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Creep and Tensile Properties of Alloy 800H-Hastelloy X Weldments

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H. E. McCoy and J. F. King

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H. E. McCoy and J. F. King

ABSTRACT

Hastelloy X and alloy 800H were joined satisfactorily by the gas tungsten arc welding process with ERNiCr-3 filler and the shielded metal arc welding process with Inco Weld A filler. Test specimens were of two types: (1) made entirely of deposited Inco Weld A and (2) machined transverse across the weldments to include Hastelloy X, filler metal (ERNiCr-3 or Inco Weld A), and alloy 800H. They were aged 2000 and 10,000 h and subjected to short-term tensile and creep tests. Inco Weld A and ERNiCr-3 are both suitable filler metals and result in welds that are stronger than the alloy 800H base metal.

INTRODUCTION

Gas-cooled reactor concepts that use a steam cycle have materials such as Hastelloy X in the hottest part of the system and steels such as 2 1/4 Cr-1 Mo in the coldest portion. Materials such as alloy 800H can be used at intermediate temperatures, so techniques must be developed for making welds between these materials. This particular study concentrated on the weld joint between Hastelloy X and alloy 800H. Suitable techniques were developed for making joints by the gas tungsten arc and shielded metal arc welding (GTAW and SMAW) processes, test welds were prepared, samples were aged to 10,000 h, test samples were machined, and creep and tensile tests were run.

EXPERIMENTAL DETAILS

The chemical compositions of the materials used in this study are listed in Table 1. The Hastelloy X and alloy 800H were each 12.7-mm-thick (0.5-in.) plate conforming to specifications AMS 5536G and ASTM B 409-73, respectively. These plates were prepared for welding by machining a weld joint geometry of 75° included angle with a 1.6-mm (1/6-in.) root face.

Table 1. Test materials

	Material			
	Alloy 800H	Hastelloy X	Inco Weld A	ERNiCr-3
Heat	HH7728A	4284	D-28159	A3143T382V
Product form	Plate	Plate	Wire	Wire
Diameter				
mm	12.7	12.7	4.8	1.6
in.	0.5	0.5	0.18	0.06
Content, %				
Ni	31.85	Bal	68.70	72.15
Fe	46.00	19.06	9.05	0.11
Cr	19.46	21.79	15.04	20.90
Mo		8.82	0.89	
Mn	0.90	0.59	1.52	3.34
Si	0.24	0.35	0.41	0.03
Cu	0.54		0.30	0.03
Ti	0.42		0.06	0.42
C	0.08	0.06	0.03	0.02
Co		2.40	<0.01	0.02
Other	0.43 Al	0.63 W	2.29 Nb	2.88 Nb+Ta

Weldments joining the Hastelloy X to alloy 800H were then made by use of two welding processes and filler alloys. Inco Weld A electrodes conforming to AWS specification A5.11 class ENiCrFe-2 were deposited by the SMAW process, and AWS specification A5.14 class ERNiCr-3 filler wire was deposited by the GTAW process.

The test welds were cut into specimen blanks. The test specimen had a gage section 3.2 mm (0.13 in.) in diameter by 25 mm (1.0 in.) long, and several specimens were machined from the as-welded plates with the gage section containing weld metal deposit and both base metals. Some of the specimen blanks were annealed 2000 or 10,000 h in inert gas at 482, 593, or 649°C. The creep testing environment was helium containing small amounts of H_2, CH_4, or CO. The details of the environment and testing method were reported previously.[1]

One additional test weld was prepared with a 90° included angle and Inco Weld A filler metal. Specimens of only weld metal with the above gage dimensions but with slightly different end configurations were prepared. Creep and tensile tests were run in air to determine the properties of deposited Inco Weld A weld metal.

EXPERIMENTAL RESULTS

MICROSTRUCTURAL EXAMINATIONS

Typical photomicrographs of alloy 800H are shown in Fig. 1. The material has a reasonably large grain size with numerous coarse and fine precipitates. The microstructure of Hastelloy X is shown in Fig. 2. The material has a mixed grain size and stringers of large carbide particles. The fusion lines on each side of the ERNiCr-3 weld metal are shown in Fig. 3. The fusion line etched more distinctly on the alloy 800H side than on the Hastelloy X side because of the greater difference in chemical composition. The fusion lines of the weldment made with Inco Weld A are shown in Fig. 4. The materials look very sound, but there is greater contrast on the alloy 800H side.

TENSILE TESTS

Tensile properties of the two base metals and those of ERNiCr-3 weld deposit were obtained from the literature[2–3] and are shown in Fig. 5. On the basis of yield strength, alloy 800H is by far the weakest, Hastelloy X intermediate, and ERNiCr-3 the strongest. On the basis of tensile strength, alloy 800H is the weakest, ERNiCr-3 intermediate, and Hastelloy X the strongest.

The results of tests on deposited Inco Weld A are shown in Table 2 and in Fig. 5. The yield strength of Inco Weld A is higher than those of alloy 800H and Hastelloy X and about equivalent to that of deposited ERNiCr-3. The tensile strength of Inco Weld A is higher than that of alloy 800H but lower than those of ERNiCr-3 and Hastelloy X. Note in Table 2 that the ductility of the deposited Inco Weld A is very good. One sample was at 649°C for 16,900 h before tensile testing, and the properties were not much different from those of an unexposed sample. Thus, the filler metal showed little evidence of aging under those conditions.

Several tensile tests were performed on the weldment made by the GTAW process with ERNiCr-3 filler metal, and the results of these tests are given in Table 3 and in Fig. 5. The yield and tensile stresses of these samples were above those given in the literature for alloy 800H, but all

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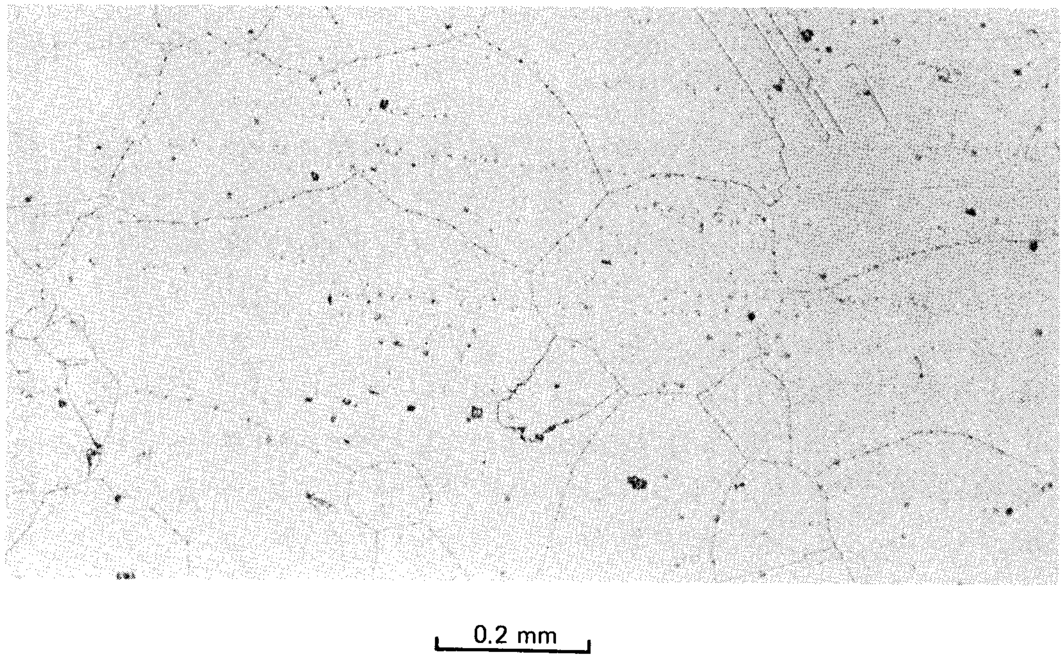

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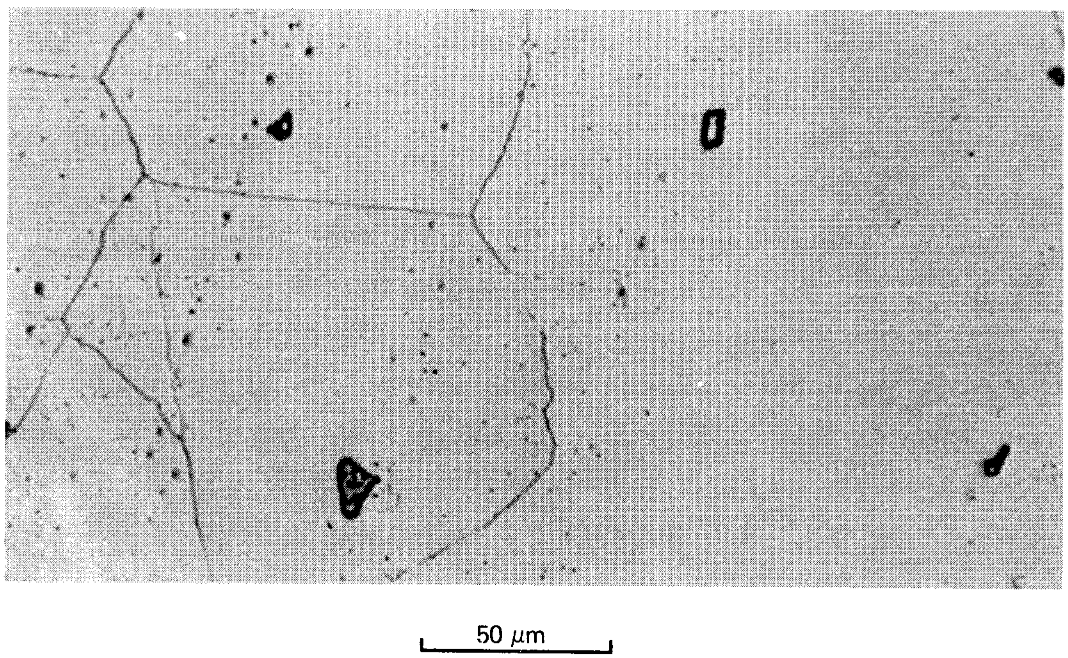

Fig. 1. Microstructure of as-received alloy 800H. Etched with aqua regia.

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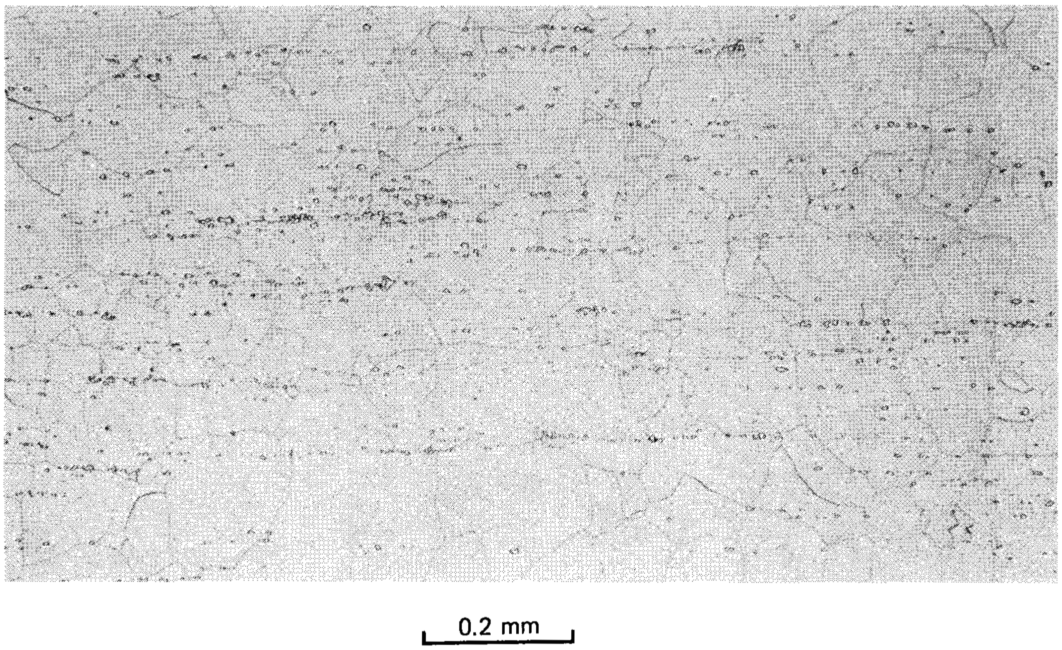

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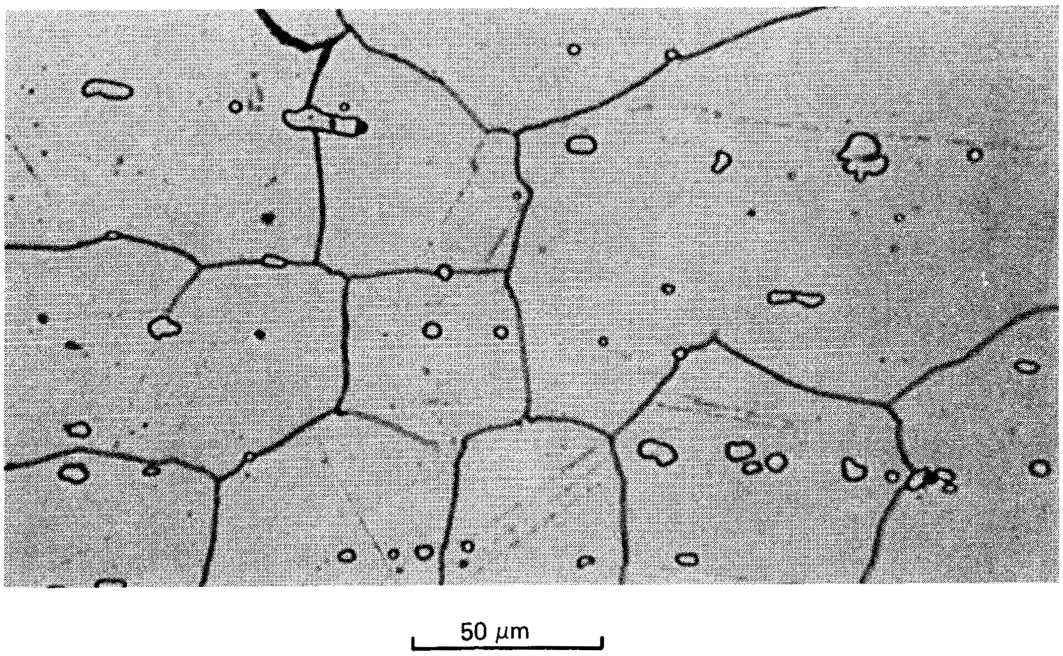

Fig. 2. Typical microstructure of as-received Hastelloy X. Etched with aqua regia.

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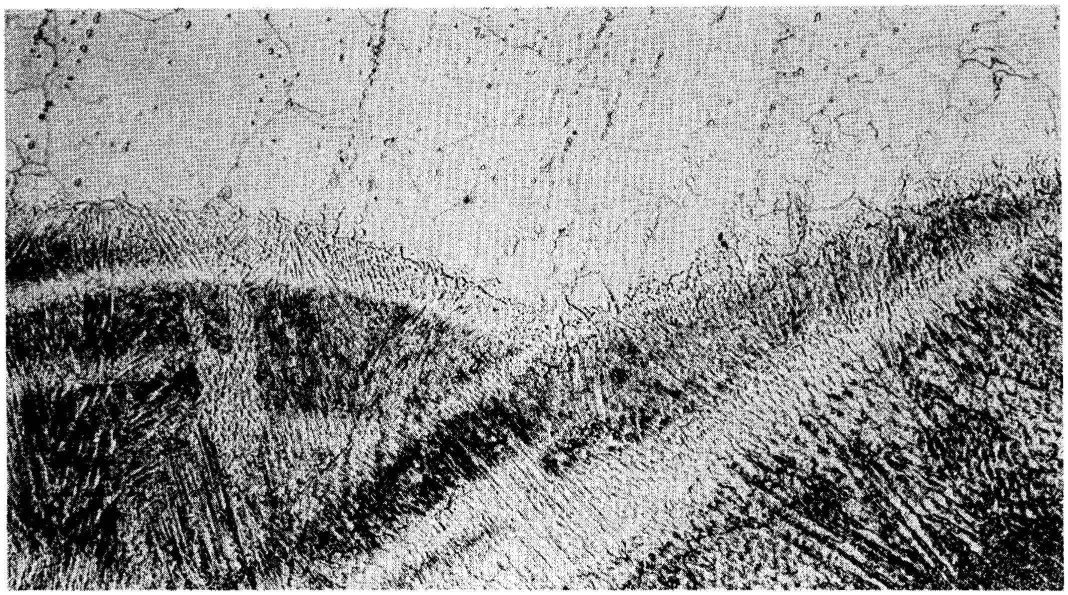

(*a*) 0.2 mm

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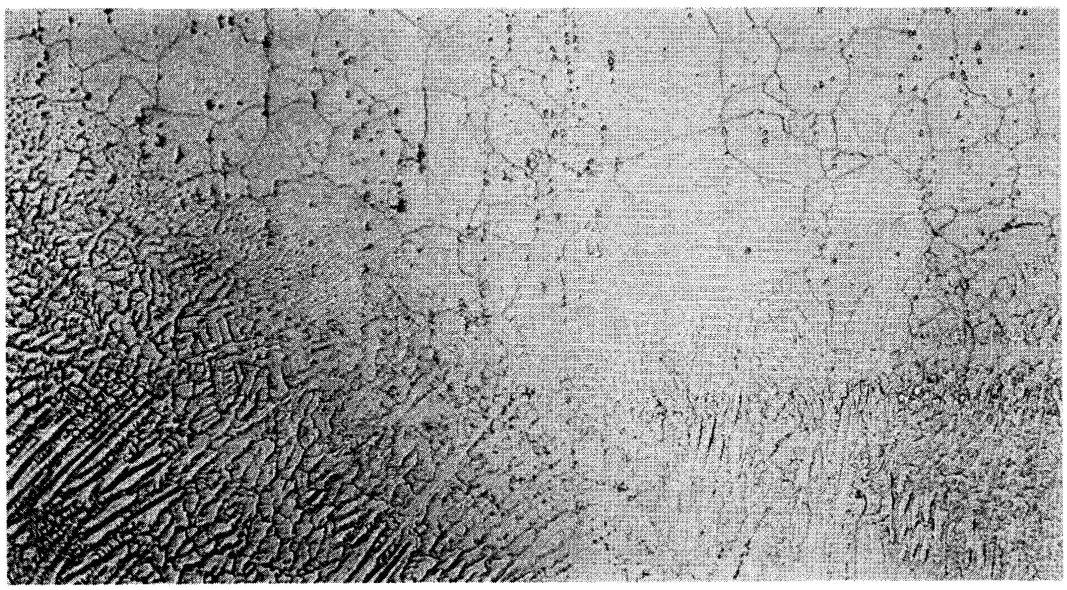

(*b*) 0.2 mm

Fig. 3. Fusion line of alloy 800H—Hastelloy X gas tungsten arc weldment made with ERNiCr-3 filler metal. (*a*) Fusion line on alloy 800H side. (*b*) Fusion line on Hastelloy X side, etched with aqua regia.

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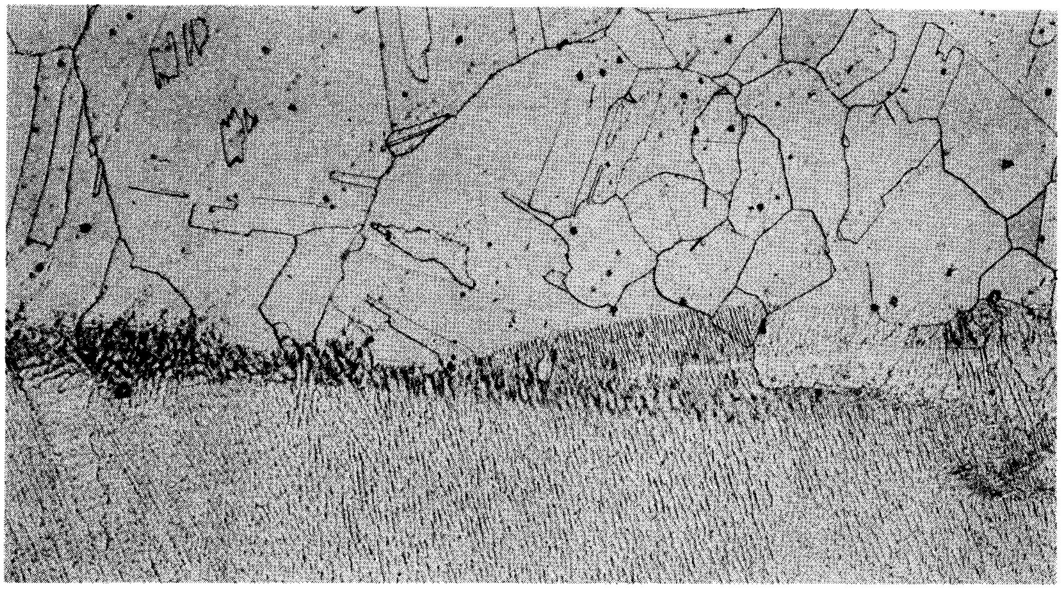

(*a*) 0.2 mm

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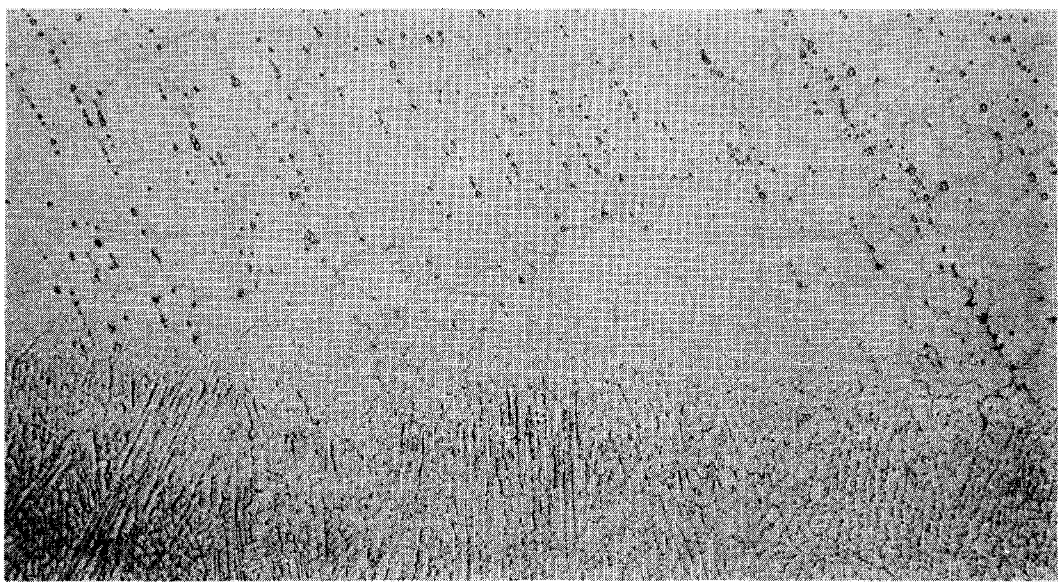

(*b*) 0.2 mm

Fig. 4. Fusion line photomicrographs of alloy 800H—Hastelloy X shielded metal arc weldment made with Inco Weld A electrodes. (*a*) Fusion line on alloy 800H side. (*b*) Fusion line on Hastelloy X side, etched with aqua regia.

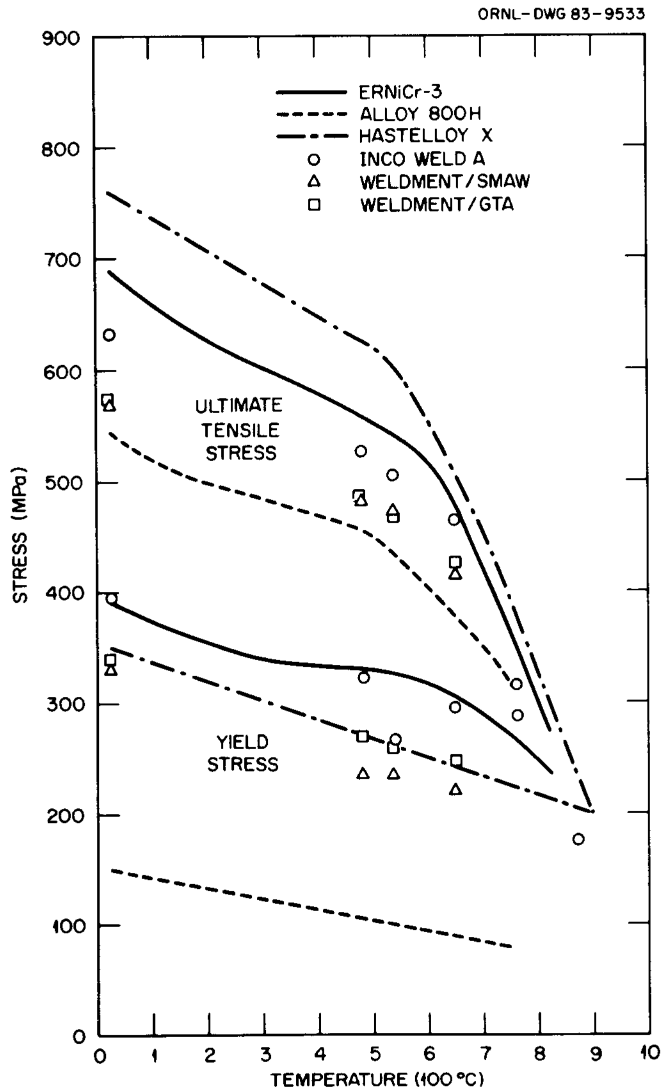

Fig. 5. Comparison of tensile properties of materials involved in this study.

failures occurred in alloy 800H. Apparently the strength of the alloy 800H involved in these tests is higher than that of the material reported in the literature. The data in Table 3 show that the weld deposit is deforming but considerably less than is the alloy 800H base metal, where failure occurred. The 2000- and 10,000-h periods of aging caused some small changes in tensile properties, but the general trend seemed to be a slight hardening and reduction in fracture strain. The weld metal also deformed less, so it must also have hardened slightly during aging.

Table 2. Tensile properties of as-deposited Inco Weld A

Test	Test temperature		0.2% Yield stress		Ultimate tensile stress		Elongation (%)		Reduction of area
	(°C)	(°F)	(MPa)	(ksi)	(MPa)	(ksi)	Uniform	Total	(%)
16943	25	77	396	57.4	633	91.8	38.1	41.1	44.2
22205[a]	25	77	350	50.8	653	94.7	36.0	36.0	27.5
16944	482	900	327	47.4	528	76.6	37.5	40.5	52.4
16945	538	1000	265	38.5	506	73.4	40.4	43.4	48.0
16946	649	1200	296	43.0	464	67.3	32.5	39.3	38.2
17032	760	1400	288	41.7	315	45.7	59.1	62.1	73.4
17033	871	1600	174	25.3	174	25.3	1.0	48.6	38.9

[a]Creep tested 16,900 h at 103 MPa (15 ksi) and 649°C before tensile testing.

Similar tensile results are shown in Table 4 and Fig. 5 for the weldment made by the SMAW process with Inco Weld A. This weldment had tensile properties similar to those of the weldment made with ERNiCr-3 by the GTAW process. This similarity is not too surprising because both weldments failed in the alloy 800H base metal. It is a bit surprising that the deformation in the Inco Weld A weld deposit is also quite similar in both weldments even though the ERNiCr-3 is stronger than the Inco Weld A (Fig. 5). The slight tendency for hardening and embrittlement to occur from exposure at elevated temperatures also shows up in this weldment, so it may be a characteristic of the alloy 800H rather than the filler metal.

CREEP TESTS

Creep test results on all-weld-metal samples of deposited Inco Weld A are summarized in Table 5. Creep test results for GTAW (ERNiCr-3 filler) and SMAW (Inco Weld A) weldment samples are given in Tables 6 and 7, respectively. A general view of relative strengths at 649°C can be obtained from Figs. 6 and 7. Data from the literature[1,3,4] are shown for ERNiCr-3, Hastelloy X, and alloy 800H, and data points are shown for Inco Weld A and the two weldments. Note in Fig. 6 that alloy 800H had the

Table 3. Tensile properties of alloy 800H–Hastelloy X weldments made with ERNiCr-3 filler metal by the gas tungsten arc welding process

Test	Aging conditions			Test temperature		0.2% Yield stress		Ultimate tensile stress		Elongation (%)		Reduction of area (%)	
	Temperature		Time										
	(°C)	(°F)	(h)	(°C)	(°F)	(MPa)	(ksi)	(MPa)	(ksi)	Uniform	Total	Total	In weld metal
16721			0	25	77	339	49.2	568	82.4	19.0	20.0	63.8	16.3
16722			0	482	900	269	39.0	484	70.3	24.0	24.2	50.4	24.9
16723			0	538	1,000	260	37.7	469	67.9	24.0	24.5	54.0	12.5
16724			0	649	1,200	247	35.9	425	61.7	18.0	19.0	14.1	14.0
			0										
16792	482	900	2,000	25	77	346	50.2	588	85.4		21.2	37.6	17.0
16794	538	1,000	2,000	25	77	409	59.4	641	93.0		22.9	45.8	4.2
16796	649	1,200	2,000	25	77	391	56.8	646	93.8		14.1	29.5	10.8
16793	482	900	2,000	482	900	278	40.4	506	73.4		26.5	54.6	7.1
16795	538	1,000	2,000	538	1,000	276	40.0	520	75.4		23.8	42.6	7.2
16797	649	1,200	2,000	649	1,200	307	44.6	437	63.4		8.6	33.0	1.6
126-8	482	900	10,000	25	77	362	52.6	619	89.8	22.7	25.0	56.2	22.8
126-13	538	1,000	10,000	25	77	440	63.8	717	104.1	17.4	19.9	49.6	10.6
126-19	649	1,200	10,000	25	77	392	56.9	566	82.1	13.8	17.5	51.3	18.3
126-9	482	900	10,000	482	900	270	39.2	496	72.0	23.2	25.6	51.9	16.0
126-14	538	1,000	10,000	538	1,000	322	46.8	571	82.9	18.3	20.2	44.1	2.7
126-20	649	1,200	10,000	649	1,200	302	43.8	439	63.7	7.1	10.0	38.5	3.5

Table 4. Tensile properties of alloy 800H–Hastelloy X weldments made with Inco Weld A filler metal by the shielded metal arc welding process

Test	Aging conditions			Test temperature		0.2% Yield stress		Ultimate tensile stress		Elongation (%)		Reduction of area (%)	
	(°C)	(°F)	Time (h)	(°C)	(°F)	(MPa)	(ksi)	(MPa)	(ksi)	Uniform	Total	Total	In weld metal
16730			0	25	77	329	47.7	568	82.3	21.0	21.7	55.8	11.3
16731			0	482	900	235	34.1	480	69.6	23.0	25.2	52.5	20.2
16732			0	538	1,000	235	34.1	474	68.7	25.0	25.5	47.0	18.0
16733			0	649	1,200	220	31.9	415	60.2	20.0	21.0	40.4	9.4
16762	482	900	2,000	25	77	315	45.7	584	84.7		24.7	63.8	6.9
16766	649	1,200	2,000	25	77	402	58.3	654	94.8		16.9	52.4	14.2
16763	482	900	2,000	482	900	226	32.8	492	71.3		27.2	58.9	10.7
16765	538	1,000	2,000	538	1,000	248	36.0	505	73.2		26.6	42.0	7.0
16767	649	1,200	2,000	649	1,200	301	43.7	432	62.6		10.4	35.3	5.0
118–8	482	900	10,000	25	77	335	48.6	602	87.3	20.1	23.2	55.2	10.3
118–13	538	1,000	10,000	25	77	402	58.3	681	98.8	17.9	20.2	49.0	10.4
118–19	649	1,200	10,000	25	77	392	56.9	675	97.9	12.4	14.4	49.1	11.7
118–9	482	900	10,000	482	900	247	35.8	483	70.1	22.2	24.5	52.2	11.0
118–14	538	1,000	10,000	538	1,000	287	41.6	525	76.2	18.8	20.6	49.6	8.1
118–20	649	1,200	10,000	649	1,200	292	42.3	447	64.9	9.0	11.4	40.6	4.0

Table 5. Creep properties of Inco Weld A weld metal

Test	Test temperature (°C)	Stress (MPa)	Stress (ksi)	Time to indicated strain (h) 1%	2%	5%	Time to tertiary creep (h)	Minimum creep rate (%/h)	Time to rupture (h)	Elongation (%) Loading	Elongation (%) Creep	Reduction of area (%)
20541	482	482	70	28			28	2.7×10^{-2}	47	33.0	8.9	38.9
20537	538	414	60	25	115			6.0×10^{-3}	436	16.5	7.6	29.3
20535	649	241	35	10	23	47	31	7.9×10^{-2}	177	0.9	40.5	58.3
20542	649	172	25	120	242	540	600	1.1×10^{-2}	1,675	0.3	25.9	53.9
22205[a]	649	103	15					2.5×10^{-6}	>16,900[a]	0.2	0.8	
20512	760	138	20	3	6	10	4	2.2×10^{-1}	27	0.9	52.5	44.8
20519	760	103	15	1	12	57	50	5.5×10^{-2}	129		30.4	34.3
22190	760	69	10	1,300				4.5×10^{-4}	1,330	0.3	2.5	1.9

[a]Discontinued before failure.

Table 6. Creep properties of alloy 800H—Hastelloy X weldments made with ERNiCr-3 filler metal by the gas tungsten arc welding process

Test	Aging conditions			Stress		Time to indicated strain (h)			Time to tertiary creep	Minimum creep rate	Time to rupture	Elongation (%)		Reduction of area (%)	
	Temperature		Time												
	(°C)	(°F)	(h)	(MPa)	(ksi)	(1%)	(2%)	(5%)	(h)	(%/h)	(h)	Loading	Creep	Total	In weld metal
								Tested at 482°C							
19417			0	482	70						0	24.2		54.6	14.1
18445			0	414	60					2.0×10^{-5}	15,373	10.2	0.96	28.6	3.9
22740	482	900	2,000	482	70					6.0×10^{-5}	1,964	21.7	1.9	36.0	17.0
19807	482	900	2,000	414	60					1.7×10^{-5}	9,578	10.2	5.5	32.0	2.9
19801	482	900	10,000	551	80						0	25.0		56.3	9.6
19804	482	900	10,000	414	60					1.5×10^{-4}	3,929	9.9	4.2	26.8	4.0
								Tested at 538°C							
18867			0	414	60	1	155			1.4×10^{-3}	340	9.2	4.5	21.8	3.8
18452			0	345	50					4.2×10^{-4}	5,721	0.75	5.5	17.0	1.3
19808	538	1,000	2,000	414	60					5.8×10^{-4}	556	6.9	3.1	18.7	1.3
19809	538	1,000	2,000	345	50					1.0×10^{-4}	4,686		5.4	7.7	
19803	538	1,000	10,000	414	60	600	1,300		1,220	1.1×10^{-3}	1,469	0.84	5.4	14.0	0.2
22737[a]	538	1,000	10,000	345	50	5,250				1.3×10^{-4}	>11,347	1.27	3.1		
								Tested at 649°C							
19412			0	241	35	118	168		101	3.5×10^{-3}	186	0.45	4.9	21.6	1.0
18703			0	172	25	938	1,930	2,180	1,880	6.0×10^{-4}	2,189		5.1	15.7	0.5
22739	649	1,200	2,000	241	35	13	25	44	27	8.0×10^{-2}	54		12.7	48.1	0.0
22241	649	1,200	2,000	172	25	380	600	835	300	1.7×10^{-3}	839	0.4	8.3	41.0	0.0
19799	649	1,200	10,000	241	25	8	16	37	37	1.3×10^{-1}	50.4		1.3	58.2	0.8
21588	649	1,200	10,000	172	25	335	450	610	280	1.2×10^{-3}	621	0.5	7.1	43.3	

[a]Test in progress.

Table 7. Creep properties of alloy 800H—Hastelloy X weldments made with Inco Weld A filler metal by the shielded metal arc welding process

Test	Aging conditions: Temperature (°C)	Aging conditions: Temperature (°F)	Aging conditions: Time (h)	Stress (MPa)	Stress (ksi)	Time to indicated strain (h) (1%)	Time to indicated strain (h) (2%)	Time to indicated strain (h) (5%)	Time to tertiary creep (h)	Minimum creep rate (%/h)	Time to rupture (h)	Elongation (%) Loading	Elongation (%) Creep	Reduction of area (%) Total	Reduction of area (%) In weld metal
Tested at 482°C															
19416			0	551	80						0	20.4		43.4	9.4
19418			0	482	70						0	21.9		40.2	10.9
18442			0	414	60	8,200			11,550	3.6×10^{-5}	11,555		4.9	25.9	13.6
21571	482	900	2,000	551	80						0	26.6		71.2	36.0
19805	482	900	2,000	414	60					1.5×10^{-3}	12,673	10.4	2.3	31.0	
19801	482	900	10,000	551	80						0	25.0		56.3	11.9
22239	482	900	10,000	414	60					7.0×10^{-6}	9,193	8.8	4.5	29.7	6.7
Tested at 538°C															
18863			0	414	60					1.2×10^{-3}	315	9.5	4.4	37.6	23.3
18443			0	345	50					1.3×10^{-4}	3,266	4.6	2.0	15.9	1.6
19806	538	1,000	2,000	414	60	114			210	1.0×10^{-3}	211	9.3	5.5	28.4	22.2
18870	538	1,000	2,000	345	50					1.8×10^{-4}	3,569	3.0	2.9	22.5	0.5
19802	538	1,000	10,000	414	60	395			525	2.3×10^{-3}	527	2.4	3.9	20.6	2.2
22679[a]	538	1,000	10,000	345	50	5,500				1.5×10^{-4}	12,236	0.83	2.9		
Tested at 649°C															
19419			0	241	35	82	104	158	100	1.2×10^{-2}	163	0.85	8.6	33.1	3.2
18444			0	172	25	650	1,800	2,318	1,665	6.5×10^{-4}	2,318	0.16	15.2	20.4	1.9
19817	649	1,200	2,000	241	35	11	21	44	21	8.1×10^{-2}	64	0.04	13.5	53.6	9.8
19820	649	1,200	2,000	172	25	650	1,025	1,635	795	1.3×10^{-3}	1,680	0.03	8.2	25.0	12.0
19800	649	1,200	10,000	241	35	5	11	27	30	1.8×10^{-1}	43.3	0.2	15.0	44.6	3.5
21570	649	1,200	10,000	172	25	200	393	798	420	4.2×10^{-3}	1,109	0.2	11.9	45.1	3.2

[a]Test discontinued before failure.

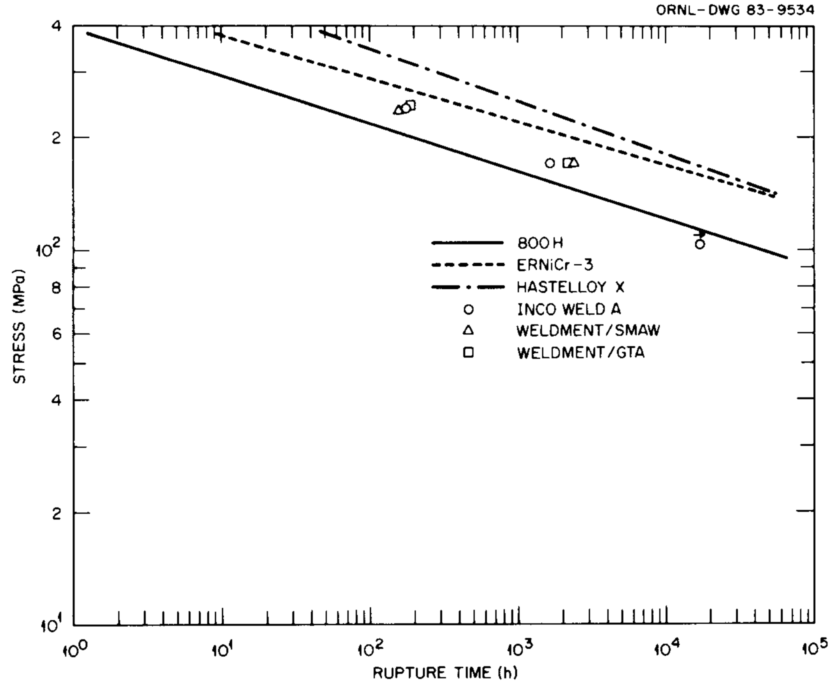

Fig. 6. Stress-rupture properties of materials involved in this study at 649°C.

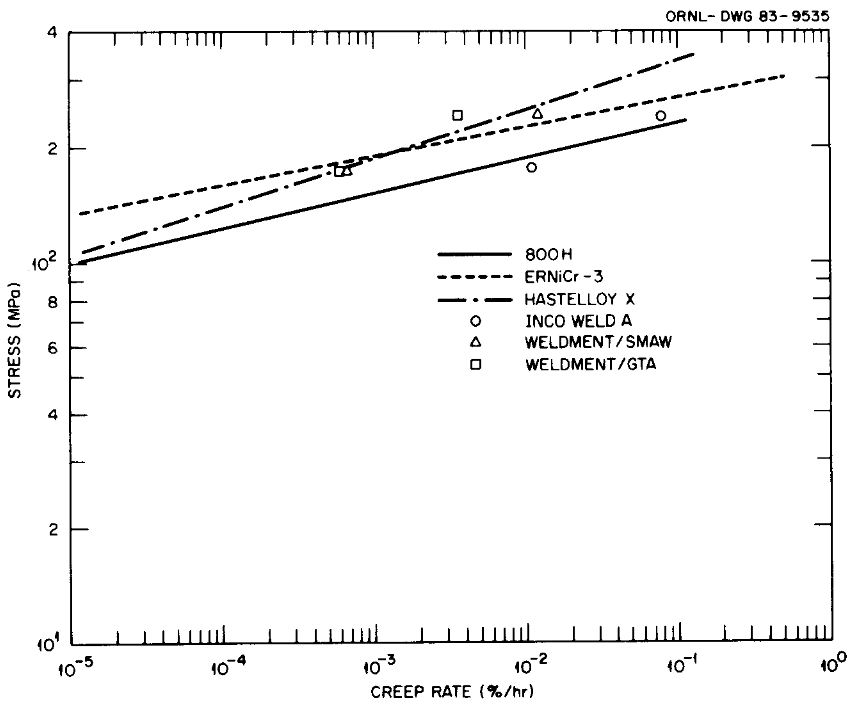

Fig. 7. Minimum creep rates of materials involved in this study at 649°C.

lowest rupture strength and that Hastelloy X had the highest. The Inco Weld A and the two weldments had almost identical strengths and fell between the lines for alloy 800H and ERNiCr-3. All weldment samples failed in the alloy 800H base metal.

The minimum creep rates of the three materials are shown in Fig. 7. At a given stress level, alloy 800H has the highest minimum creep rate; ERNiCr-3 and Hastelloy X have lower minimum creep rates and cross as a function of stress. The Inco Weld A had a minimum creep rate about equal to that of alloy 800H. The two weldments had lower creep rates, about equal to those of Hastelloy X and ERNiCr-3. A detailed examination of the data in Tables 6 and 7 indicates that aging at 482°C and 649°C softened the material and aging at 538°C hardened the material. The amount of deformation in the Inco Weld A was higher than that in the ERNiCr-3 under the same conditions, indicating that the ERNiCr-3 has higher creep strength. Fracture consistently occurred in the alloy 800H, and the two weldments responded similarly to aging, so the property changes due to aging likely reflect effects on the alloy 800H properties.

SUMMARY

Hastelloy X and alloy 800H were joined satisfactorily by the GTAW process with ERNiCr-3 filler and by the SMAW welding process with Inco Weld A electrodes. Test specimens were made of the deposited Inco Weld A. The yield strength of Inco Weld A was higher than those of alloy 800H and Hastelloy X and about equal to that of ERNiCr-3. The tensile and creep strengths of Inco Weld A were greater than those of alloy 800H but less than those of Hastelloy X and ERNiCr-3. Transverse specimens were made of the two weldments so that the gage sections included Hastelloy X, filler metal, and alloy 800H. Transverse samples were aged for 2000 and 10,000 h at 482, 538, and 649°C in an inert environment. Tensile and creep tests on the aged samples showed modest changes in mechanical properties, and these changes are attributed primarily to changes in the alloy 800H, where failure occurred.

Inco Weld A and ERNiCr-3 both are suitable filler metals for joining Hastelloy X to alloy 800H. The tensile and creep strengths of both filler metals exceed those of alloy 800H. Our tests on deposited Inco Weld A and those of other investigators[4] on ERNiCr-3 show that these filler materials retain good properties after long exposure times.

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