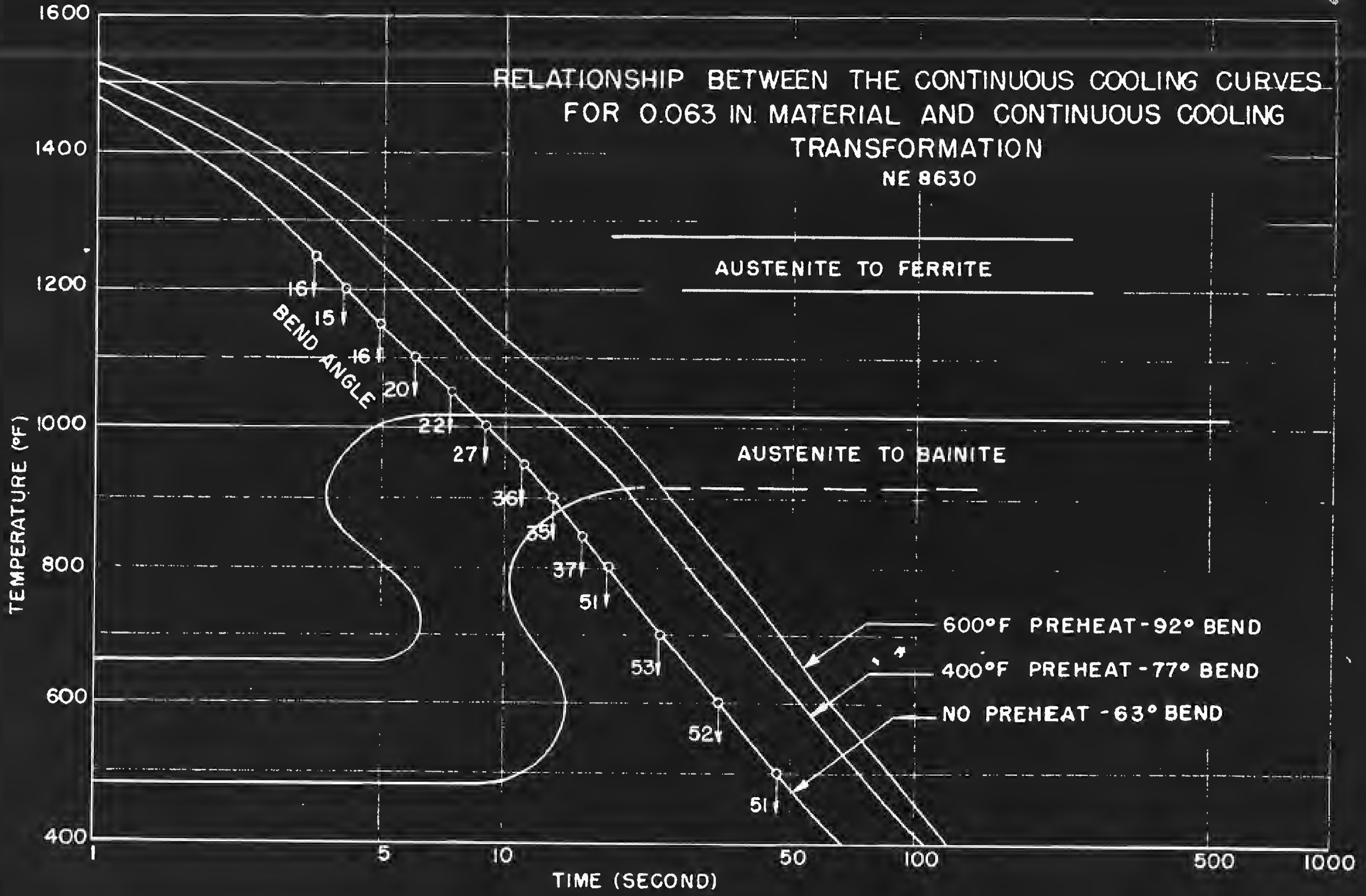
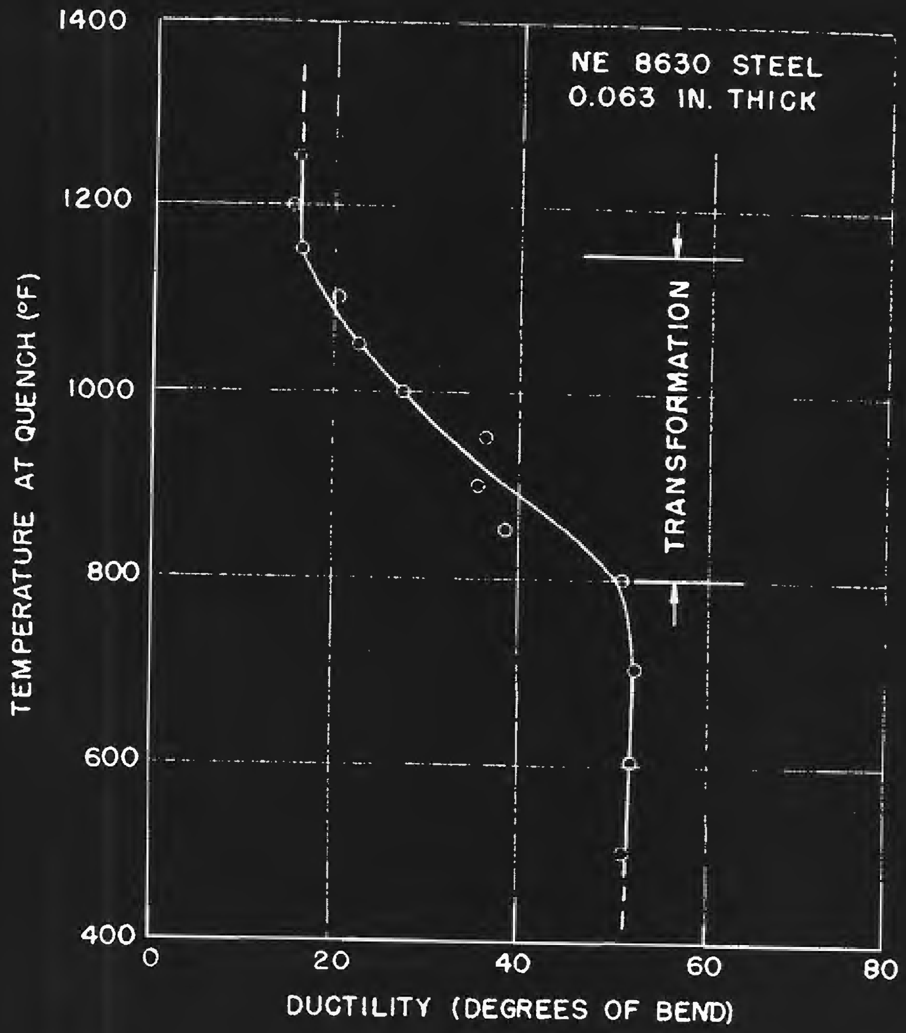
PLATE 5

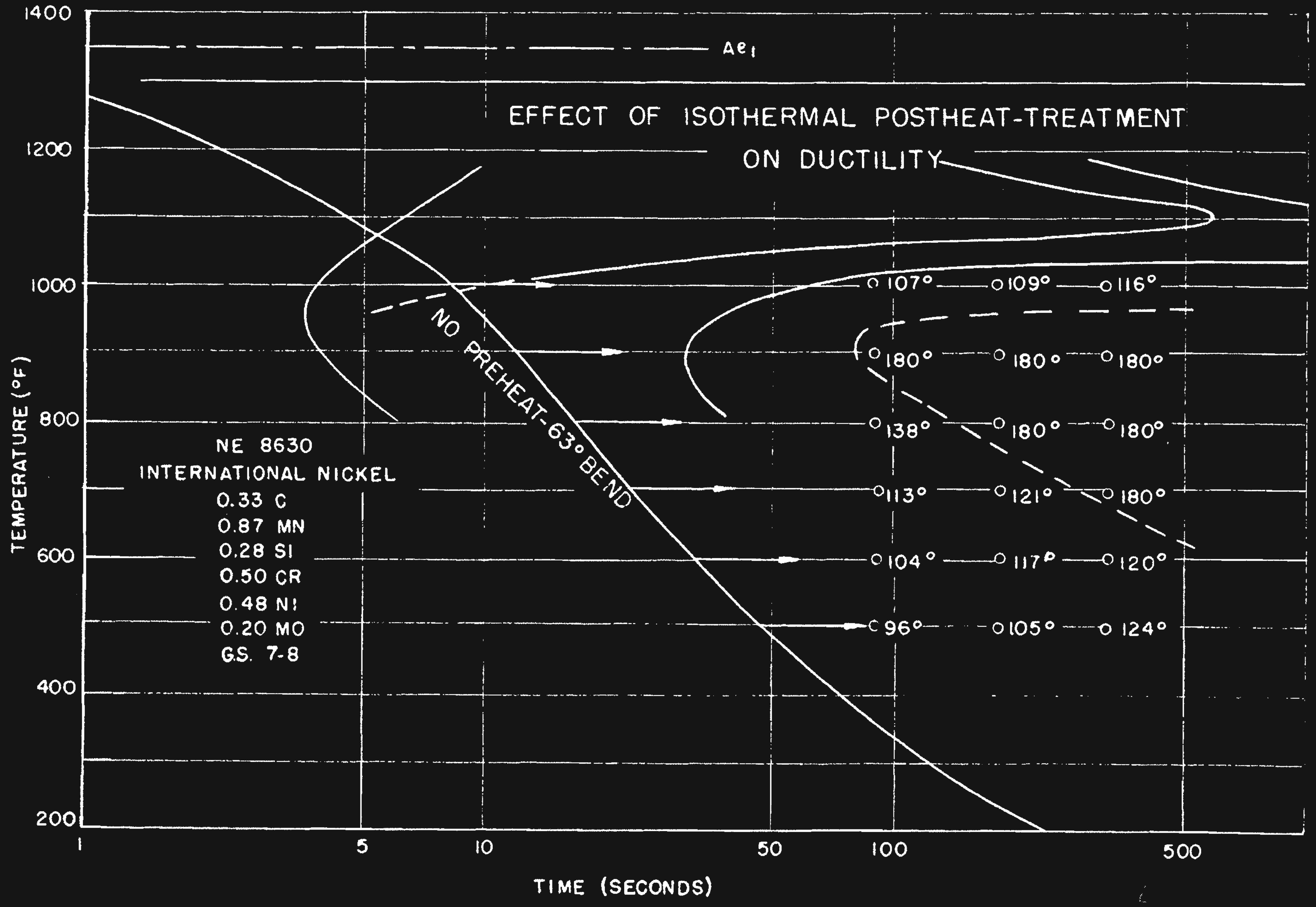


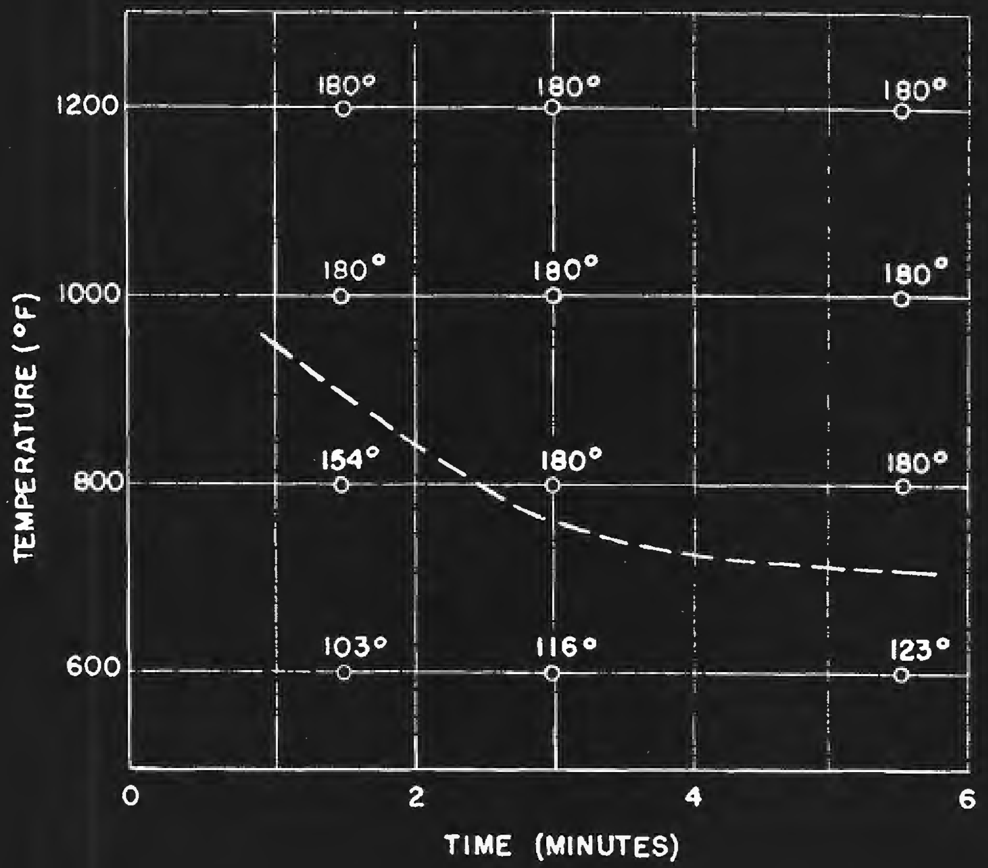
RELATIONSHIP BETWEEN THE CONTINUOUS COOLING CURVES FOR 0.063 IN. MATERIAL AND CONTINUOUS COOLING TRANSFORMATION

NE 8630



CHANGES IN DUCTILITY UPON CONTINUOUS COOLING TRANSFORMATION


EFFECT OF ISOTHERMAL POSTHEAT-TREATMENT ON DUCTILITY
Ae1
NO PREHEAT-63° BEND
NE 8630
INTERNATIONAL NICKEL
0.33 C
0.87 MN
0.28 SI
0.50 CR
0.48 NI
0.20 MO
G.S. 7-8
107°
109°
116°
180°
180°
180°
138°
180°
180°
113°
121°
180°
104°
117°
120°
96°
105°
124°
TEMPERATURE (°F)
1400
1200
1000
800
600
400
200
TIME (SECONDS)
1
5
10
50
100
500

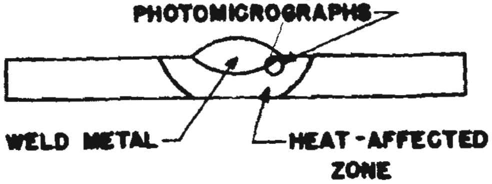


EFFECT OF TORCH "STRESS-RELIEVING" ON THE DUCTILITY OF THE HEAT-AFFECTED ZONE OF UNPREHEATED 0.063 IN. STEEL PLATE NE 8630

250 X

750 X

DUCTILITY-LONG. BEAD WELD-63° BEND
WELD METAL HARDNESS
VICKERS (10 KG.) 289-312
HEAT-AFFECTED ZONE HARDNESS
VICKERS (10 KG.) 425-437



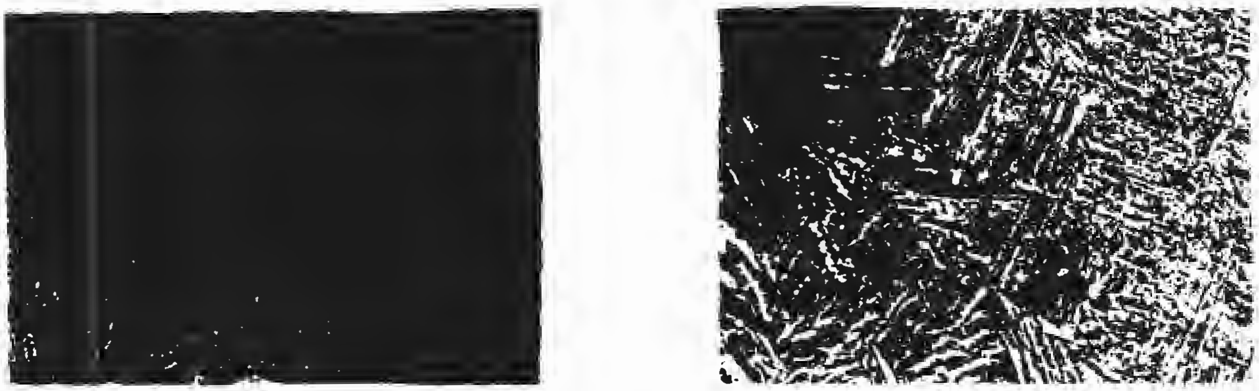
EFFECT OF WELDING WITHOUT PREHEAT ON THE
MICROSTRUCTURE OF WELD AREAS IN NE 8630 STEEL

PLATE 10

250 X

750 X

400°F PREHEAT
DUCTILITY-LONG. BEAD WELD-77° BEND
WELD METAL HARDNESS
VICKERS (10 KG.) 268-309
HEAT-AFFECTED ZONE HARDNESS
VICKERS (10 KG.) 348-421



250 X

750 X

600° F PREHEAT
DUCTILITY-LONG. BEAD WELD-92° BEND
WELD METAL HARDNESS
VICKERS (10 KG.) 249-276
HEAT-AFFECTED ZONE HARDNESS
VICKERS (10 KG.) 348-413

EFFECT OF WELDING PREHEAT ON THE MICROSTRUCTURE
OF WELD AREAS IN NE 8630 STEEL

PLATE II

250 X

750 X

TORCH "STRESS RELEIVED" 600°F FOR 3 MIN.
DUCTILITY-LONG. BEAD WELD - 180° BEND
WELD METAL HARDNESS
VICKERS (10 KG.) 249 - 260
HEAT-AFFECTED ZONE HARDNESS
VICKERS (10 KG.) 266 -339

250 X

750 X

ISOTHERMAL POSTHEAT - TREATMENT
900°F FOR 3 MIN.
DUCTILITY - LONG. BEAD WELD - 180° BEND
WELD METAL HARDNESS
VICKERS (10 KG.) 230-256
HEAT-AFFECTED ZONE HARDNESS
VICKERS (10KG.) 252-325

EFFECT OF POST-HEAT-TREATMENT ON THE MICROSTRUCTURE
OF WELD AREAS IN NE 8630 STEEL

APPENDIX

Since Navy Aeronautical Specification PH-11 for producing satisfactory properties in the weld area of medium alloy steels lists normalizing after welding as a satisfactory post-heat-treatment, it was felt that cooling curves for normalized specimens of various wall thickness and diameters might be useful in a comparison with cooling curves for preheated and postheated thermal cycles.

The tests were made on various sheet and tube sizes of NE 8630 and SAE 4130 steels. Thermocouple wires were flash welded to the center of 6 by 9 inch sheet specimens and to the outside surface and center with respect to length of 15 inch tube specimens. Cooling curves were determined with the "Speedomax" recorder. All specimens were austenitized at 1650°F for 15 to 20 minutes and then cooled in still air. After removal from the furnace, sheet specimens were suspended in a vertical position and allowed to cool. Tube specimens were held in a horizontal position while cooling in order to eliminate possible convection of air currents through the tube. The normalized cooling curves superimposed on continuous cooling transformation diagrams appear in Plates 13 and 14. After normalizing, two tensile specimens were cut from the center of each sheet specimen in order to determine the effect of cooling rates on the mechanical properties. Tensile properties and hardness of the normalized specimens are reported in Table III.

The cooling curves for the tubes were within the same range as the sheets and plates; therefore, instead of plotting the cooling curve for each tube, it was convenient to compare the cooling rates of the tubes with those for the sheets and plates. This comparison and the effect of sheet and tube wall thickness on the time required to cool from 1600°F to 400°F are shown in Plate 15.

TABLE III

MECHANICAL PROPERTIES OF NORMALIZED SHEETS

Steel	Nominal Thickness (Inches)	Yield Strength at 0.2% off-set (1000) p.s.i.	Tensile Strength (1000)p.s.i.	Elong. in 2 in. (%)	Average Hardness (VHN)
NE 8630	0.250	89/92	118/123	19/21	258
NE 8630	0.125	98/100	122/124	17	278
NE 8630	0.063	101/103	123/126	16/17	280
NE 8630	0.028	108/111	133/137	12/15	285
SAE 4130	0.250	89/92	118/119	19	258
SAE 4130	0.125	103/105	131/133	17	285
SAE 4130	0.063	106/109	135/137	15/16	304
SAE 4130	0.028	108/111	134/140	12/13	317

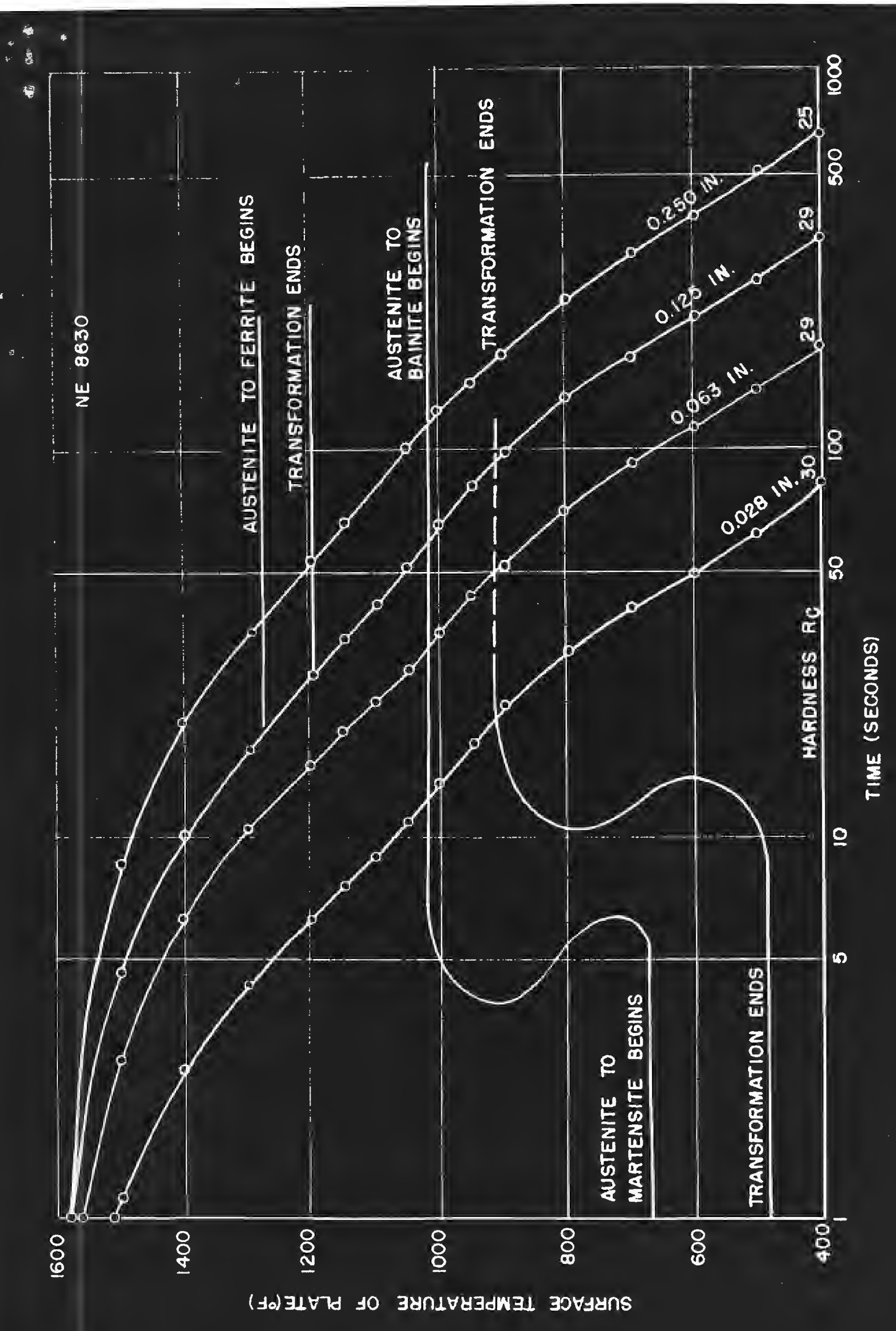


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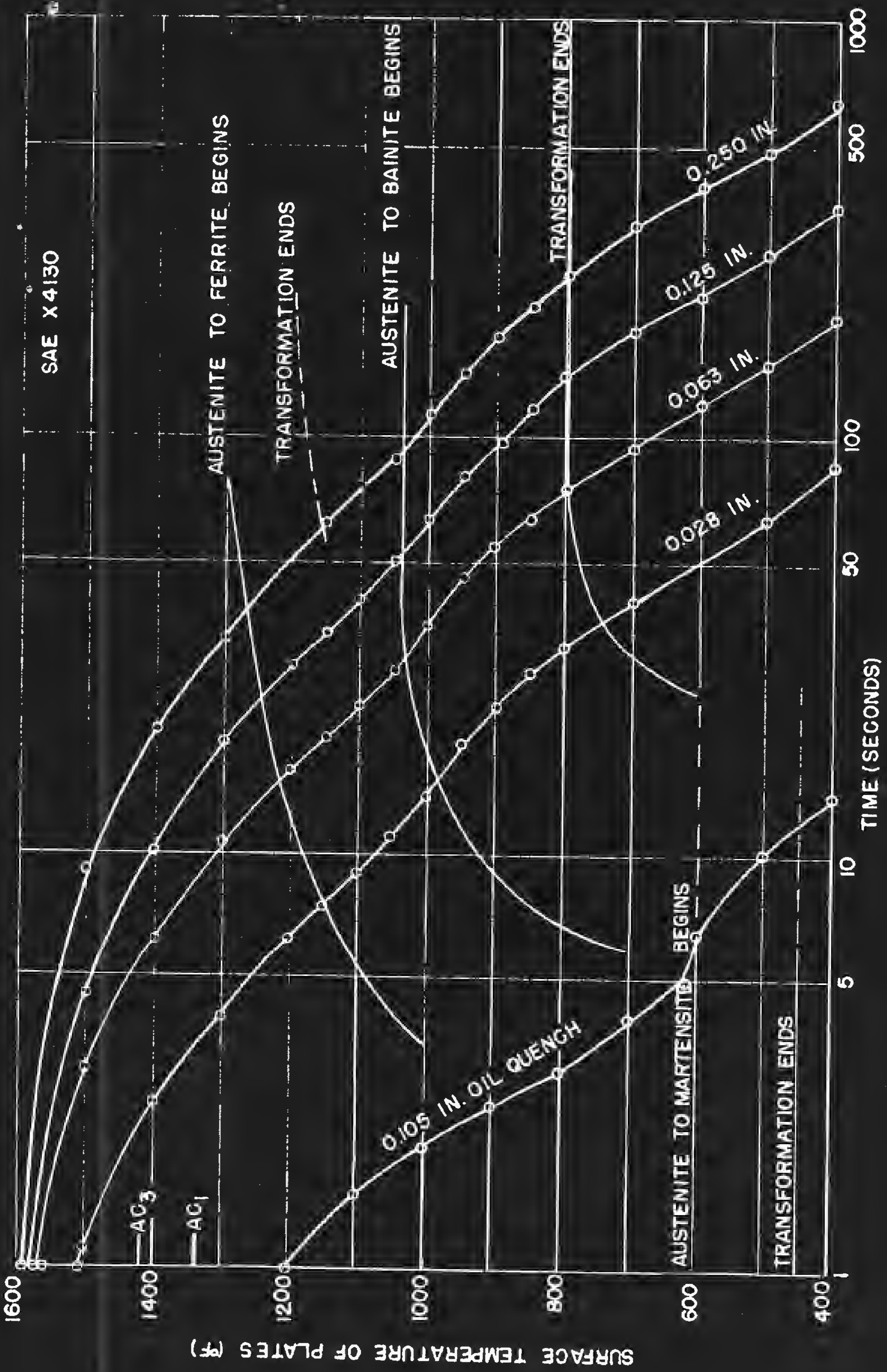
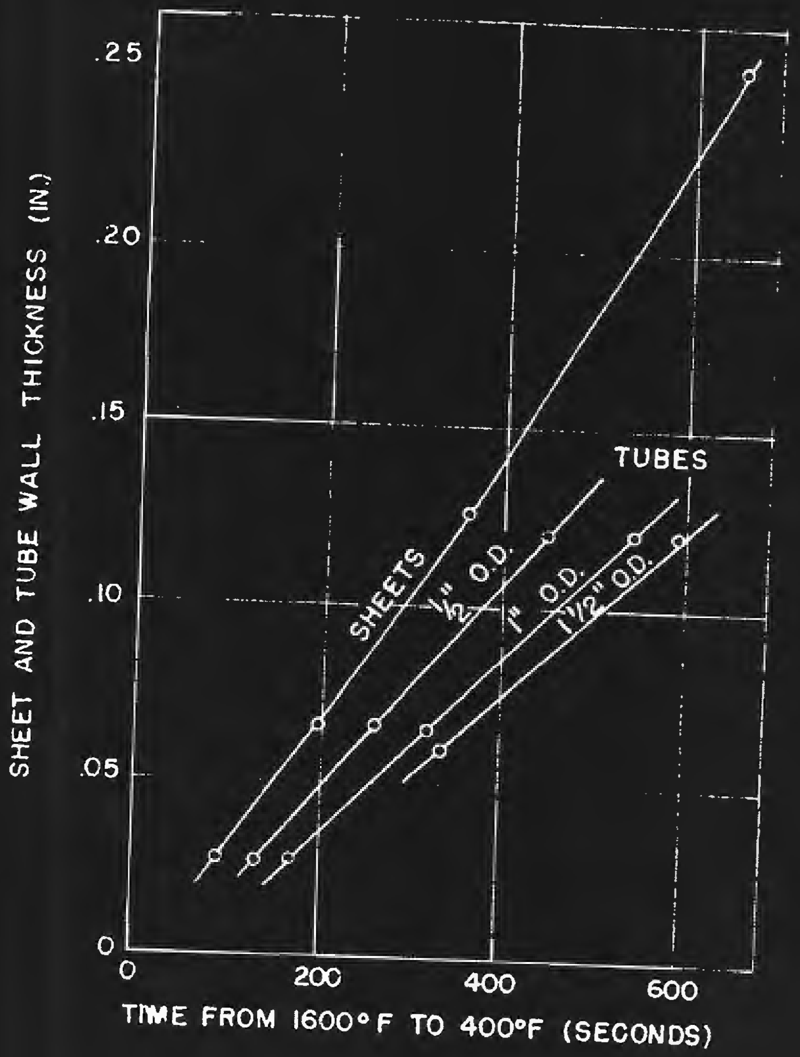
PLATE 13



CONTINUOUS COOLING CURVES

PLATE 14



COMPARISON OF THE NORMALIZING COOLING RATES OF SHEET AND TUBES