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WATERTOWN ARSENAL LABORATORY

EXPERIMENTAL REPORT

NO. WAL. 647/9

REPAIR WELDING OF CAST ARMOR

Determination of Mechanical Properties of Simulated Repair Weld Deposits Made with Five Commercial Alloy Steel Electrodes

BY
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Capt., Ord. Dept.

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REPAIR WELDING OF CAST ARMOR

Determination of Mechanical Properties of Simulated Repair Weld Deposits Made with Five Commercial Alloy Steel Electrodes

The object of this study

OBJECT

was ~~To~~ compare the strength and notched bar impact toughness of weld metal deposits made with the subject electrodes and tested as-welded, drawn after welding, and quenched and drawn (6 inch plate thickness simulated) after welding.

SUMMARY

1. Strength and impact resistance of weld deposits made with five commercial electrodes alloyed to give weld metal of relatively high hardenability have been determined (See Table II). Weld metals were tested in the as-welded, as-welded and drawn, and quenched and drawn conditions. Welding and heat treating procedures were chosen to simulate conditions of repairs in 6 inch thick cast armor.

2. Based on present ballistic test criteria for repair welded cast armor it appears that:

a. A deposit with .10 - .15% carbon and moderate hardenability, e.g., 1.8% Mn, .40% Mo, gives best combination of strength and impact resistance in the as-welded condition.

b. A deposit with relatively high carbon content and hardenability gives best properties in the as-welded and drawn condition. A better combination of strength and toughness was obtained for this condition than for the as-welded condition. However, use of alloys to gain increased strength by secondary hardening at the tempering temperatures resulted in severe loss in impact resistance.

c. Relatively high carbon and alloy contents are required to obtain acceptable strength and impact resistance for repair welds in heavy sections of cast armor quenched and tempered after welding. Since high preheat and interpass temperatures, to avoid weld metal cracking, are permissible when full heat treatment follows welding, increase in carbon and alloy content beyond that of the present deposits appears desirable.

3. No significant directional effects were observed for specimens taken transverse and parallel to the welding direction. No appreciable temper embrittlement was observed for weld metal deposits furnace cooled from the tempering temperature.

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4. Nonballistic test requirements of 200 BHN minimum and 18 ft. lbs. V-notch Charpy impact at -40°F are suggested for repair welds on the basis of the present test data and the present ballistic qualification criteria. A decrease in allowable minimum hardness near the center of section thickness for weld deposits in heavy section of cast armor quenched and tempered after welding (e.g. 175 BHN for 6 inch thickness) would be necessary for present weld metal compositions. The most desirable relation between strength and toughness for optimum protection against ballistic penetration and shock may vary from that suggested above, depending upon thickness of armor, extent of defect, and nature of anticipated ballistic attack. Further study of this aspect of the problem appears desirable.

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INTRODUCTION

Defective armor castings or partially fabricated weldments can sometimes be repaired by welding, with consequent large saving in materials, labor, and time. Most fabrication welding of armor is done with austenitic electrodes of the Mn or Mo modified 18% Cr - 8% Ni types, but because of the large areas involved in many repair welds and the frequent necessity for heat treatment after welding which produces undesirable carbide precipitation at the base metal interface of austenitic welds, it is generally more economical and more desirable to repair weld with ferritic electrodes.

The requirements for a repair weld in armor are a sound deposit which will develop resistance to ballistic penetration and shock to a degree comparable to the base armor. When defects are found in an armor casting before heat treatment it is usually desirable to make the repair before final heat treatment. When defects such as quench cracks are found after heat treatment it is desirable to repair without further heat treatment or with only a redraw treatment.

It is well established that resistance to ballistic penetration increases with hardness, while resistance to ballistic shock improves with notched bar impact energy. Low strength weld joints in high strength armor may however have low shock resistance, even when the weld metal has relatively high notched bar impact properties, because ballistic deformation is largely confined to the low strength weld metal. Since both ballistic penetration and shock performance are controlled by strength and notch bar impact resistance, these nonballistic tests may be used to evaluate repair weld deposits for cast armor.

The optimum combination of strength (strength and hardness measurements are equivalent) and toughness may be obtained in a weld metal which has been deposited as small stringer beads with low interpass temperature or has been hardened in small section by drastic quenching (cooled rapidly to give a fully hardened martensitic structure in either instance) and then tempered to the desired strength level. Plain carbon weld deposits, especially with low carbon content, will fully harden only when cooled extremely rapidly. The progressive addition of suitable alloys permits full hardening of the deposit with decreasing rates of cooling. Certain alloys such as chromium and molybdenum which form complex carbides have the additional effect of retarding the rate of softening upon tempering.

Considerable ballistic data are available from firing records for a large number of 2 inch thick cast armor ballistic test plates with repair welded simulated area defects of various depths. Post ballistic metallurgical examinations of some of these plates have been made[1,2]. At present, Specification AXS-492, Rev. 5 requires that a double I welded ballistic shock test plate and an area defect welded ballistic penetration test plate

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1. Watertown Arsenal Laboratory Report No. WAL 647/7, "Repair Welded Cast Armor, Metallurgical Examination of Samples from Four Ballistically Tested Two Inch Thick Plates", A. M. Turkalo and S. A. Herres, 28 August 1944.

2. Watertown Arsenal Laboratory Report No. WAL 647/8, "Repair Welded Cast Armor, Metallurgical Examination of Samples Representing Ninety-Six Two Inch Thick Ballistic Test Plates, A. M. Turkalo and S. A. Herres, 7 February 1945.

of 2 inch thick cast armor be used for qualification of all repair welding procedures for cast armor of 2 inch and greater thickness. Any electrode which is thus ballistically qualified may be used for repair welding. Ordnance Department, U. S. Army Tentative Specification AXS-1450 covers one type of ferritic electrode which has been used for much of the repair welding of armor castings. One purpose of this specification is to permit interchange of various brands of this type electrode without requalification by ballistic tests. The following analysis range for deposited weld metal is specified by AXS-1450.

C	Mn	Si	S	P	Mo
.10/.15	1.65/1.95	.20/.50	.035 max.	.035 max.	.30/.40

This type electrode was originally developed by the Arcos Corporation and later adopted and slightly modified by other electrode manufacturers under N.D.R.C. sponsorship. It has a lime or lime-titanium base coating of the type used on 18-8 austenitic electrodes, and gives a weld deposit of lower hydrogen content than welds made with electrodes having the usual commercial type coatings for ferritic electrodes. The lower hydrogen permits welding of armor steels without danger of base metal underbead cracking and with less tendency toward general hydrogen embrittlement of the weld metal.

This type of weld metal requires a preheat and interpass temperature of 200 to 400°F to prevent weld metal cracking during welding of a restrained weld or a plug weld in 1-1/2 inch thick and heavier gage armor. Recently armor castings up to 12 inches thick have been made. The cooling rate of weld deposits which are made with high preheat and interpass temperatures or of welded areas which are rehardened by quenching or part of a heavy section casting are relatively very slow. It has been estimated that the 1450 type weld metal will harden only when water quenched as a section of less than 3/4 inch thickness. The deterioration in properties of repair welds in heavy sections are therefore a matter of considerable concern.

The purpose of this report is to determine the relative properties of repair welds made with available commercial electrodes both of the 1450 and other alloy ferritic types. Comparisons are made for properties of deposits in the as-welded, drawn, and quenched and tempered conditions.

TEST MATERIALS AND TEST PROCEDURE

Table I lists the electrode brands names, diameters preheat and interpass temperatures and currents and voltages for the thirteen pad deposits included in this investigation. Pad deposits were built up to approximately 2-3/4 x 3-3/4 x 7 inches in 8 inch sections of 4 inch wide mild steel channel beam. Diluted and surface weld metal was removed by machining pad to 2 x 2-1/4 x 6 inch dimensions. All pad deposits required more than 8 hours to weld and were allowed to cool overnight and then torch heated to the designated interpass temperature before recommencing welding.

Weld pads No. 1, 2, 3, 4, 7, and 8 were split transversely; one half of each pad was drawn and V-notch Charpy specimens longitudinal to the direction of welding were obtained from each half of pad. Weld pads No. 5, 10 and 12 were split longitudinally; one half of each pad was drawn and V-notch Charpy specimens both longitudinal and parallel to direction of, welding as well as .252 inch diameter tensile bars parallel to the direction of welding were obtained.

Weld pads number 6, 9, 11, and 13 were water spray quenched as inserts in a six inch thick plate. After the quenching, the insert pads were removed for Brinell hardness survey, and tempered. Charpy specimens were taken transverse to the direction of welding to represent metal near the plate metal surface, at midwall, and at center of six inch thick section. Charpy specimens and .252 inch diameter tensile bars were also taken longitudinal to the direction of welding with notch of Charpy bar and center of tensile bar at midwall (halfway between end of insert-quenched surface, and center of insert center of plate thickness).

Brinell hardness readings (1000 Kg load) were taken on individual Charpy bars and approximate tensile strength determined by the hardness conversion table given in Federal Specification QQ M-151a, Amendment 2 (Impact tests were made on duplicate standard Charpy V-notch impact test specimens at testing temperatures of +70°F and -40°F). Chemical analyses were made of chips and spectrograph bars machined from broken Charpy specimens.

Heat treatment procedures for repair weld deposits are governed by the requirements of the cast armor. The temperature of a draw treatment after welding must not exceed the draw temperature of the armor nor should it be below 1100°F because of danger of temper embrittlement of the armor. A draw treatment for as-welded deposits at 1175°F, two hours hold, and air cool was used in the present investigation.

In order to determine a method of simulating the cooling rate of weld deposits as-quenched in 6 inch cast armor sections, reference was made to data obtained by the Process Metallurgy Section of this Laboratory. (See Figures 1a, 2a, and 3a of Appendix A.) It was originally proposed to use small sections air cooled to simulate large sections water quenched, but the data of Figure 3a (Appendix A) indicated that the simularity of cooling curves was not adequate to justify this expedient. Therefore, a 6 inch thick mild steel plate approximately 36 inches square with a 12 inch square hole was used for quenching of weld metal pad deposits as inserts.

Mild steel plates 3/4 inch thick were welded over this hole and the weld pad deposits machined to 2-1/4 x 2 x 6 inch dimensions were inserted through 2-1/4 x 2 inch holes in the 3/4 inch cover plates and welded into position so that the two ends of the pads were flush with the surfaces of the 6 inch plate and only the ends of the pads were exposed to the quenching medium. Two insert pads were quenched with water spray at one time. A thermocouple welded at the middle of the length of one pad deposit was used during each quench to obtain cooling curves which were compared with that for the center of the 6 inch plate (Figure 1a, Appendix A).

The two cooling curves thus obtained for insert pads followed very closely the cooling curve for spray quench of solid 6 inch plate. After the quenching, the insert pads were taken out of the plate, surface ground for hardness surveys, and then tempered at 1200°F, two hours hold, and air cooled. Charpy and tensile specimens were obtained as described above.

DATA AND DISCUSSION

Electrode Operating Characteristics and Soundness of Weld Deposits

Murex type 90 electrode is intended for welding with either AC or DC current, high strength structural plate in the flat or horizontal position. Its operating characteristics are good, but the relatively thick slag deposit might be disadvantageous for repair welds. No visible porosity and no cracks were observed in pad deposits.

Shield Arc 100 is an all position DC electrode. Operating characteristics are excellent and slag light. No cracks or visible porosity were observed in pad deposits.

AW2C is a DC electrode with a lime base mineral coating. Operating characteristics in the flat and horizontal positions appear to be similar to those of a good austonitic (19-9) electrode. Extreme porosity is encountered unless electrode is used at relatively very high current. Even then it was found necessary to preheat this electrode at about 400°F shortly before its use to avoid considerable porosity near start of each bead. This was the only electrode which was preheated. No cracks were observed during welding of pads.

AW4 has a titanium base coating with low cellulose content. Its operating characteristics appear to be similar to AW2C. No visible porosity was observed in pad deposits, but one pad developed a severe transverse crack when the partially welded pad was allowed to cool overnight. The crack progressed through successive layers as the welding was completed. The duplicate pad did not crack.

Chromend 2M has a lime base mineral coating. Its operating characteristics appear to be similar to AW2C. Slight porosity occurs near start of beads. No cracks were observed in pad deposits.

Chemical Analyses: TABLE VII

Chemical analyses of the weld deposits were as follows:

Dia.	Electrode	C	Mn	Si	S	P	Ni	Cr	Mo	V	Ti
3/16	AW2C	.11	1.91	.29	.020	.022	Nil	.025	.40	Nil	trace
3/16	AW4 - 10013	.07	.53	.28	.032	.018	Nil	2.35	.47	Nil	trace
5/32	Shield Arc 100	.08	.45	.28	--	--	Nil	.20	.75	.13	trace
5/32	Murex 90	.05	.45	.05	.023	.021	1.14	.31	.63	Nil	trace
3/16	Chromend 2MS	.12	.88	.52	.023	.023	Nil	1.79	.42	Nil	trace

AW2C is the only electrode included in this investigation which falls within the chemical analysis range included in Ordnance Department, U. S. Army Tentative Specification AXS-1450.

Hardness, Tensile, and Charpy Tests

All hardness, tensile, and notched bar impact test data are tabulated in Table II. Charpy impact bars were taken both parallel and transverse to the direction of welding from a majority of the weld deposits, but this variable does not appear significant.

Reference to Report No. WAL 647/8[3] indicated that the hardness and notched bar impact values obtained for the AW2C deposits welded at 212°F. minimum interpass temperature are similar to those of repair weld deposits in ballistically tested plates prepared with the same electrode by industrial facilities. Ballistic test results indicate adequate resistance to ballistic penetration and satisfactory resistance to ballistic shock for large area defect repair welds in such plates tested in the as-welded condition. Resistance to ballistic penetration falls off with decrease in hardness of the weld deposit heat treated after welding in area defect welded test plates. Resistance to ballistic shock for double I plates welded with this type electrode is borderline according to the present qualification criteria and there are indications that ballistic shock performance of the weld metal would fall off more rapidly than that of the armor plate if plates were tested at higher velocity of impact or at subnormal temperatures.

On this basis of the ballistic criteria it appears that AW2C has the best combination of tensile and impact properties of the weld deposits tested in the as-welded condition. Resistance to ballistic penetration of the two high strength deposits of AW4 and Chromend 2MS should be superior but it is probable that their resistance to shock would be unsatisfactory. Proof of this would require ballistic shock testing. Strength of deposits made with the higher preheat and interpass temperature range is lower, but impact resistance is not improved, indicative of the expected effect of a higher preheat producing a slower cooling rate and giving coarse carbide distribution.

In the as-welded plus 1175°F draw condition, the AW2C deposit has properties quite similar to those as-welded and the same may be said of the Murex 90 deposit which is lower in strength. Shield Arc 100 has gained strength due to secondary hardening brought about by vanadium, but has lost considerable impact resistance and is therefore less suitable. AW4 and Chromend deposits have dropped in strength and gained in impact resistance, and the latter deposit appears to have an excellent combination of strength and toughness. The higher strength and impact resistance of Chromend than that of AW4 deposits in both the as-welded and drawn conditions must be almost entirely due to the higher carbon content, and a similar improvement would be expected for a Murex 90 type analysis with somewhat higher carbon content.

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3. See footnote 2, page 3.

A plot of hardness versus distance from the plate surface for the insert pads as-quenched in 6 inch thick plate is shown in Figure 1. This gives an indication of the relative hardenability of the four* weld metals under the particular conditions of quenching of a weld repair in a thick casting. It would be expected that the order of hardness would be the same as that for the as-welded deposits; so the reversal in hardness of AW2C and AW4 welds may be a result of incomplete solution of the carbides of the latter during the austenitizing treatment.

The hardnesses of the four weld deposits tempered after insert quench are shown in Table II. Both resistance to ballistic penetration of industrially welded area defect repair weld test plates and ballistic shock resistance of double I test plates made with AW2C electrode have been inferior for plates quenched and tempered after welding to those tested as-welded or drawn. Ballistic cracking of a double I plate may increase with low strength of weld deposit, as well as with low notched bar impact resistance because deformation during ballistic testing is confined principally to the weld metal. Accordingly, the strength of weld metal deposits as quenched and tempered in heavy sections of cast armor should have strength and impact resistance approaching those of AW2C in the as-welded condition. Of the quenched and tempered deposits, Chromend approaches this requirement while AW2C is lower in strength with slightly better impact resistance. Murex 90 and AW4 deposits are inferior in both strength and impact resistance, an expected result of their relatively low carbon and consequent lack of hardenability.

When quenched in small section (1/2 inch square bars) and tempered, the AW2C and particularly the Chromend deposit improved markedly, in strength and impact resistance. A comparison of bars water-quenched and furnace cooled from the tempering treatment indicates that none of the weld metals is appreciably susceptible to temper brittleness, but as many cast armor compositions are susceptible to temper embrittlement, it is not advisable to temper repair welded plates below 1100°F or to cool slowly from higher tempering temperatures (See effect of stress relieving treatments WAL Report No. 647/8[4]).

GENERAL COMMENTS

In specifying requirements for repair welding of cast armor, two problems must be considered: (1) Properties obtainable in deposits made with various available electrodes, (2) Properties required for ballistic protection in a given application.

The data herein reported indicate that the following principles apply to the first problem: (1) In the as-welded condition, a deposit with very low carbon and very high hardenability would give best combination of strength and hardness. As it is not practical to use welding conditions which would give a rapid cooling rate (low interpass temperature and small

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* Shield Arc 100 was not included in quench and temper tests because of its embrittlement in the as-welded and drawn condition.

[4] See footnote 2, page 3.

beads) carbon content of .10 - .15% and moderate hardenability (as in AW2C deposit) gives moderate strength and impact resistance. Higher carbon or alloy content gives increased strength but lower impact (as in the Chromend deposit). Lower carbon or alloy content gives decreased strength and no improvement in impact resistance. (2) In the drawn condition a deposit with relatively high carbon and alloy content gives the best combination of strength and impact resistance. Use of an alloy element which produces secondary hardening at the tempering temperature does not appear desirable because the gain in strength may be accompanied by a loss in impact resistance. The draw treatment should be lower than that used in the armor plate heat treatment, but not below 1100°F, because of the danger of temper embrittlement for most cast armor compositions. Within this range some compromise between loss in strength and gain in toughness with increased draw temperature is possible. (3) In the quenched and tempered condition a relatively high carbon content and sufficient alloy for high hardenability is indicated. Since high preheat and interpass temperature is permissible to avoid weld metal cracking, increases in both carbon and alloy content beyond those of the present deposits is indicated. Heat treatment is governed by requirements of the armor plate composition.

Hydrogen embrittlement does not appear to be a serious problem in repair weld deposits made at high preheat and interpass temperatures, and the type of electrode coating may not be important from this point of view. The problem of weld metal cracking should be investigated in the light of recent British research[5] which indicates a very critical sulphur limit to prevent cracking of weld metals with relatively high carbon, manganese, or silicon contents.

Nonballistic test requirements of 200 BHN minimum and 18 ft. lbs. Charpy impact minimum at -40°F for repair weld deposits are suggested by these test data and the present ballistic qualification criteria. A decrease based on thickness of section in minimum hardness allowable at the center of section thickness for weld deposits quenched and tempered after welding e.g. to 175 BHN for 6 inch section thickness, would be necessary for present weld metal compositions. Qualification and routine inspection control tests to assure sound crack free weld repairs with specific welding procedures used by industrial facilities would also be necessary.

The second problem of establishing properties necessary for ballistic protection with a given type of armor and weld repair requires further study. The present 2 inch thick double I ballistic shock plate certainly does not represent a ballistic test of the properties of weld repairs in heavy section armor which is quenched and tempered after welding. If it is known that the strength-impact properties required for optimum shock performance of weld metal in the 2 inch thick double I plate are similar to those required for repair welds in heavy sections, then requirements for a nonballistic test of the latter may be specified.

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5. "Influence of Sulphur and Phosphorus on Weldability of Mild Steel", L. Reeve, Trans. Institute of Welding, Vol. 8, No. 2, May 1945.

The most desirable relation between strength and notch bar impact resistance for optimum protection against ballistic penetration and shock possibly should vary depending upon thickness of armor, extent of weld, and nature of ballistic attack anticipated in combat. Such considerations may determine whether the high strength and low impact resistance of a deposit such as Chromend in the as-welded condition, would be more desirable for some applications, or whether the properties of a high hardenability deposit in the as-welded and drawn condition should be specified whenever possible.

VIII

TABLE I

Welding Procedure Data for Weld Pad Deposits

Weld Pad No.	Electrode Mfgr. Brand	Diameter in.	Preheat °F.	Interpass °F.	Current DC Rev. Pol. Amps.	Voltage
1	Lincoln Electric Shield Arc 100	5/32	212	212-350	155-160	23-24
2	" " "	5/32	350	350-500	155-160	23-24
3	Harnischfeger AW2C*	5/32	212	212-350	160-165	22-24
4	" "	5/32	350	350-500	160-165	22-24
5	" "	3/16	212	212-350	215-220	22-24
6	" "	3/16	212	212-350	215-220	22-24
7	Metal & Thermit Murex Type 90	5/32	212	212-350	150-155	25-26
8	" " "	5/32	350	350-500	150-155	25-26
9	" " "	5/32	212	212-350	150-155	25-26
10	Harnischfeger AW4	3/16	212	212-350	205-215	23-24
11	" "	3/16	212	212-350	205-215	23-24
12	Arcos Corp. Chromend 2MS	3/16	212	212-350	215	19-20
13	" "	3/16	212	212-350	215	19-20

* The electrode was preheated to 400°F. immediately before welding.

TABLE II IX

Results of Hardness, Tensile and V-Notch Charpy Impact Tests for Weld Pad Deposits in As-Welded, Drawn, and Quenched and Tempered Conditions

As-Welded

	BHN	Approximate TS Converted From BHN* psi.	Tensile Tests TS psi.	YS psi. .1%	RA %	Charpy V-Notch** Ft. Lbs. at +70	-40
SA 100	209	101,500				31L	19L
5/32" diameter	227	109,000				43L	17L
212°F Preheat							
SA 100	185	90,500				29L	17L
5/32" diameter	209	101,500				39L	16L
350°F Preheat							
AW2C	200	98,500				40L	16L
5/32" diameter	218	102,000				55L	15L
212°F Preheat							
AW2C	178	88,500				39L	14L
5/32" diameter	209	101,500				47L	22L
350°F Preheat							
AW2C			105,000	88,000	62.8	62L	18L
3/16" diameter			109,600	96,500	64.8	46L	22L
212°F Preheat			112,000	99,000	63.2		
						60T	---
						60T	
90	178	88,500				44L	19L
5/32" diameter	193	95,000				41L	22L
212°F Preheat							
90	171	85,000				46L	22L
5/32" diameter	185	90,500				47L	26L
350°F Preheat							
AW4			128,000	115,000	21.8	13L	9L
3/16" diameter			136,000	123,000	47.0	17L	4L
212°F Preheat			115,000	110,000	14.0		
						24T	
						17T	
Chromond 2MS			140,600	124,000	11.0	23L	7L
3/16" diameter			148,000	126,000	41.0	19L	6L
212°F Preheat			138,800	126,000	19.8		
						36T	
						19T	

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*According to conversion table given in Federal Specification QQ M-151a, Amendment 2.

**L Charpy impact specimen taken parallel to direction of welding.
T Charpy impact specimen taken transverse to direction of welding.

TABLE II (CONTINUED) IX cont

As-Welded and Draw 1175°F, 2 hrs., Air Cool

		Approximate TS Converted From BHN	Tensile Tests			Charpy V-Notch Ft. Lbs. at	
	BHN	psi.	TS psi.	YS psi. .1%	RA %	+70	-40
SA 100	227	109,000				21L	15L
5/32" diameter	248	118,500				26L	4L
212°F Preheat							
SA 100	209	101,500				28L	5L
5/32" diameter	218	102,000				24L	7L
350°F Preheat							
AW2C	209	101,500				66L	22L
5/32" diameter	218	102,000				58L	27L
212°F Preheat							
AW2C	200	98,500				58L	14L
5/32" diameter	209	101,500				63L	22L
350°F Preheat							
AW2C			104,400	91,500	57.4	75L	24L
3/16" diameter			105,600	93,000	44.6	70L	26L
212°F Preheat			104,000	92,000	59.9		
						78T	
						69T	
90	185	90,500				44L	25L
5/32" diameter	193	95,000				43L	29L
212°F Preheat							
90	185	90,500				42L	22L
5/32" diameter	193	95,000				43L	19L
350°F Preheat							
AW4			114,200	104,000	54.8	30L	5L
3/16" diameter			115,200	105,000	32.8	33L	3L
212°F Preheat			106,000	101,000	26.8		
						29T	
						31T	
Chromend 2M-5			120,000	104,000	65.5	56L	22L
3/16" diameter			115,600	101,000	62.8	55L	20L
212°F Preheat			117,300	103,000	63.2		
						83T	
						69T	

TABLE II (CONTINUED)

Spray Quenched as Insert and Temper at 1200°F, 2 hrs., Air Cool

	Distance from Plate Surface	BHN	Approximate TS Converted From BHN psi.	Tensile Tests TS psi.	Tensile Tests YS psi. .1%	Tensile Tests RA %	Charpy V-Notch Ft. Lbs. at +70°F	Charpy V-Notch Ft. Lbs. at -40°F
AW2C	Near Surface	192	94,500				96T	42T
3/16" diameter							87T	40T
212°F Preheat								
	Midwall	178	88,500	90,400	69,800	68.4	100T	38T
				88,200	68,000	69.8	99T	39T
				90,200	68,500	67.8	93L	35L
							93L	50L
	Center	165	83,000				89T	47T
							105T	55T
90	Near Surface	192	94,500				41T	13T
3/16" diameter							48T	15T
212°F Preheat								
	Midwall	165	83,000	77,800	66,200	63.8	51T	16T
				82,800	66,500	63.8	54T	9T
				80,400	64,500	58.4	51L	12L
							55L	4L
	Center	163	82,500				54T	23T
							55T	5T
AW4	Near Surface	187	91,500				82T	25T
3/16" diameter							50T	15T
212°F Preheat								
	Midwall	159	80,500	85,000	57,000	49.8	61T	8T
				84,000	56,500	64.8	61T	8T
				82,000	55,500	53.0	60L	20L
							63L	18L
	Center	154	78,000				56T	25T
							51T	28T
Chromend 2MS	Near Surface	200	98,500				96T	38T
3/16" diameter							97T	32T
212°F Preheat								
	Midwall	193	95,000	94,000	66,800	72.2	83T	33T
				94,000	66,500	70.6	84T	21T
				96,000	66,500	60.4	61L	35L
							58L	24L
	Center	185	90,500				106T	34T
							80T	39T

TABLE II (CONTINUED) IX Cont

Water Quenched as 1/2 inch Square Bars and

Tempered for 2 hrs. at 1200°F., Air Cool

	BHN	Approximate TS Converted From BHN psi.	Charpy V-Notch Ft. Lbs. at +70	Charpy V-Notch Ft. Lbs. at -40
AW2C				
WQ from Temper	248	118,500	53T 44T	29T 24T
FC from Temper	248	118,500	48T 30T	16T 20T
90				
WQ from Temper	248	118,500	22T 25T	6T 14T
FC from Temper	248	118,500	20T 24T	13T 11T
AW4				
WQ from Temper	227	108,000	39T 39T	21T 14T
FC from Temper	227	108,000	31T 44T	21T 5T
Chromend 2MS				
WQ from Temper	272	129,000	78T 73T	40T 39T
FC from Temper	272	129,000	78T 70T	38T 37T

Fig 1

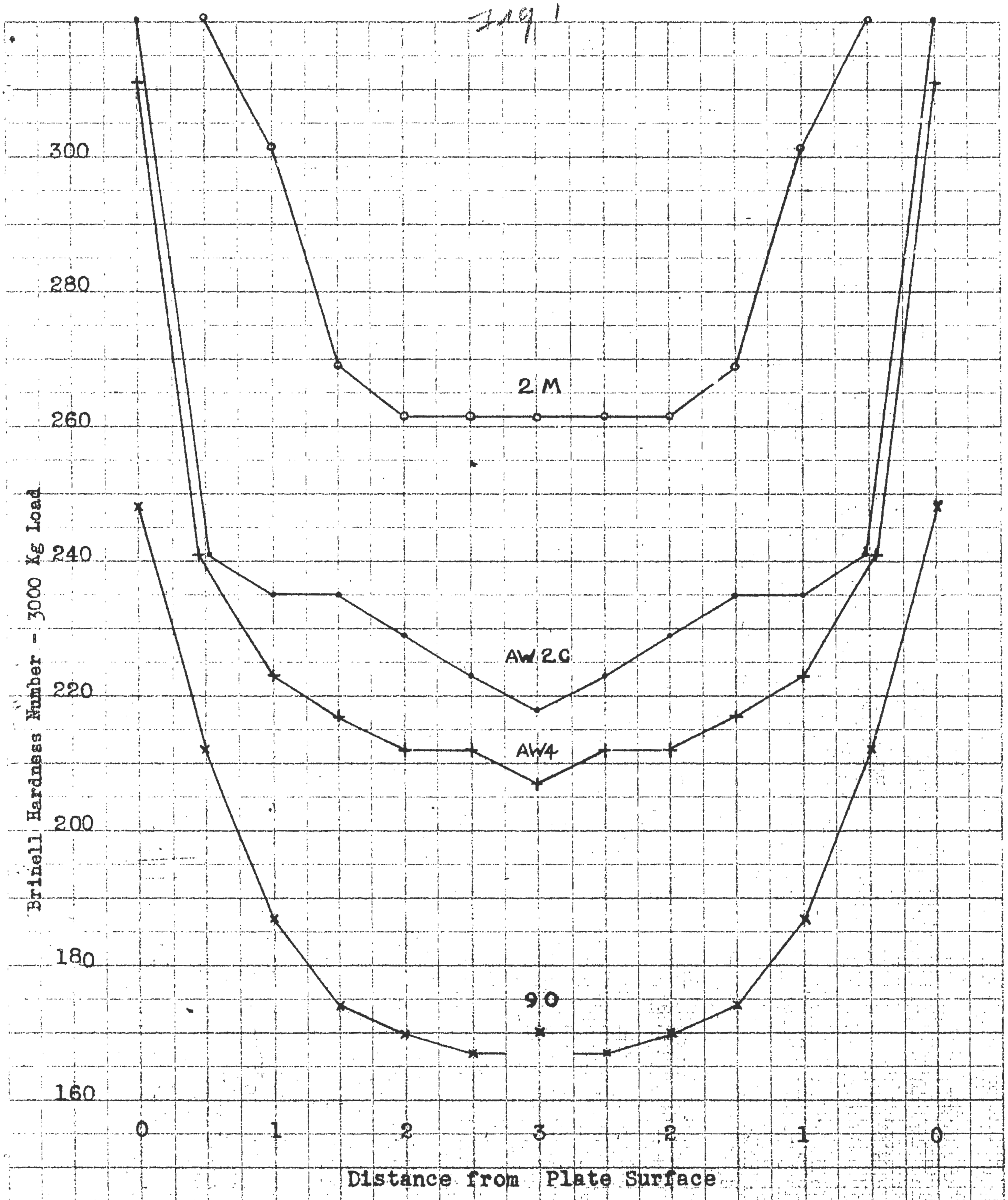

FIG. 1.

As-Quenched Hardness of Weld Pads Water Spray Quenched as Inserts in 6 inch Thick Plate.

APPENDIX A

Cooling rate data obtained by Process Metallurgy Section
Watertown Arsenal Laboratory.

Figure 1a Cooling curves at various locations in six inch armor plate during immersion water quench and water spray.

Figure 2a Temperature Distribution during water immersion quench of six inch armor plate.

Figure 3a Cooling curves from center of plates.

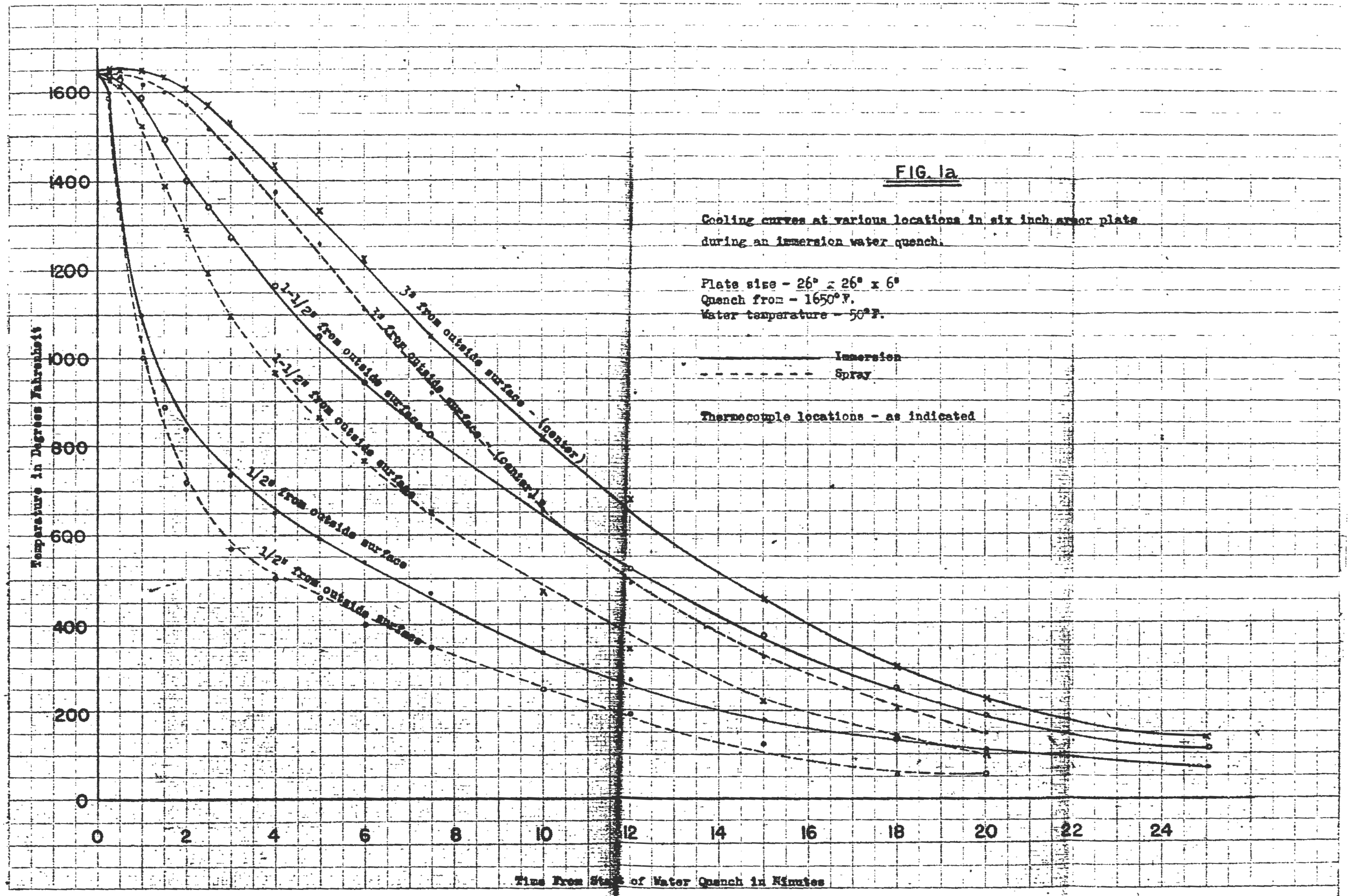

FIG. 1a

Cooling curves at various locations in six inch armor plate during an immersion water quench.

Plate size - 26" x 26" x 6"
Quench from - 1650°F.
Water temperature - 50°F.

Thermocouple locations - as indicated

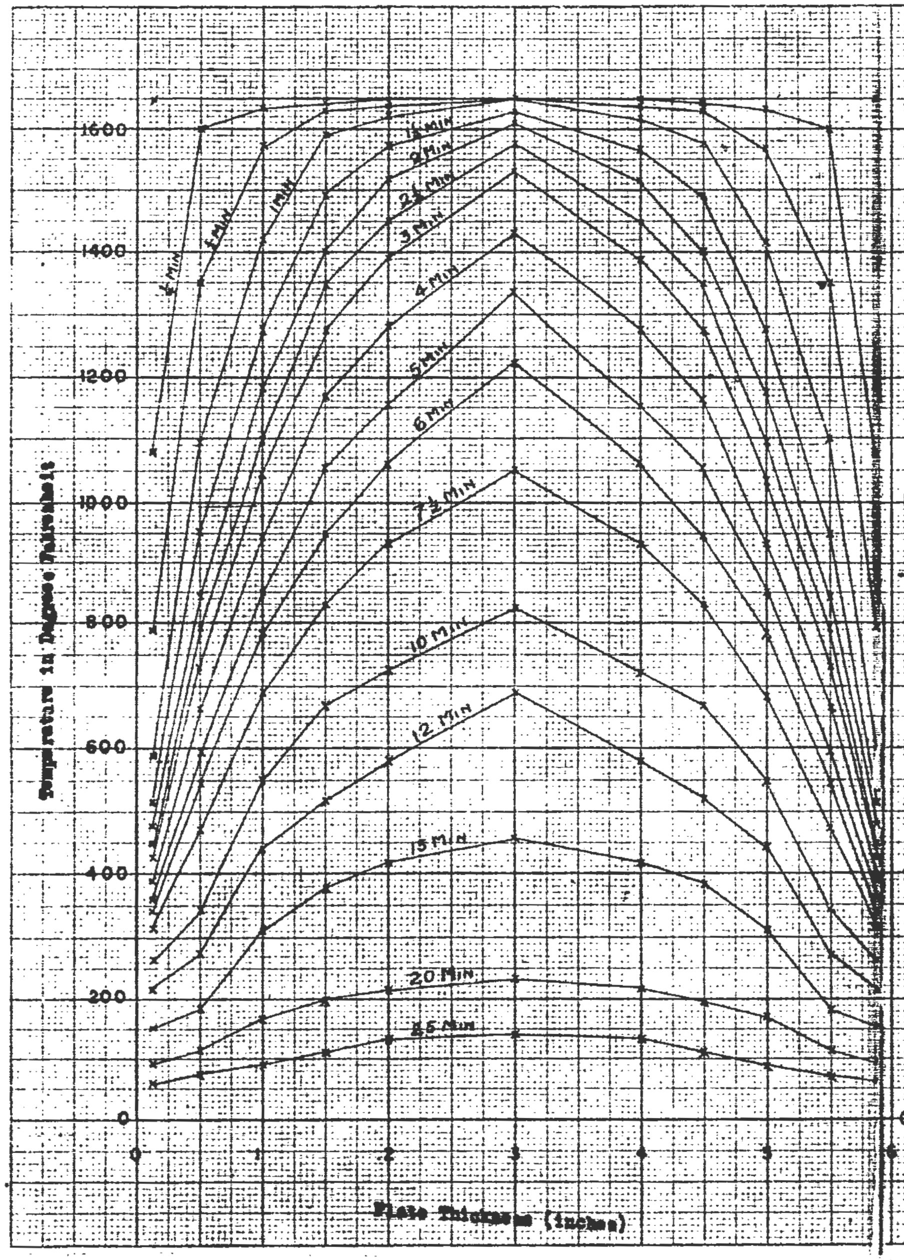

FIG. 2a

Temperature Distribution
During water immersion quench
of six-inch armor plate

Plate size - 26" x 26" x 6"
Quenched from 1650°F. in
Water (50°F.) tank
Tank - 1700 gal. cap.
Circulation - 375 gal./min.
Times - as indicated

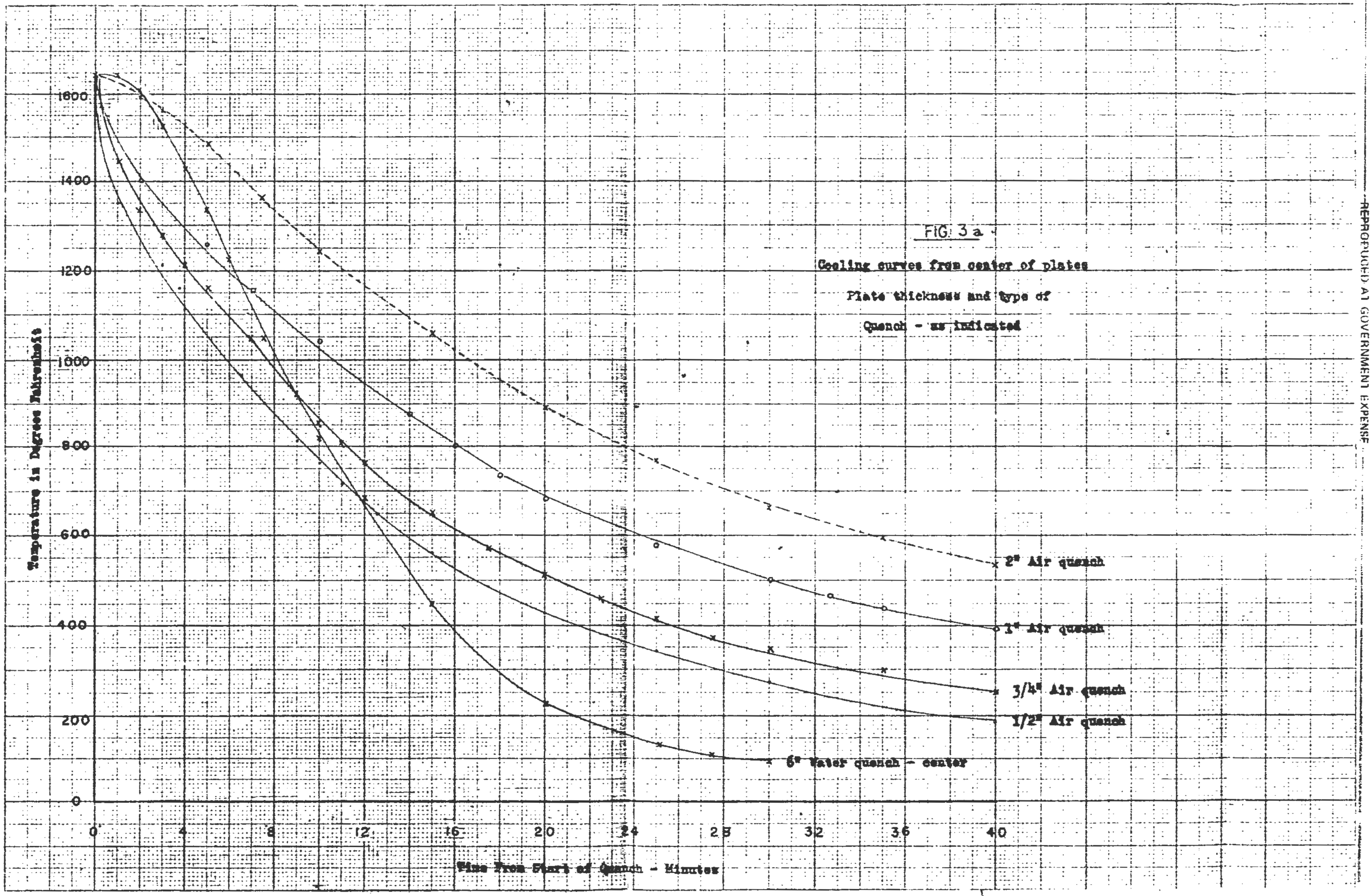

FIG. 3 a

Cooling curves from center of plates

Plate thickness and type of

Quench - as indicated