248008

DP-MS-85-4

ALLCOR® WELDING AND WELDMENT CORROSION RESISTANCE

by

C. F. Jenkins and T. A. Jones

Savannah River Plant
E. I. du Pont de Nemours and Company
Aiken, SC 29808

A paper proposed for presentation at the
ASM Metals Congress, Metallography-Welding
Toronto, Ontario
October 13-18, 1985

and for publication in the proceedings

DP-MS-85-4

ALLCORR[R] WELDING AND WELDMENT CORROSION RESISTANCE*

by

C. F. Jenkins and T. A. Jones

E. I. du Pont de Nemours and Company
Savannah River Plant
Aiken, South Carolina 29808

ABSTRACT

The corrosion and mechanical properties of Allcorr[R] are affected by precipitation of coarse secondary phases at grain boundaries occurring during welding or heat treatment at 700-1100°C. Welding parameters were varied in an attempt to minimize property degradation and develop an acceptable joining technique for the alloy. The flow characteristics of Allcorr[R] allow welding with low heat input, though special care is required to insure full penetration. Low heat input welding preserves the good corrosion resistance of the alloy. A solution heat treatment at 1200°C restores maximum corrosion resistance in Allcorr[R].

---

* The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

INTRODUCTION

Allcorr (UNS N06110) is a high performance nickel-base alloy designed for service in highly corrosive atmospheres. It has seen its widest use in oil field down-hole applications. Du Pont is evaluating the alloy for a critical off-gas service involving severe temperature and chemical exposures.

In the down-hole service and for most other past applications of the alloy, welds have not been used. However, welding is required in the off-gas system. Moreover, if Allcorr is to be generally utilized, knowledge of weldability and mechanical properties is essential. For optimum usage, it is desirable that weldments of the alloy possess properties similar to the base metal.

A high degree of weldability is reported for Allcorr [1]. In preliminary studies, autogenous welds had good appearance and good fusion characteristics. Filled welds also had good flow characteristics and fused well. However, some test solutions vigorously attacked the fusion zones suggesting that investigation of Allcorr welding is needed. Dissimilar metal bonds between Allcorr and C-276 also require study due to DuPont's particular applications of this alloy.

Requirements for a welding study include a determination of optimum welding parameters, characterization of the microstructure, determination of the composition in the fusion zone, selection of optimum filler material, and determination of effects of post-weld heat treatments. In addition, mechanical properties and information about corrosion rates are needed for Allcorr.

EXPERIMENTAL PROCEDURE

Materials

Allcorr and Hastelloy C-276 plate and welding rod were used for this study. Chemical analyses of the alloys are contained in Table 1.

Welding

Allcorr and Hastelloy C-276 plates were prepared as shown in Figure 1. Single-V joint configuration was investigated. The standard weld run was six inches long.

All welding was by the GTAW method and backing strips were used. Shielding was with argon at 25 cfh. The principal combinations of base and filler metal studied were:

1) Hastelloy C-276 to C-276, C-276 filler
2) Allcorr to Hastelloy C-276, Allcorr filler
3) Allcorr to Allcorr, Allcorr filler

Other combinations were evaluated for guidance in optimizing the filler material. Autogenous welds and welds with filler of the same composition as the parent material are normally more susceptible to corrosion than welds with a composition adjusted filler [2]. However, the best filler to date has been Allcorr.

Sample plates were welded with DC straight polarity using a Hobart Cyber-TIG, model CT-300 welding machine. Approximate DC values were 11.5 volts and 145 amps. The average travel speed was five inches per minute. This resulted in a total heat input of 17,000-30,000 joules/inch for each TIG pass. Welding energy levels were varied to compare low and high heat input effects. The bulk of the work was done at low to medium heat input (17,000-25,000 j/in). In addition, interpass temperatures were varied between $200^{o}F$ and $500^{o}F$. Using 3/32 in. rod approximately 7 TIG passes were required to complete the weld on the .440 inch thick Allcorr plate.

Welds were examined visually and radiographically. Test specimens including tensile, bend, and corrosion samples were then prepared as shown in Figure 2.

Corrosion

Corrosion tests were used for rating weldment serviceability and to differentiate between good and bad weld procedures. Corrosion of Allcorr, Allcorr weldments and simulated HAZ was studied in various acid media. These included a formic/halide solution which is mildly reducing, the Streicher solution (ASTM A262) which is oxidizing, a synthetic paper industry scrubber solution (oxidizing), and a synthetic waste off-gas condensate (oxidizing). The latter is representative of the intended service environment at SRP.

Metallography

Following exposure, corrosion test coupons were sectioned and examined metallographically. Both optical microscopy and scanning electron microscopy (SEM) were used to study weld microstructure. Chemical microsegregation within the weld was investigated using energy dispersive X-ray analysis in the SEM. A computer enhanced X-ray diffraction technique [3] was employed for investigating the nature of the phases observed in the weld zones.

Heat Treatments

Heat treatments were performed in a Lindberg air furnace on both welded and as-received Allcorr samples. Soaking temperatures ranged between 650°C (1200°F) and 1200°C (2200°F).

RESULTS AND DISCUSSION

Welding Characteristics

Allcorr material is readily weldable. Its flow characteristics are similar to other nickel-base alloys [4], but it tends to be slightly more sluggish and requires more heat to sustain a melt. This can result in defects if the welder is unaware of the difference compared with other alloys, the Hastelloys for example. The Allcorr alloy can melt, flow to colder metal and cold shut while appearing to be fused to the base material. Such lack of fusion and lack of penetration defects occurred in some of the early sample welds.

It was found that joint configurations with an approximate included angle of 75° and small lands, 1/16-inch or less, work well in welding Allcorr material and achieving full penetration. Care is required in adding sufficient heat to insure complete fusion without excessive microstructural segregation. The latter can embrittle and also affect corrosion resistance, as will be illustrated.

A weld is shown in Figure 3. A dispersed second phase is present throughout the weld zone. The phase appears during the welding process but further precipitation occurs in the region where the weld bead is heated to high temperatures during subsequent weld passes. Corrosion resistance of the matrix in the vicinity of such precipitates in other complex nickel-base alloys is often decreased as a result of local depletion of specific elements, such as chromium or molybdenum.

Cleanliness in the weld area during joining is necessary to minimize weld defects. Inert gas shielding must be complete and backing gas should be used continuously on the root pass. If good gas coverage is not obtained, oxide formation occurs. Oxides have a higher melting temperature and will accumulate at the top of the molten puddle. They solidify first and appear in the final weld as a slushy form at the top of the weld. If this occurs, increased gas coverage is required.

The Allcorr and C-276 combinations studied are very tolerant to small weld defects. Where small defects are present, ductility decreases slightly, but the tensile strength of the weldments remains virtually unchanged.

Mechanical Properties

Face bend and side bend specimens taken from the test welds were tested at room temperature. Cracking or fissuring did not occur even when weld undercut existed, Figure 4. The tests showed that the welds were relatively ductile, the quality was good, and Allcorr toughness was acceptable.

Tensile tests were conducted at ambient temperature and at 550°C, on both as-welded and heat-treated specimens. Results are contained in Table 2.

Yield strengths of the Allcorr and C-276 weldments are somewhat higher than those of the alloys without welds. The weld strength of the Allcorr weld metal is reported to be higher than that of parent Allcorr [5]. This explains the reduced overall deformation observed during tensile tests, Table 2. In fact, most of the elongation occurred in base metal, as shown in Figure 5. Overall elongation of an Allcorr weldment is about 60% of unwelded material. In as-welded Allcorr and C-276, all of the fractures occurred in parent materials. In the dissimilar metal samples, fracture always occurred in the Allcorr parent metal.

For heat treated specimens, a tendency toward embrittlement exists. This tendency coincides both with precipitation on grain boundaries and with intergranular fracture, Figures 6-8. Severe embrittlement is obtained after extended exposure at 900°C (1650°F).

Corrosion and Metallography

Weldments of Allcorr and Allcorr/Hastelloy C-276 were corrosion tested in as-welded and heat treated states, with heat treatments representative of exaggerated conditions for multipass and repair welding and service upsets. Table 3 illustrates the relative effect of oxidizing vs. reducing acid environments on Allcorr. Corrosion resistance in oxidizing nitric/halide is high, whereas rapid grain boundary attack occurs in reducing formic acid/halide solution, Figure 9.

Table 4 contains results for C-276 and Allcorr tested in an oxidizing sulfuric acid solution [6]. C-276 corrosion is severe after long exposure at 900°C (1650°F). Corrosion of Allcorr in this solution is unaffected, though substantial precipitation occurs in both the wrought and cast structures, Figures 6-7.

Severe pitting is observed in weld zones of Allcorr in a special test solution representative of a paper industry scrubber environment. This extreme environment is used in several laboratories for evaluating corrosion resistance of iron-base and nickel-base alloys. It is often true that pitting resistance of the weld metal in complex alloys is less than that of corresponding parent material, and this is related to segration phenomena in the weld [4,7,8]. Attack proceeds rapidly along grain boundaries in the fusion zone, slower elsewhere, Figure 10. The pitting appears to be independent of weld energy input or general weld quality.

In Table 5 a corrosion rate for the as-welded material is compared to those for several heat treated conditions. Holding at 1200°C (2200°F) for one hour reduces the corrosion rate by 500X and eliminates the exaggerated weld pitting. This is essentially a solution heat treatment and eliminates most precipitates, as indicated by Raghavan, et.al. [10]. Thus, the pitting behavior correlates with the presence of the precipitate. Heat treatment at 1200°C following fabrication is required for some environments and beneficial for maximizing corrosion resistance.

The above results do not necessarily preclude use of as-welded Allcorr except in the scrubber environment. For example, exposure to a complex process off-gas condensate, Table 6, yields very low rates of corrosion for Allcorr and C-276. A somewhat higher corrosion rate occurs for C-276 and slight pitting and crevice attack is reported [9]. Type 304L stainless steel has a high rate of corrosion and is grossly pitted in this solution.

In addition to the globular precipitates decorating the grain and twin boundaries in the Allcorr, acicular precipitates are also observed, Figure 11. These tend to be crystallographically oriented and occur in both wrought material and in the cast structure of the weld zone, Figures 6-7. The precipitation is time and temperature dependent, Figures 12-13, and its presence correlates with corrosion.

The Allcorr matrix adjacent to the precipitate is attacked in reducing environments leading to matrix relief and loss of bonding. This is evident in the weld area shown in Figure 14. Semi-quantitative X-ray analyses of particles in the fusion zones of Allcorr and C-276 weldments show them to be of similar Cr concentration, but dramatically higher Mo and lower Ni than the respective nominal compositions, Table 7. Diffraction techniques indicate the particles in the Allcorr have a tetragonal crystal structure, whereas a rhombohedral structure occurs in the Hastelloy alloy [11]. The phase is primarily sigma in Allcorr, and is probably mu-phase in the C-276. This is in agreement with recent published data [10].

Depletion of molybdenum from the matrix surrounding the precipitates affects corrosion resistance significantly. The localized corrosion observed along the boundaries in the reducing formic acid solution is consistent with this theory. Mo improves resistance to crevice corrosion; as depletion occurs, the boundary between the two phases becomes a crevice with the matrix side subject to attack. This is observed in Figure 14 and it is important because the precipitation occurred during normal welding.

CONCLUSIONS

- Allcorr has good melt characteristics. It is similar to other high nickel alloys, exhibiting a degree of sluggishness in the melt which affects penetration, fusion, and repair weld techniques.
- Allcorr welds are tolerant to small weld defects.
- Allcorr weldments exhibit good ductility, and high yield and tensile strengths. Dissimilar metal joints involving Allcorr and Allcorr weld filler have properties similar to Allcorr.
- The Allcorr weld zone is stronger than the parent metal.
- Allcorr is subject to sigma phase formation in the temperature range of 1600 - 2000°F. Corrosion resistance along grain boundaries decorated by sigma particles may be dramatically decreased.
- The temperature range of 1600 - 2000°F is common to the heat-affected zone of a weld. In multiple-pass welding of thick wall material sufficient time at temperature will occur to cause development of sigma phase and possible corrosion problems. Thin wall material will experience less time at undesireable temperatures and be less susceptible to precipitation and associated corrosion problems if good welding practice is followed.

- The cast structure (welds) should be minimized to attain the highest corrosion resistance possible. As-welded material and material reheated to 2000°F - which occurs repeatedly during multipass and repair welding, for example - was severely corroded in a synthetic scrubber solution and less severely corroded in other solutions.

- A 2200°F heat treatment following welding is beneficial in establishing the highest corrosion resistance attainable for Allcorr® weldments. This is a solution treatment, and eliminates most precipitates. Unfortunately, most fabricated structures cannot be heated to such a high temperature without significant distortion, so that this approach can be used to only a very limited extent.

- Repair welding will be a problem in that the effect of reheating in the mid-range of temperature is to further reduce corrosion resistance, as a result of additional precipitation.

- The corrosion rate of Allcorr® weldments, as-welded or heat treated, in a melter off-gas condensate solution is negligible, and no pitting was observed. This is directly applicable for the DuPont Defense Waste Off-Gas System quencher and condenser vessels. Allcorr is acceptable and has been selected for this application.

References

1. Allcorr, Teledyne-Allvac Catalog No. TA5M4831001.

2. Members Report Summary - Report No. 250/1984, Welding Institute Research Bulletin, V26, No. 4, April, 1985.

3. C. L. Mallory and R. L. Snyder, Control and Processing of Data from an Automatic X-Ray Powder Diffractometer, Advances in X-Ray Analysis, Volume 22, Plenum Press, 1979.

4. A. J. Sedriks, Corrosion Resistance of Austenitic Fe-Cr-Ni-Mo Alloys in Marine Environments, International Metals Review, 1982, Volume 27 No. 6, 321.

5. Weldability of Allcorr, TechNews, Teledyne-Allvac Bulletin (1985).

6. ASTM A262, Practice B.

7. G. E. Hale, Pitting Corrosion Resistance of High Alloy Austenitic Stainless Steel Weld Metals, The Welding Institute, October, 1984.

8. A. Garner, How Stainless Steel Welds Corrode, Metals Progress, April, 1985, 31-36.

9. R. A. Corbett, Unpublished Data.

10. M. Raghavan, R. R. Mueller, G. A. Vaughn, and S. Floreen, Determination of Isothermal Sections of Nickel Rich Portion of Ni-Cr-Mo System by Analytical Electron Microscopy, Metallurgical Transactions, Volume 15A, May, 1984, 783-792.

11. E. Sturcken, Unpublished Data.

TABLE 1. CHEMICAL ANALYSES OF ALLCORR AND HASTELLOY C-276 STARTING MATERIALS

MATERIAL	SIZE	HEAT NO.	ELEMENT, WT% C	S	Mn	Si	Cr	Mo	Cb+Ta	W	V	Co	Ti	Fe	Ni
ALLCORR	.44" PLATE	W498-5	.030	.001	.01	.02	30.93	9.97	.42	1.97	.01	.01	.24	.11	BAL.
ALLCORR	.093" ROD	Y078	.033	.003	.01	.02	30.94	10.13	.41	2.01	.02	.01	.26	.13	BAL.
C-276	.375" PLATE	2760-3-3659	.002	.002	.48	.03	16.26	15.75	-	4.04	.11	1.13	-	6.05	BAL.
C-276	.094" ROD	2760-4-3679	.003	<.002	.48	.02	15.51	15.50	-	3.73	.13	.77	-	5.99	BAL.

TABLE 2

TENSILE PROPERTIES OF ALLCORR® AND C-276 WELDMENTS AT AMBIENT AND 550°C

	CONDITION	TEST TEMPERATURE	YIELD STRENGTH	TENSILE STRENGTH	ELONGATION
A.	BASE ALLCORR®	25°C	47 KSI	103 KSI	74%
	AS WELDED	25	54	109	44
	AS WELDED	550	28	75	52
	900°C, 100 HRS	25	65	93	0
	900°C, 100 HRS	550	63	105	6
B.	BASE C-276	25	49	113	65
	AS WELDED	25	56	124	55
	AS WELDED	550	34	81	38
	900°C, 100 HRS	25	52	103	6
	900°C, 100 HRS	550	41	89	11
C.	ALLCORR/C-276 WELDMENTS				
	AS WELDED	25	53	107	46
	AS WELDED	550	28	74	41
	900°C, 100 HRS	25	52	100	4
	900°C, 100 HRS	550	43	102	14

TABLE 3

HEAT TREATED ALLCORR[R] ALLOY

ALLOY CONDITION	ACID F (MPY)	ACID N (MPY)
As received	21	3
2000^{o}F, 60 min., AQ	38	3
1900^{o}F, 20 min., AQ	37	3
1700^{o}F, 20 min., AQ	48	5
1500^{o}F, 10 min., AQ	18	4

F: 10% HCOOH, 1% HCl, .1% HF

N: 10% HNO_3, 2.25% HCl, .2% HF, .2% H_2SO_4

TABLE 4

CORROSION RESULTS FOR HEAT TREATED NICKEL-BASE ALLOYS IN THE STREICHER* TEST

MATERIAL	CORROSION - MILS/MONTH			
	AS-WELDED	600°C (100 HRS)	700°C (24 HRS)	900°C (100 HRS)
C-276/C-276	21	24	116	127
C-276/Allcorr	8	11	98	96
Allcorr/Allcorr	2	2	2	2

----

*ASTM A262, Practice B [6]. Boiling 50% Sulfuric Acid + 3 wt% $Fe_2(SO_4)_3$

TABLE 5

CORRUSION DATA, HEAT TREATED ALLCORR[R] WELDMENTS (MPY)

CONDITION	SCRUBBER SOLUTION
AS-WELDED	200
2200°F, 1 HR.	<1
2200°F, 1 HR. AGED - 2000°F, .25 HR.	20
AGED - 2000°F. .25 HR.	560

7% H_2SO_4, 3% HCl + 1 wt% $FeCl_3$ + 1 wt% $CuCl_2$; Boiling.

TABLE 6

CORROSION OF ALLCORR, C-276 AND 304L OFF-GAS SOLUTION

MATERIAL	CORROSION RATE (MPY)
C-276/C-276	2
C-276/Allcorr	1
Allcorr/Allcorr	<1
304L/304L	276

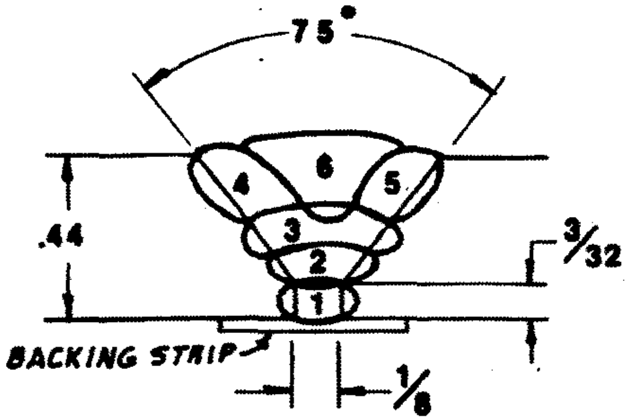
SOLUTION

By Weight .25% Cl^-, .03% F^-, .003% I^-, .08% $SO_4^{=}$, .1% NO_3^-, .1% Hg^{++}; pH 2.2, 90°C

TABLE 7

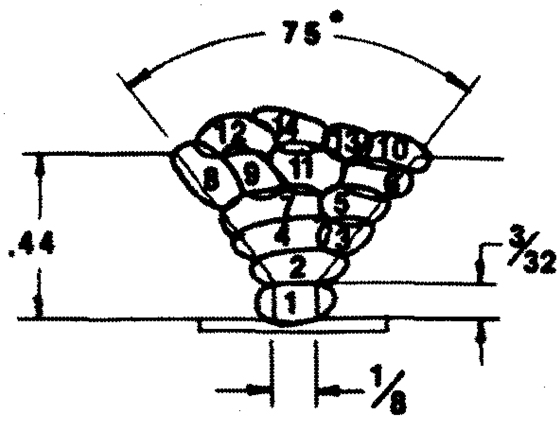
ALLOY COMPOSITION OF WELD MATERIAL, WEIGHT %

ZONE	MATERIAL REGION	CR	FE	NI	MO
Fusion	Matrix - C-276	18.9	4.6	57.7	16.7
	Particle -	18.1	3.1	37.1	39.1
Fusion	Matrix - Allcorr	27.6	1.1	58.3	11.3
	Particle -	28.7	1.0	46.0	21.9
C-276	Nominal	15.5	6.5	58	15.5
Allcorr	Nominal	31	<1.0	56	10



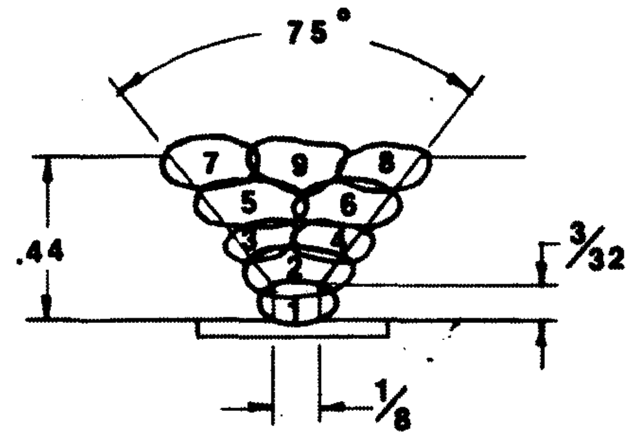
SAMPLE No. 1

HIGH HEAT INPUT; 6 PASSES;
INTERPASS TEMPERATURE < 200F



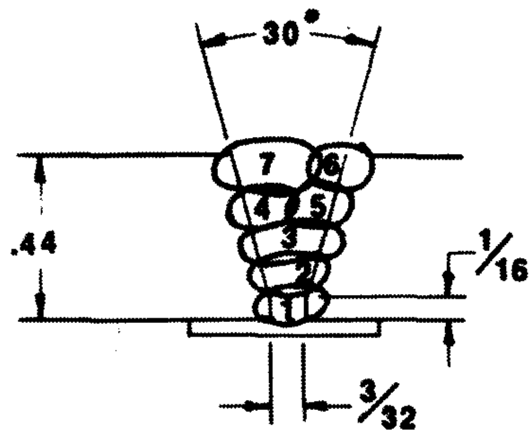
SAMPLE No. 2

LOW HEAT INPUT; 14 PASSES;
INTERPASS TEMPERATURE < 200F



SAMPLE No. 3

MEDIUM HEAT INPUT; 9 PASSES
INTERPASS TEMPERATURE < 500F



SAMPLE No. 4

LOW TO MEDIUM HEAT INPUT;
7 PASSES

FIGURE 1. Summary of TIG welding parameters used to join Allcorr material. Allcorr backing strip, Allcorr filler material, DCSP and Argon cover gas was used.

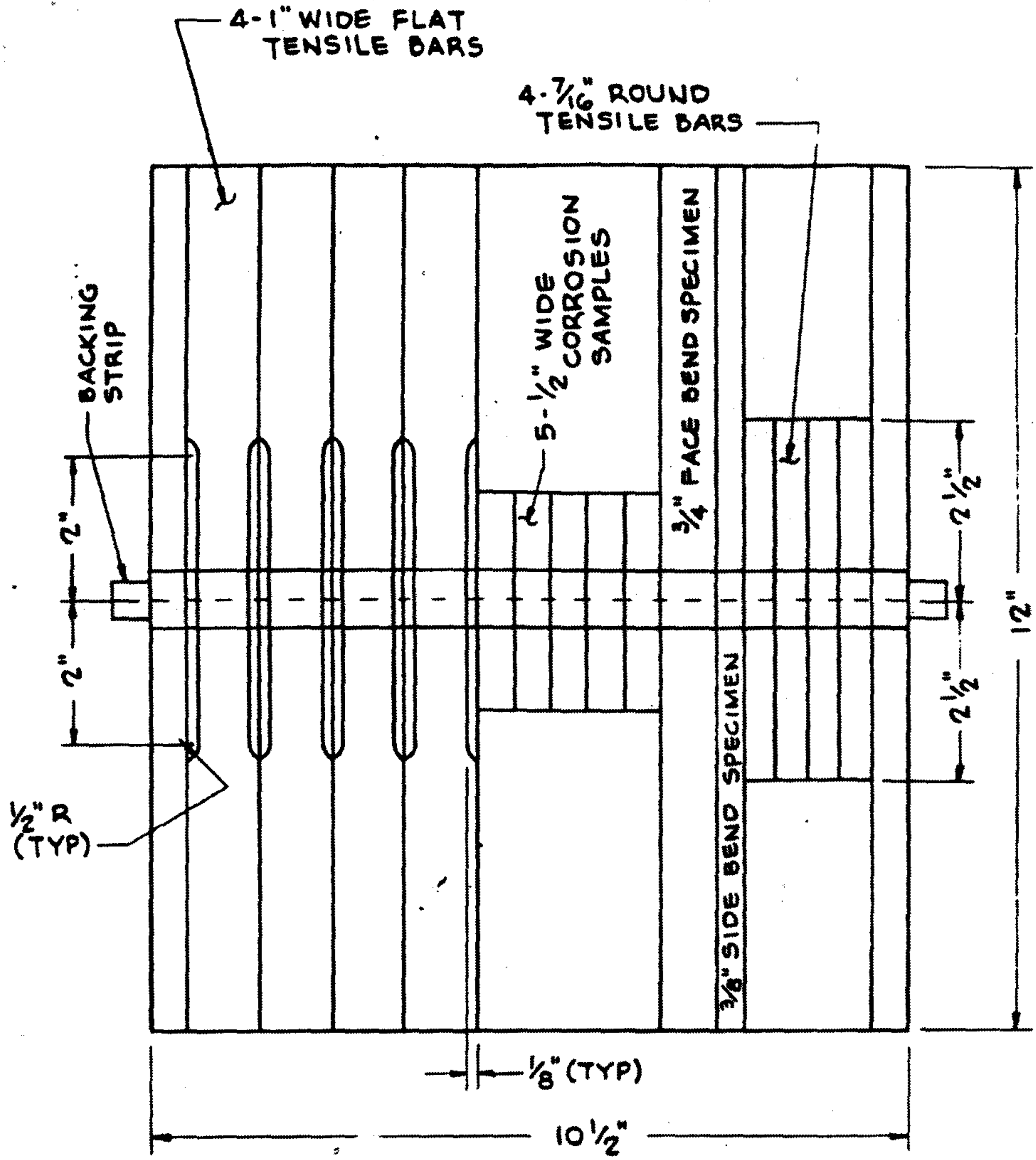
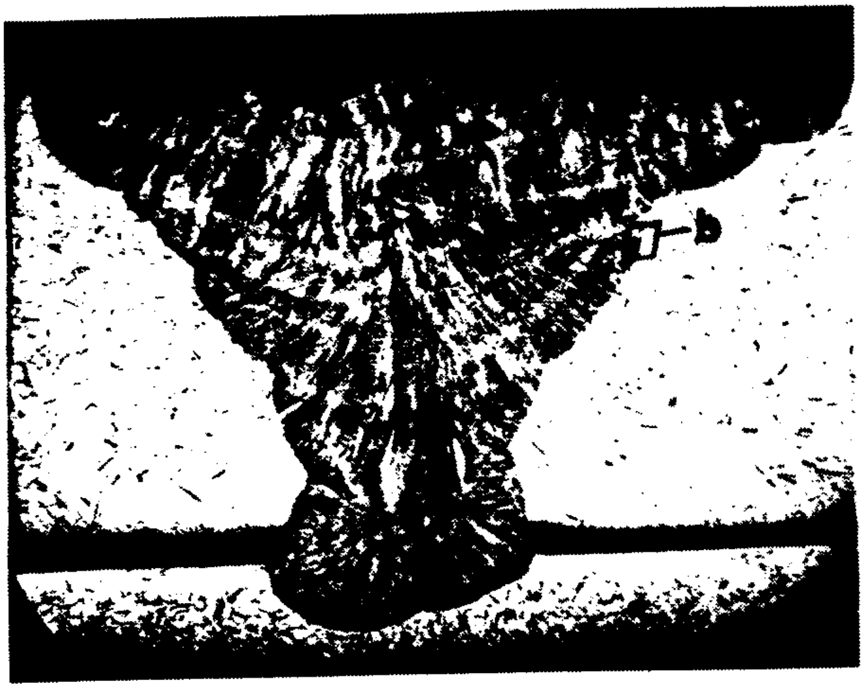


FIGURE 2. TEST SPECIMEN POSITIONS ON WELDED SAMPLE PLATES. WELD CROWNS AND ROOT-SIDE PENETRATIONS ARE MACHINED FLAT.

a



b

Negative Nos. EE41651A, 41652A

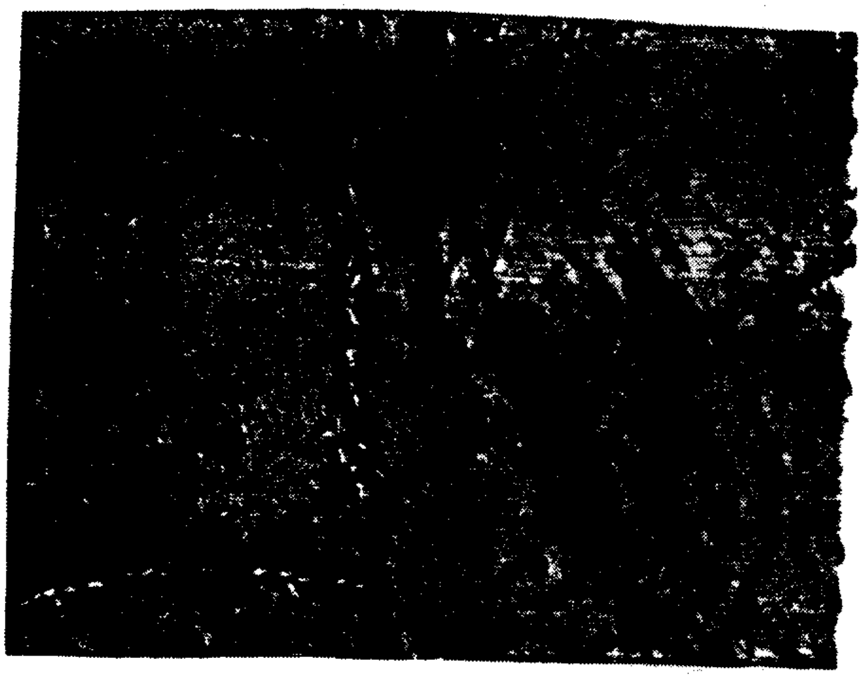
FIGURE 3. PHOTOMACROGRAPH (6X) AND PHOTOMICROGRAPH (80X) OF ALLCORR WELD.

MAG. APPROX. 2.5X   NEG. NO. EE-41682A

FIGURE 4. ALLCORR FACE BEND SPECIMEN.
NO-BREAK TEST DEMONSTRATES DUCTILITY
OF THE MATERIAL.

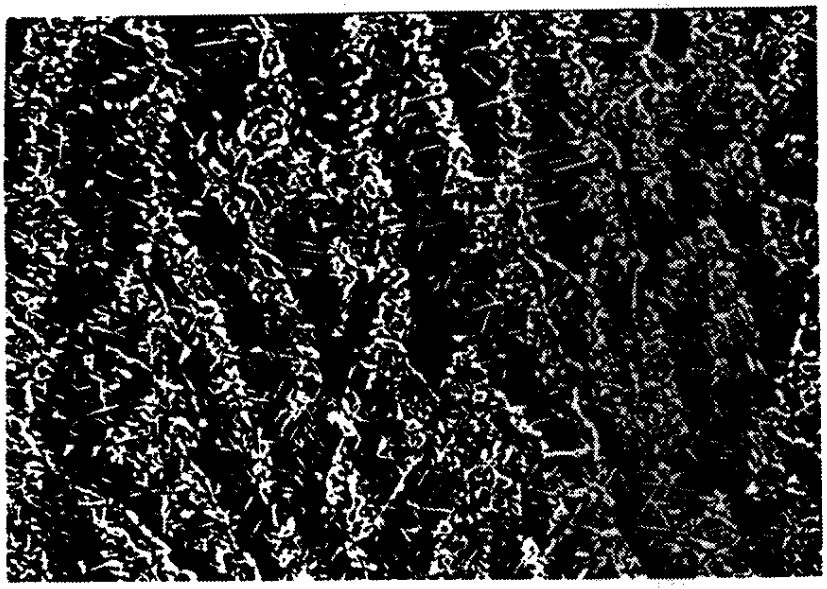
MAG. APPROX. 3.5X NEG. NO. EE-42813-5

FIGURE 5. ALLCORR TENSILE SPECIMEN SHOWING THAT PLASTIC DEFORMATION OCCURS IN THE LOWER YIELD STRENGTH BASE MATERIAL BUT NOT IN THE FUSION ZONE.



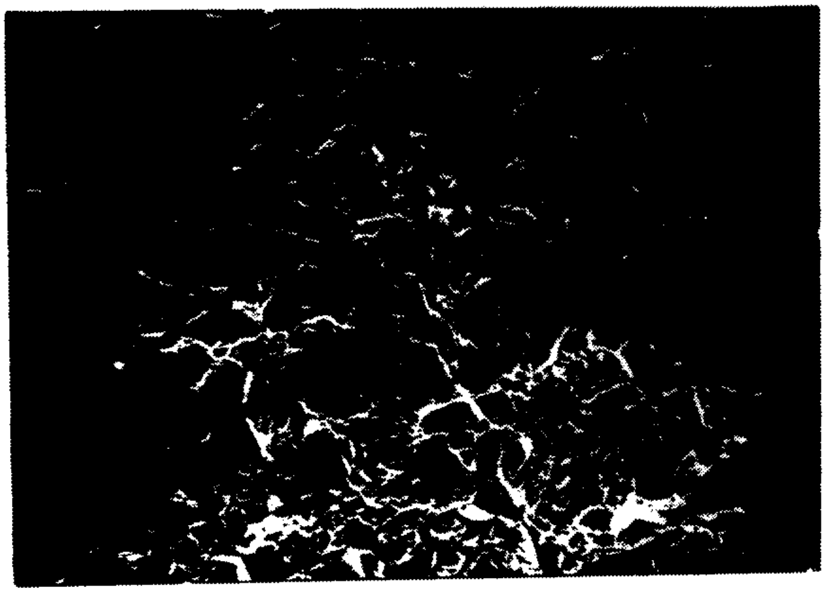
MAG. APPROX. 400X NEG. NO. EE-73738M

FIGURE 6. PHOTOMICROGRAPH OF ALLCORR WHICH HAS BEEN REHEATED AND AGED 1 HOUR AT 2000°F. NOTE ACICULAR PRECIPITATES TEND TO BE CRYSTALLOGRAPHICALLY ORIENTED. ROUNDED PLATELETS AND GLOBULES DECORATE GRAIN AND TWIN BOUNDARIES.



MAG. APPROX. 900X NEG. NO. EE-76241M

FIGURE 7. SCANNING ELECTRON PHOTOMICROGRAPH OF FUSION ZONE IN ALLCORR WELD AFTER 100 HOURS AT 900°C (1650°F). THERE IS EXTENSIVE PRECIPITATION ALONG DENDRITE BOUNDARIES AND AN ACICULAR PRECIPITATE BETWEEN THE DENDRITES. NOTE THE SIMILARITY TO THE STRUCTURE IN FIGURE 6.



MAG. APPROX. 30X NEG. NO. EE-76219M

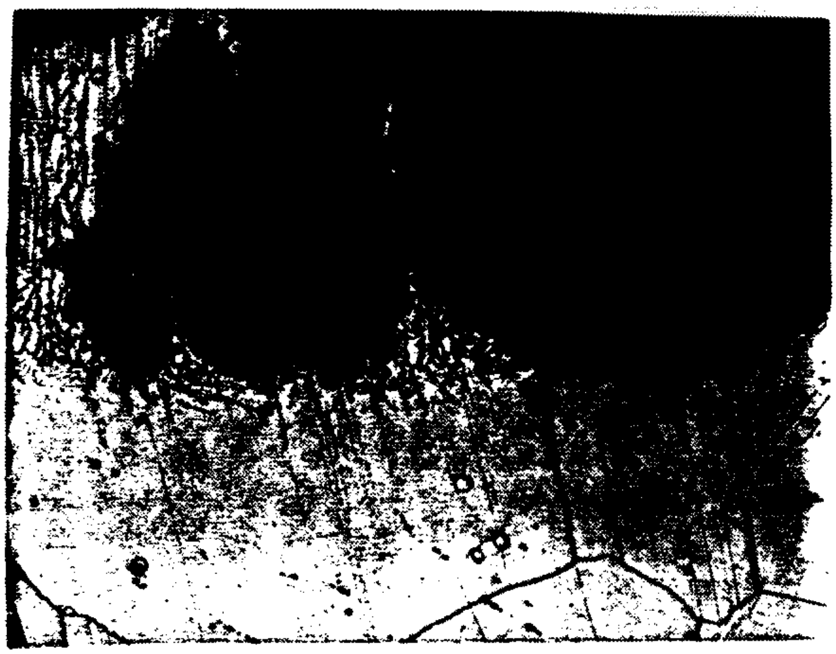
FIGURE 8. SEM FRACTOGRAPH OF AN ALLCORR TENSILE SPECIMEN HEAT TREATED 100 HOURS AT 900°C AND TESTED AT 25°C. INTERGRANULAR FAILURE IS DUE TO GRAIN BOUNDARY PRECIPITATION.

MAG. APPROX. 40X NEG. NO. EE-41233A

MAG. APPROX. 200X NEG. NO. EE-41241A

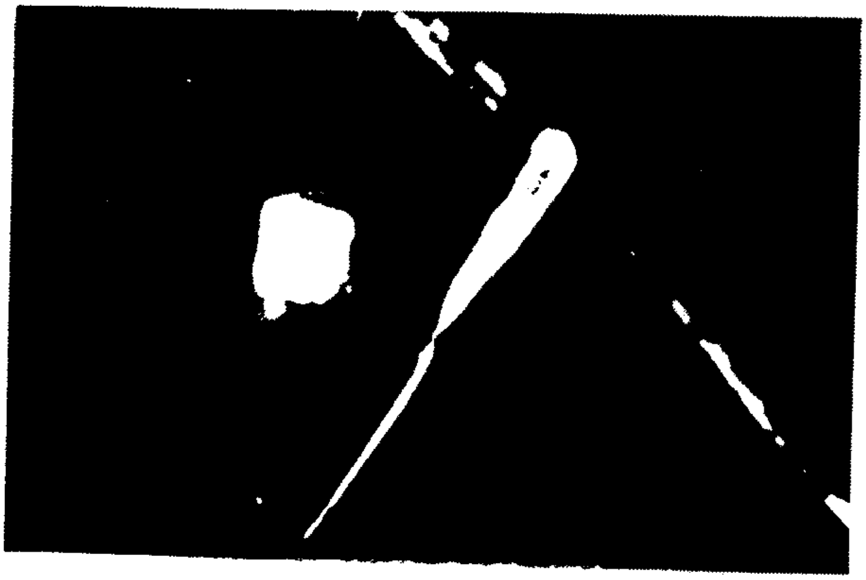
FIGURE 9. SURFACE AND ETCHED CROSS-SECTIONAL VIEWS OF ALLCORR EXPOSED TO FORMIC ACID/HALIDE SOLUTION AFTER HEAT TREATMENT AT 930°C (1700°F). GRAIN BOUNDARY ATTACK IS EVIDENT.

MAG. APPROX. 4X   NEG. NO. EE-42606A



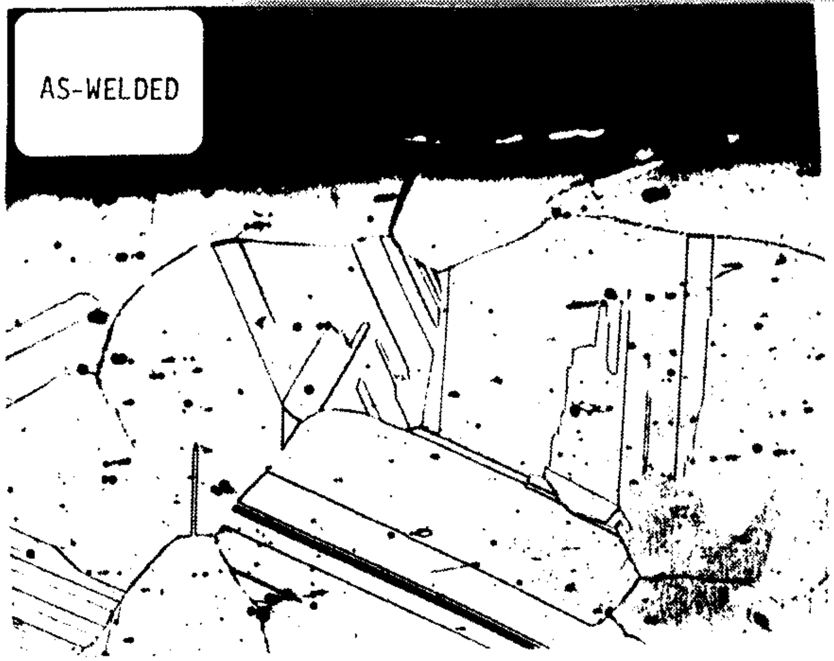
MAG. APPROX. 100X   NEG. NO. EE-42601A

FIGURE 10. MACROGRAPH AND PHOTOMICROGRAPH ILLUSTRATING PITTING ATTACK IN THE ALLCORR WELD ZONE BY A PAPER INDUSTRY SCRUBBER SOLUTION. THE WELDMENT WAS RE-HEATED TO 1095°C (2000°F). NOTE THAT ATTACK IS ALONG GRAIN BOUNDARIES.



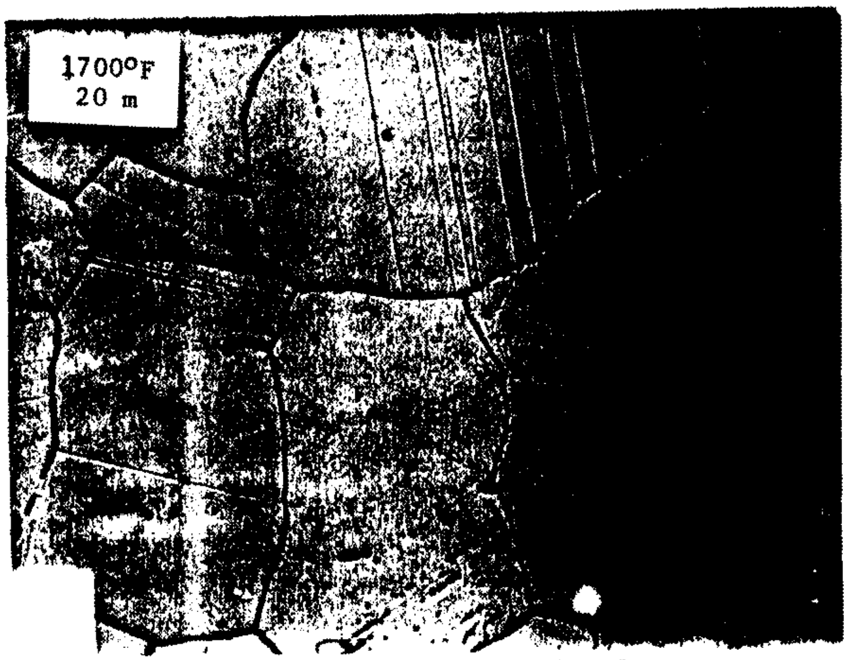
MAG. APPROX. 5000X NEG. NO. EE-73846M

FIGURE 11. ACICULAR PRECIPITATE IN ALLCORR AGED AT 1095°C (2000°F) FOR 1 HOUR.



MAG. APPROX. 100X NEG. NO. EE-42402A

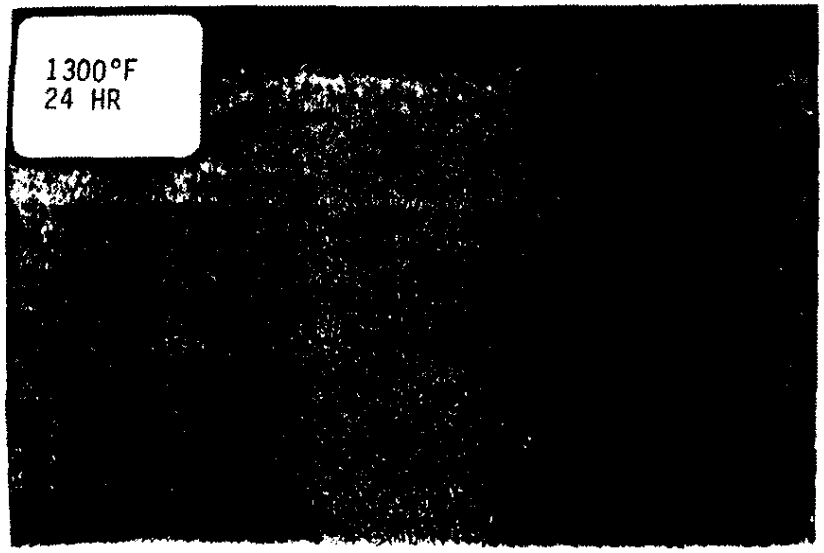
MAG. APPROX. 100X NEG. NO. EE 42405A



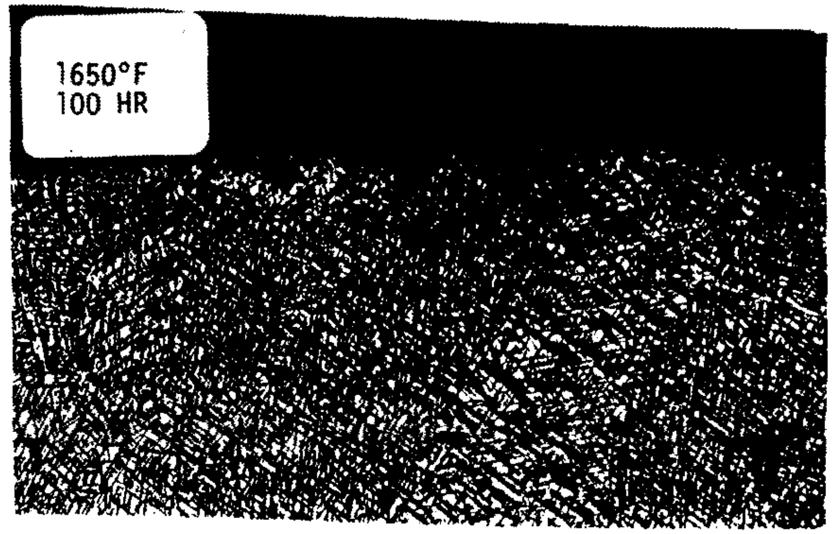
MAG. APPROX. 200X NEG. NO. EE-41246A

MAG. APPROX 200X NEG NO EE-41247A

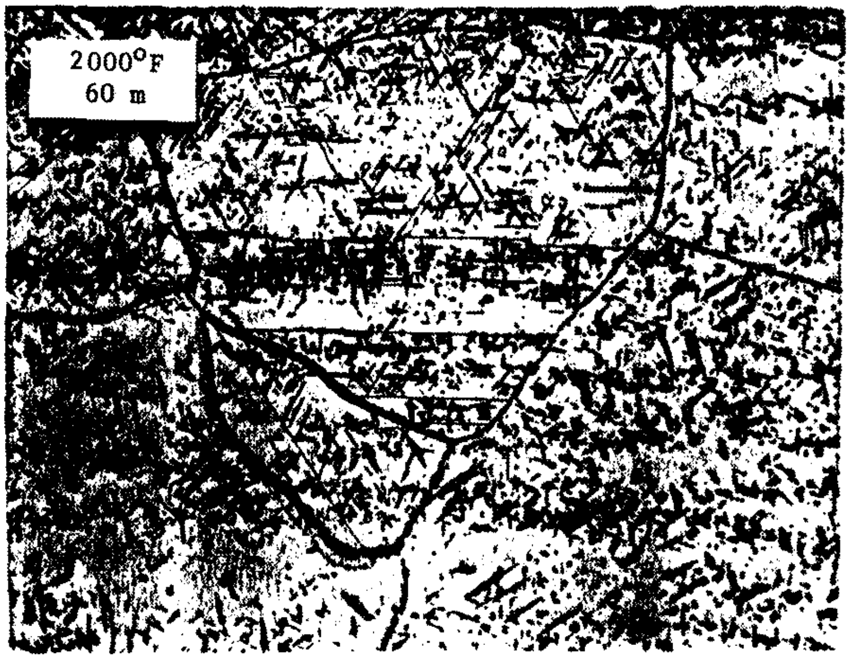
FIGURE 12. ALLCORR PHOTOMICROGRAPHS ILLUSTRATING THE EFFECT OF HEAT TREATMENT FOR SHORT TIMES IN THE RANGE 25° - 930°C (75° - 1700°F). PRECIPITATION IS NOT EVIDENT AT 600°C (1110°F) EVEN AFTER 100 HOURS, BUT CAN BE SEEN ON GRAIN BOUNDARIES AT 930°C (1700°F) AFTER ONLY 20 MINUTES. CORROSION RESISTANCE IS NOT AFFECTED BY THE 600°C EXPOSURE.



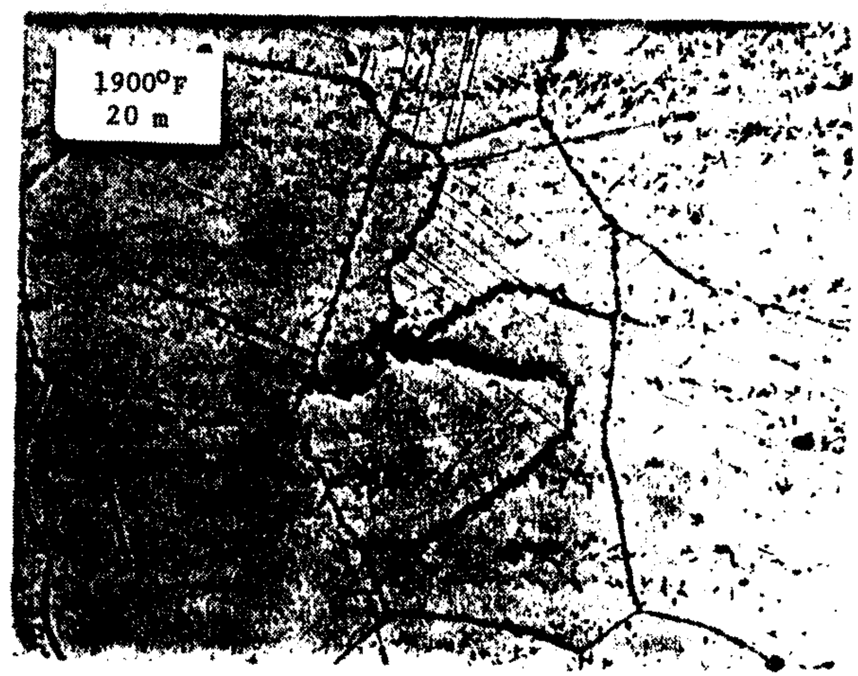
MAG. APPROX. 100X   NEG. NO. EE-42406A



MAG. APPROX. 100X   NEG. NO. EE-42401A

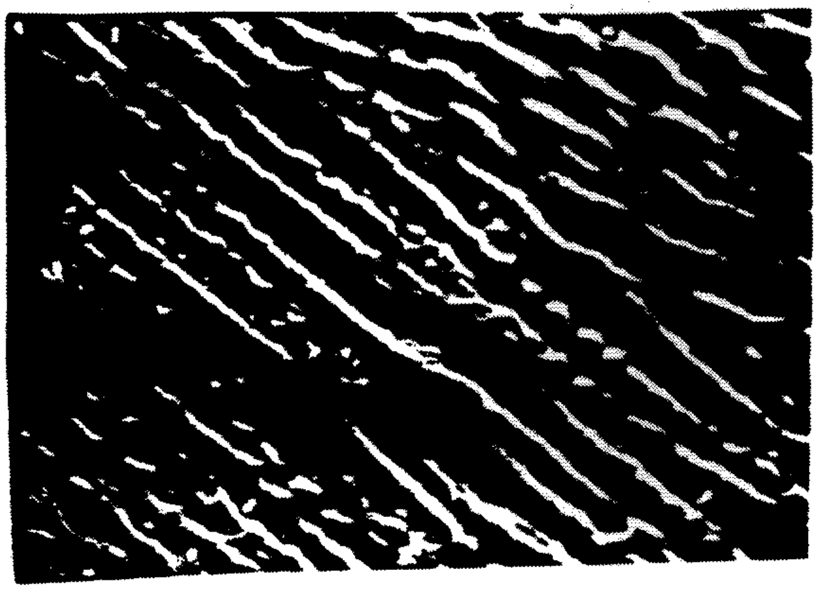


MAG. APPROX. 200X   NEG. NO. EE-41244A



MAG. APPROX. 200X   NEG. NO. EE-41236A

FIGURE 13. ALLCORR PHOTOMICROGRAPHS ILLUSTRATING THE EFFECT OF HEAT TREATMENT FOR LONGER TIMES IN THE RANGE 700° - 1095°C (1300° - 2000°F) - (COMPARE FIGURE 12). ACICULAR PRECIPITATION DEVELOPS ALONG CRYSTALLOGRAPHIC DIRECTIONS. AFTER 100 HOURS AT 900°C, THE GRAINS ARE VIRTUALLY COMPLETELY COVERED WITH THE PRECIPITATE.



MAG. APPROX. 1750X   NEG. NO. EE-75590M

FIGURE 14. ELECTRON PHOTOMICROGRAPH OF A POLISHED SECTION FROM ALLCORR WELD ZONE. NOTE THE MATRIX RELIEF AND LOOSE PARTICLES.