WELDABILITY EVALUATIONS AND WELDMENT PROPERTIES OF HASTELLOY X*

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ABSTRACT

Studies of weldability and weldment properties were conducted on commerical heats of Hastelloy X. Weldment preparation was done using several combinations of welding techniques and filler metals. Evaluation methods employed included hot cracking susceptibility and tensile and creep properties measured both before and after aging at 593 to 871°C for up to 10,000 h.

INTRODUCTION

Hastelloy X, a wrought solid-solution strengthened Ni-base alloy, is one of the prime candidate materials for high-temperature structural components in HTGR systems of advanced design. In particular, it is the reference alloy for Class B thermal barrier cover plates in General Atomic Company designs for steam cycle/cogeneration HTGRs. The materials used in such applications must be weldable and the mechanical properties of their weldments must be compatible both with those of the base metal and the design requirements.

Although Hastelloy X is known to be a weldable alloy, the use of this material for critical components of the HTGR makes it desirable to more fully understand its welding behavior and the properties of its weldments under expected service conditions. To this end, a number of studies were undertaken. In the first of these, the heat-to-heat variability of hot cracking susceptibility was evaluated by the Spot Varestraint testing of nine commercial heats of Hastelloy X. A typical heat from these was selected for examination of the effects of welding

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method and filler metals on weldability and weldment behavior. The weldments so produced were aged and/then mechanically tested. Both an inert gas and HTGR-helium were used as aging environments. Weldment properties and aging effects were evaluated by tensile and creep testing. The details and results of these studies are described in the sections which follow.

WELDABILITY TESTING AND WELDMENT PREPARATION

Weldability testing, was conducted on several commmercial heats of Hastelloy X using the Spot-Varestraint hot cracking test.[1] This was to determine the extent of heat-to-heat variation in susceptibility toward hot cracking. In this test, the specimen was subjected to a gas tungsten-arc spot weld thermal cycle for sufficient time to establish approximately steady-state thermal conditions. Concurrent with interruption of the arc current, an augmented strain was applied to the specimen by bending. Cracking data were obtained by measuring cracks in the heat-affected-zone outside of the weld fusion zone.

A total of nine different heats of Hastelloy X plate material were obtained for this comparison. Six heats were in the form of 9.5-mm-thick plate and three were 12.7-mm-thick. The chemical composition of each plate conformed to ASTM specification B-435. The results of this study (Fig. 1), show that relatively large variations in hot cracking tendency exist for these heats. No correlation of hot cracking tendency with chemical composition was evident. The heat of Hastelloy X exhibiting the most cracking has been used extensively in laboratory welding experiments and has given no problems to date. Therefore, we concluded that all other heats in this group should have good weldability and a troublesome heat, if it exists, would show much higher levels of hot cracking in the Spot-Varestraint test.

The base material selected for subsequent weldment mechanical property studies was a heat of Hastelloy X (see Heat Number 4284 in Table 1) that fell near the middle of the range of hot cracking susceptibility previously described. Weldments were prepared using both the shielded metal-arc (SMAW) and gas tungsten-arc (GTA) welding processes. Hastelloy X was obtained both as bare wire filler metal and as coated electrodes from the same heat (Heat Number 4345). This allowed for direct comparison of weldment properties from two processes without intentional compositional differences. Hastelloy S filler metal (Heat Number 7180) was also used to join Hastelloy X by the GTA process. Weldments were prepared in 12.7-mm-thick plates using these welding processes and filler metals. Specimens were prepared from these weldments for aging and mechanical property testing.

MECHANICAL PROPERTIES TESTING RESULTS AND DISCUSSION

Creep and tensile tests were performed on two heats of Hastelloy X base metal (Heat Numbers 4936 and 2792) and the three Hastelloy X weldments described above. Test samples had a gage section 3-mm-diam by 25-mm-long with button ends for gripping. The samples were taken transverse to the weld centerline and spanned the weldment so that the gage length included weld metal, both heat-affected zones, and the base metal. The creep tests were carried out in a simulated HTGR-helium environment containing 337 μatm H_2, 32 μatm CH_4, 19 μatm CO, and 2 μatm H_2O. The details of the testing techniques were described previously.[2] Aging of test samples was performed in an inert argon atmosphere.

One of the methods used to evaluate property changes was a standard tensile test run at a strain rate of 0.005 min^{-1}. The tensile properties at 25°C for aged specimens (538–871°C) of base metal are shown in comparison with those of the unaged material in Figs. 2 and 3. The strength changes due to aging were small at all conditions except for the 2500 h exposure at 704°C where the yield stress increased about 50% and the ultimate tensile stress increased about 30%. The values for reduction in area (Fig. 3) show that aging at 538°C for up to 10,000 h caused a slight increase in ductility whereas aging at 704 and 871°C caused significant decreases. The existence of larger ductility effects at 704°C than at 871°C is probably associated with precipitate morphology. Comparison of the strength data in Fig. 2 with the ductility date in Fig. 3 reveals that the properties are not inversely proportional as might be expected (i.e., the aging condition resulting in the highest strength does not produce the lowest ductility).

Samples of the three weldments were aged for 2000 and 10,000 h in inert gas at temperatures from 593 to 871°C. The results of tensile tests on these samples and the unaged weldments are presented in Figures 4 and 5. The property changes for the weldments are considerably larger than those noted for the base metal. The greatest increases in the yield and ultimate tensile stresses (60 and 45%, respectively) occurred after aging at 650°C. Smaller increases resulted from aging at 760°C and the changes after aging at 593°C were very small. Aging at 871°C resulted in a decrease in yield stress of about 20% and a small decrease in the ultimate tensile stress of some samples. Note that the yield and ultimate tensile stresses of unaged base metal are lower than those of unaged weldments (compare Figs. 2 and 4).

The tensile reductions in area measured for both the aged and unaged weldments at 25°C are shown in Fig. 5. There are considerable differences in the ductilities of the three weldments in the as-welded condition, but all had higher ductilities than the unaged base metal (Fig. 3). Aging caused significant decreases in the ductilities of all three weldments with the maximum changes occurring on aging at 760°C. The property changes (tensile strength and ductility) are least when Hastelloy S filler is used. The weldment prepared with Hastelloy X filler metal and the SMAW welding process has much lower ductility after aging than that prepared with Hastelloy X filler metal and the GTA welding process. However, there is evidence that the ductility of the SMAW weldment is improving with aging time at the two higher aging temperatures. The possibility exists that some post weld heat treatment could be used to stabilize the properties of all three weldments during aging.

The weldments were also subjected to creep testing in simulated HTGR-helium and the results are presented in Figs. 6 and 7. (The curves in these figures are average values from tests on base metal.) In the as-welded condition the stress-rupture properties of all three weldments fall close to those for the base metal. At 593 and 649°C the weldment with Hastelloy S filler metal has the longest rupture life while at 760 and 871°C the longest rupture life is shown by the Hastelloy X filler/GTA weldment. The Hastelloy X filler/SMAW weldment has the shortest rupture life in every case. Aging for 10,000 h at 593 to 871°C and creep testing at the aging temperature was found to reduce rupture life. The ranking of strengths among the three weldments generally agrees with that noted before aging. The reduction in rupture life due to aging does not exceed a factor of four in any case and then only for relatively short rupture lives.

The minimum creep rates of the weldments are compared in Fig. 7 with those for base metal and are found to be similar. However, there are four low stress tests at 760 and 871°C which had a period with an extremely low creep rate, indicating a possible trend for weldments to have a much lower creep rate than the base metal at high temperatures. There does not seem to be a significant variation in minimum creep rate with weldment type.

The question of fracture strain in weldments is rather complex because temperature, rupture life (strain rate), aging, and weldment type are all significant variables. Most of the weldments that used Hastelloy X filler ruptured in the weld metal and most with Hastelloy S filler metal failed in the Hastelloy X base metal. Approximate fracture strains are listed in Table 2. All of the values less than 10% were obtained for the Hastelloy X filler/SMAW weldment. Aging usually had a beneficial effect on the creep fracture strain of Hastelloy X weldments.

CONCLUSIONS

The results of this study on Hastelloy X weldability and weldment properties permit the following conclusions.

1. Commercial heats of Hastelloy X show a relatively large heat-to-heat variation in hot cracking susceptibility but even the material exhibiting the most cracking could be welded satisfactorily without special precautions.

2. The largest aging effects (i.e., tensile property changes) in Hastelloy X base metal occur around 700°C.

3. Property changes resulting from aging are greater in weldments than in the base metal and peak at a slightly different temperature, 650°C. Weldments prepared by the GTA process with Hastelloy S filler metal are the most stable on aging (i.e., exhibit the least change in tensile properties) and those prepared by the SMAW process with Hastelloy X filler are the least stable.

4. The creep properties of weldments tested in the as-welded condition are similar to those of the base metal.

5. Aging of the weldments prior to creep testing reduces rupture life but improves rupture ductility. Fracture strains less than 10% are found only for the Hastelloy X filler/SMAW weldment.

REFERENCE

1. H. E. McCoy, Jr., "Creep Behavior of Hastelloy X, 2 1/4 Cr-1 Mo Steel, and Other Alloys in Simulated HTGR Helium," ORNL/TM-6822 (June 1979).

Table 1. Characterization of Hastelloy Test Materials[a]

Heat Number	Form	Chemical Analysis											
		Ni	Cr	Co	Mo	Fe	Al	Si	C	Mn	S	W	Other
4936[b]	12.7-mm (1/2 in.) plate	Bal	21.82	1.68	9.42	19.09		0.44	0.07	0.58	<0.005	0.63	
2792[b]	31.8-mm (1-1/4 in.) bar	Bal	21.25	1.94	8.99	18.96		0.41	0.10	0.57	<0.005	0.56	
4284[b]	12.7-mm (1/2-in.) plate	Bal	21.79	2.40	8.82	19.06		0.35	0.06	0.59	<0.005	0.63	
4345[b]	4-mm (5/16-in.) wire	Bal	21.92	2.09	8.85	18.81		0.40	0.08	0.70	<0.005	0.42	
7180[c]	1-mm (1/16-in.) wire	Bal	15.15	0.06	14.46	0.44	.25	0.38	0.006	0.47	0.006	<.10	0.019 La

[a] All material expect wire solution annealed by vendor, Cabot Corporation.

[b] Hastelloy X.

[c] Hastelloy S filler.

Table 2. Approximate Fracture Strains (%)

Test and Aging Temperature °C	100 h Rupture			1000 h Rupture			10,000 h Rupture		
	Base	As Welded	Welded, Aged 10,000 h	Base	As Welded	Welded, Aged 10,000 h	Base	As Welded	Welded, Aged 10,000 h
593					10, 16, 23	6, 20, 20			
649	40	10	6, 18		4, 10, 30	12, 25	35,35	22	27
760	51, 39, 52	5, 26	15, 28, 34	19, 42	8, 20, 18	20	13	9	
871		4, 16, 10	30, 43, 47	48, 29	3		14	6	

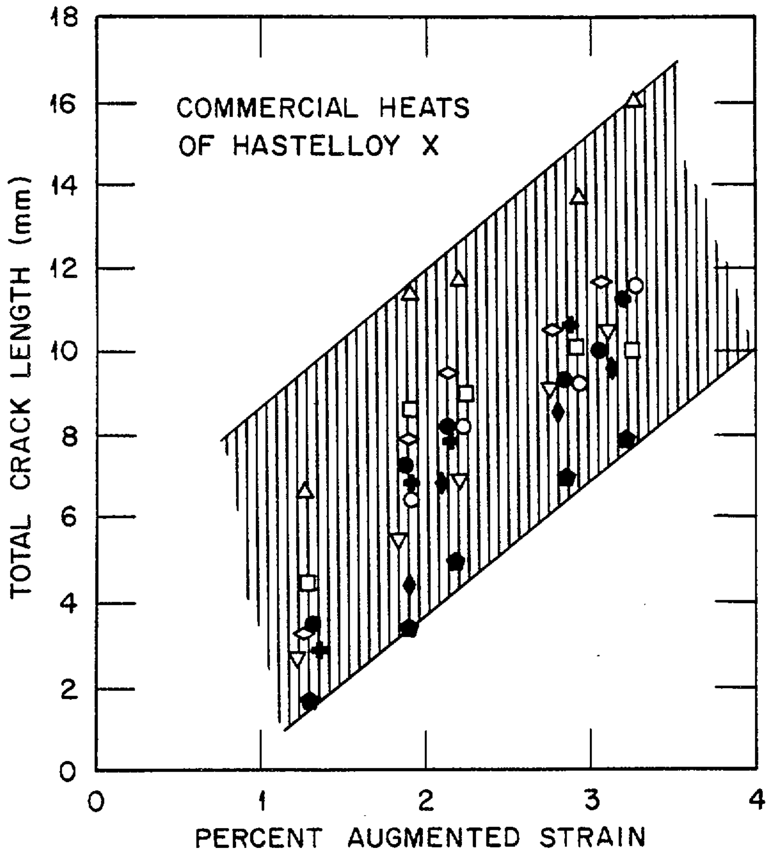

Fig. 1. Spot Varestraint Hot Cracking Data for Nine Commercial Heats of Hastelloy X Show Relatively Large Variations in Cracking Tendency.

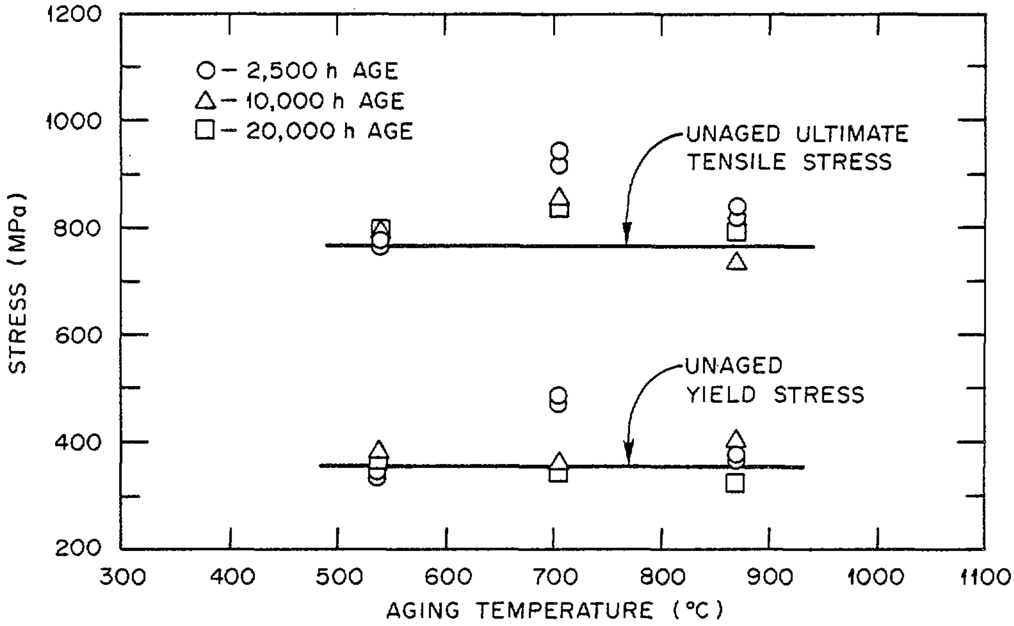

Fig. 2. Influence of Aging on the Yield and Ultimate Tensile Stresses of Hastelloy X Base Metal. Aged in the solution annealed condition and tested at 25°C at a strain rate of 0.05 min^{-1}.

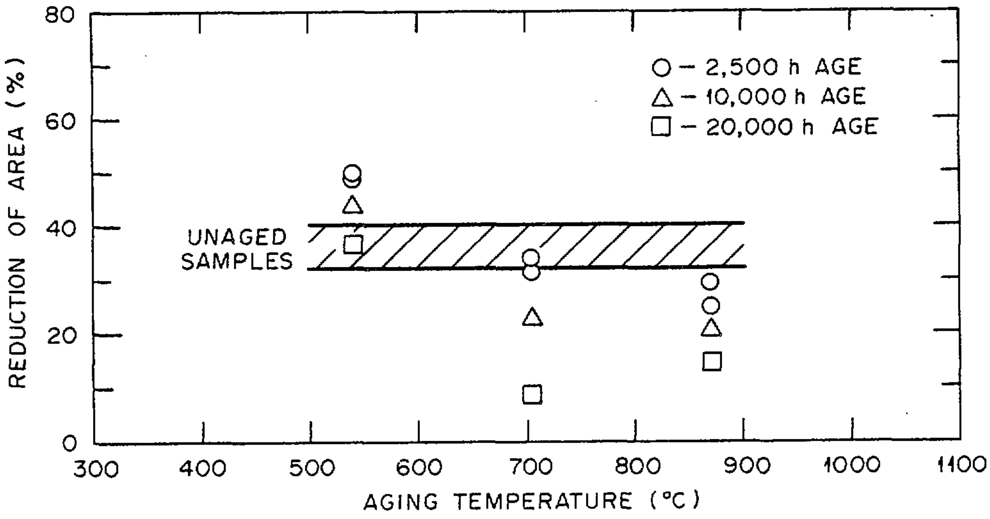

Fig. 3. Influence of Aging on the Reduction in Area of Hastelloy X. Base metal tested at 25°C at a strain rate of 0.05 min^{-1}.

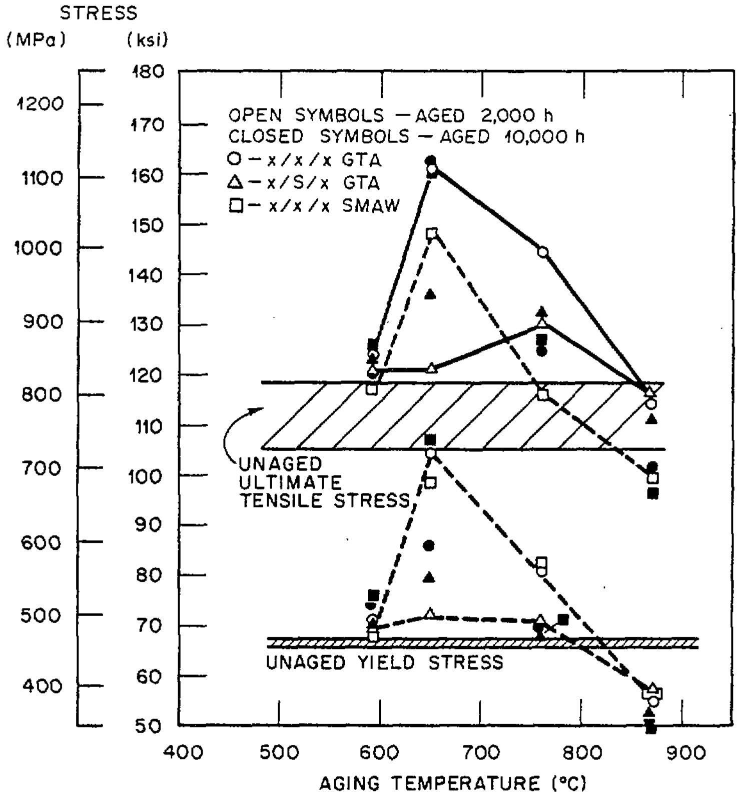

Fig. 4. Influence of Aging on the Yield and Ultimate Tensile Stresses of Three Hastelloy X Weldments. Aged at the conditions indicated and tested at 25°C at a strain rate of 0.05 min^{-1}.

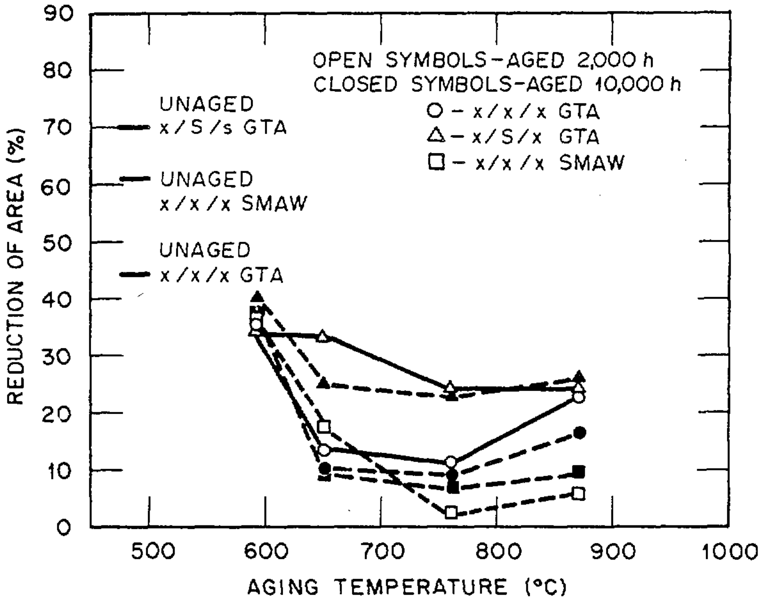

Fig. 5. Influence of Aging on the Reduction in Area of Three Hastelloy X Weldments. Aged at the indicated conditions and tested at 25°C at a strain rate of 0.05 min^{-1}.

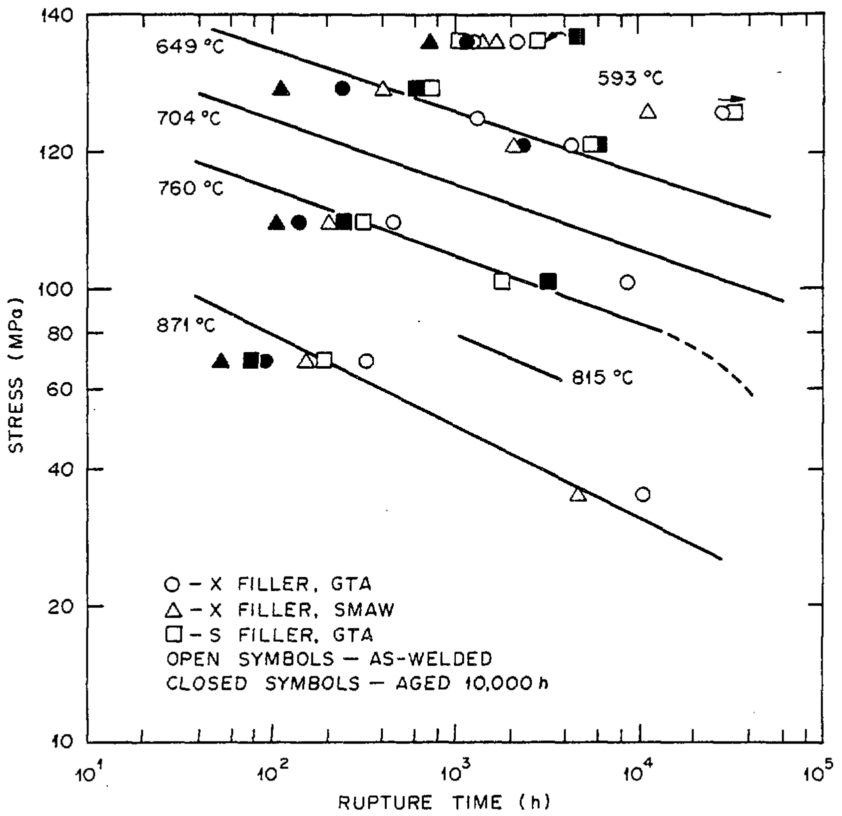

Fig. 6. Stress-Rupture Properties of Three Hastelloy X Weldments. Aged samples were aged and tested at the same temperature. Curves were detemined from tests on unaged base metal.

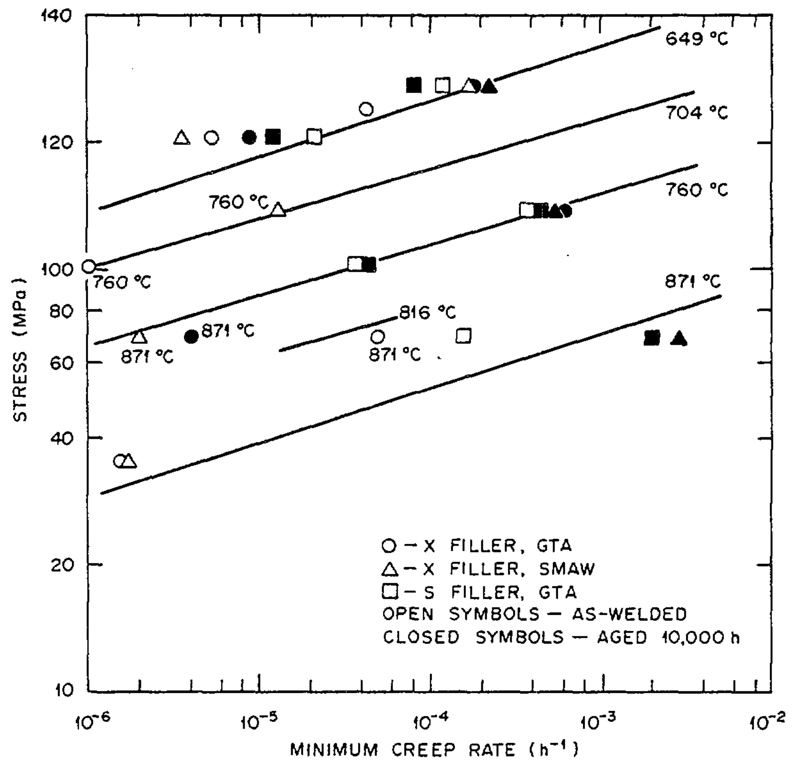

Fig. 7. Minimum Creep Rate of Three Hastelloy X Weldments. Aged samples were aged and tested at the same temperature. Curves were determined from tests on unaged base metal.