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Liquid-Copper/Zinc Embrittlement in Alloy 718

A cause of intergranular cracks in the HAZ is demonstrated

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ABSTRACT. Welding of Alloy 718 is known to cause intergranular cracks in the weld heat-affected zone (HAZ). In this work, an Alloy 718 sample that exhibited HAZ cracking revealed high Cu/Zn concentrations on the fracture surface. Previous studies on HAZ cracking of Alloy 718 have not reported high Cu/Zn concentrations on the fracture surface. It is proposed here that the presence of liquid Cu/Zn can cause liquid-metal embrittlement (LME) and HAZ cracking in Alloy 718.

Introduction

Alloy 718 is a nickel-based, precipitation hardenable alloy suitable for service at temperatures ranging from –423° to 1300°F (Ref. 1). Although it is considered very weldable, Alloy 718 is susceptible to formation of intergranular cracks in the weld HAZ. Three well-documented theories regarding the cause of HAZ cracking in nickel-based alloys are constitutional liquation (Refs. 2–7), intergranular films (Refs. 8–11), and grain boundary segregation (Refs. 11–14). These causes of HAZ crack formation have also been associated with austenitic stainless steels — Refs. 15–21.

Heat-affected zone cracking in austenitic stainless steels has also been attributed to Cu or Zn contamination of the weld area. Studies have shown that the presence of liquid Cu or Zn during welding induces cracking as a result of LME (Refs. 22–29). Nickel-based alloys have previously been reported to be insensitive to LME by elements that commonly embrittle austenitic stainless steels (Refs. 26–28). However, new studies challenge these reports and show that nickel-based alloys are susceptible to LME by common embrittling elements such as Zn, Cd and In (Ref. 29). In particular, the presence of Cd has been found to cause LME in Alloy 718 (Ref. 30).

The purpose of this paper is to demonstrate that liquid-copper/zinc embrittlement can also cause the formation of intergranular cracks in the weld HAZ of Alloy 718.

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Experimental Procedure

The Alloy 718 sample used in this study was obtained from edge-welded metal foil in the form of a bellows. Bellows consists of thin annular rings alternately welded at the inner and outer diameters forming a tube with convolutions. This particular Alloy 718 bellows failed leak testing following the gas tungsten arc (GTA) welding process. Leak testing indicated the approximate area of the crack responsible for leak test failure. The bellows was sectioned for further analysis and examined with optical microscopy, a scanning electron microscope (SEM), and energy dispersive spectroscopy (EDS). Chemical composition of the material examined as measured by atomic absorption is presented in Table 1. The results displayed in Table 1 are from a sample location remote from the fracture surface.

KEY WORDS

Alloy 718
HAZ Cracking
Nickel-Based Alloy
Cracks
Embrittlement
Liquid Cu/Zn
Copper
Zinc

The crack was found to extend from the weld bead through the HAZ of the bellows diaphragm and into the base material. Figure 1 shows the entire length of the crack. The width of the crack was found to be about 5 microns (0.0002 in.), while the length was about 175 microns (0.007 in.). The crack length is an order of magnitude greater than the width of the HAZ. The crack penetrated the entire 0.008-in. (0.2-mm) wall thickness. EDS spectra were collected of visible debris (noted by the arrow in Fig. 1) trapped in the crack.

The sample was carefully sectioned and opened along the length of the crack to study characteristics of the fracture surface. Figure 2 shows the intergranular nature of the fracture surface. Note the globules that appear on the grain boundaries. Energy dispersive spectroscopy spectra were collected of various areas of the fracture surface to determine chemical composition of the various phases. To test for the presence of Cu/Zn on the fracture surface, a line profile analysis was also performed.

Results and Discussion

Chemical composition of the Alloy 718 sample was examined to confirm

Fig. 1 — Heat-affected zone crack. 400X.

that the sample conforms to AMS 5596. Chemical composition of the Alloy 718 sample is within the specified weight percentages defined by AMS 5596. Bulk concentrations of B, P, S and Mg are below the critical levels indicated by previous studies to cause HAZ cracking due to grain boundary segregation (Ref. 14).

Figure 3 shows the EDS spectrum of debris in the HAZ crack shown in Fig. 1. Clearly, the level of Cu in the debris exceeds the concentration of Cu (0.01 wt-%) normally found in Alloy 718. This suggests that the contamination in the crack must be from an external source. During the GTA welding process, it is likely that high heat input melted the debris on the surface near the weld area, which resulted in wetting of the metal surface at the HAZ. Molten contaminant is a prerequisite for LME.

Further proof of the existence of liquid-copper/zinc embrittlement can be found on the fracture surface. Figure 4 clearly shows globules covering the intergranular fracture surface. The appearance and distribution of globules suggest that the grain boundaries were wetted by liquid metal. These globules and the intergranular fracture surface are consistent with the appearance of surfaces produced by LME (Ref. 28).

Figure 5 shows an EDS spectrum of the area depicted in Fig. 4. High Cu and Zn concentrations are noted. Figure 6 shows results of the line profile analysis. Peaks in the superimposed line graph correspond to the presence of Cu near the horizontal scan line. The analysis clearly associates high concentrations of Cu with the individual globules. It is reasonable to suspect that the Zn contamination is associated with the Cu-rich globules since Zn is not found in Alloy 718 (Table 1). Therefore, this analysis demonstrates that the globules resulted from liquid Cu/Zn that wetted the grain boundaries. The presence of Cu/Zn suggests contamination of the area that resulted in LME.

Previous studies have found that Alloy 718 is insensitive to copper-contamination cracking in the weld HAZ (Refs. 26, 27). On the other hand, other nickel-based alloys have been reported to be susceptible to liquid-zinc embrittlement (Ref. 29). Zinc has not been previously

Table 1 — Nominal Composition (wt-%) of Sample Remote from Fracture Surface

Element	Result	Specification (AMS 5596)
Ni	52.90	50.00–55.00
Cr	18.40	17.00–21.00
Fe	18.4000	Balance
Nb	5.16	4.75–5.50
Mo	2.96	2.80–3.30
Ti	1.05	0.65–1.15
Al	0.57	0.20–0.80
Co	0.14	0.00–1.00
Si	0.14	0.00–0.35
Mn	0.07	0.00–0.35
C	0.05	0.00–0.08
Cu	<0.01	0.00–0.30
B	0.002	0.000–0.006
P	0.011	0.000–0.015
S	0.001	0.000–0.15
Mg	0.01	Residual

associated with embrittlement of Alloy 718. It is not certain from this study whether the embrittling agent in this particular Alloy 718 sample was Cu or Zn.

The authors acknowledge that it is possible that cracking initially occurred by grain boundary liquation. Liquid Cu/Zn contamination could then have occurred subsequent to initial cracking if the initial cracking occurred close to external Cu/Zn contamination. However, this scenario seems unlikely due to the spatial distribution of the cracking and Cu contamination observed on the sample.

Future work could determine whether Cu/Zn can create LME in Alloy 718 without a preexisting crack. One possibility is the reaction of Alloy 718 with liquid brass. The composition of the brass could be chosen such that the liquidus temperature is below the lowest liquation temperature in Alloy 718 to determine the susceptibility to LME by Cu/Zn in the ab-

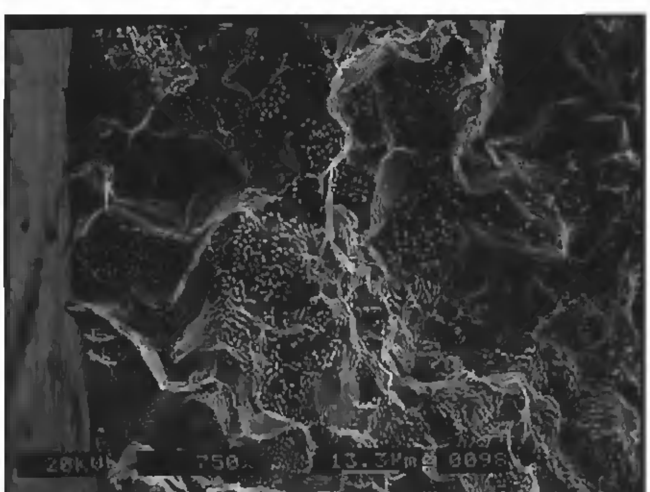

Fig. 2 — Fracture surface. 750X.

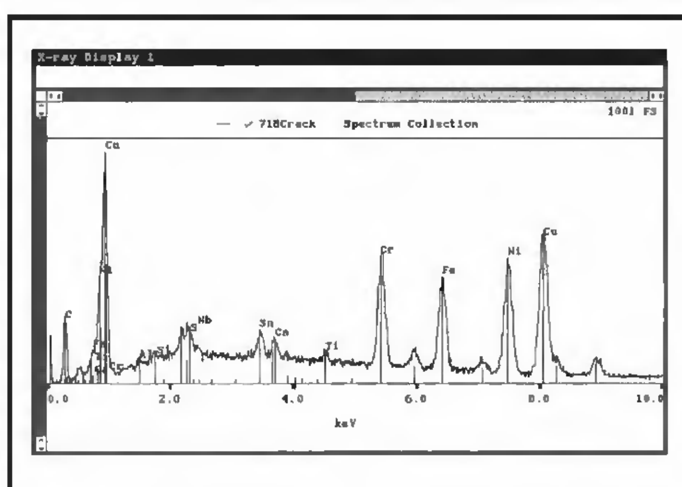

Fig. 3 — EDS spectrum of debris marked by arrow in Fig. 1.

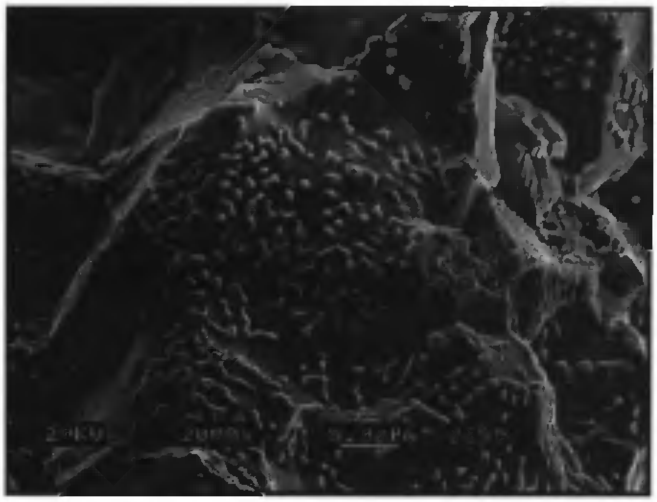

Fig. 4 — Fracture surface. 2000X.

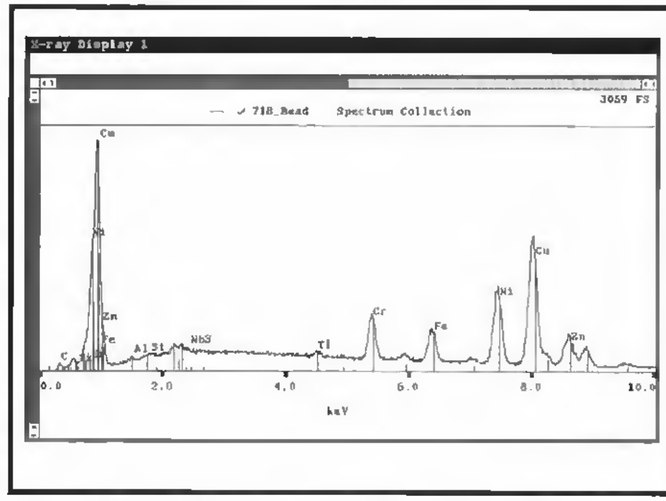

Fig. 5 — EDS spectrum of area displayed in Fig. 4.

sence of crack initiation by conventional means. This study should be conducted on multiple heats of Alloy 718 representing a range of chemical composition since not all compositions of Alloy 718 may be susceptible to LME.

Conclusions

Results of this analysis document the presence of high concentrations of Cu/Zn on the fracture surface of a HAZ crack in an Alloy 718 sample. It is proposed that wetting of the surface by liquid Cu/Zn caused weld HAZ cracking in this sample. The results of this analysis suggest that Alloy 718 is susceptible to liquid-copper/zinc embrittlement.

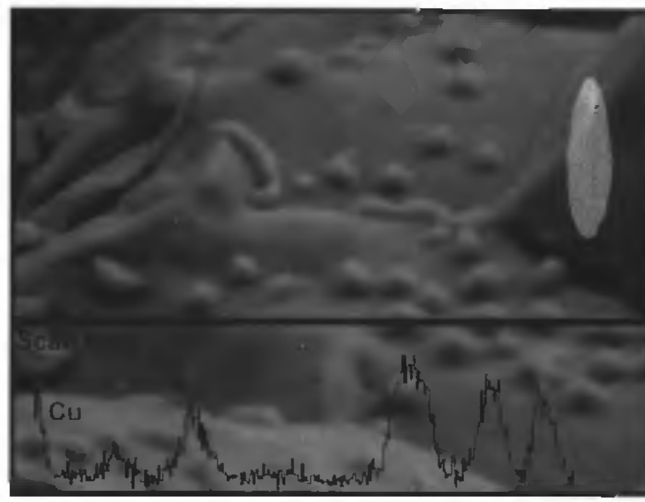

Fig. 6 — Line profile analysis of area displayed in Fig. 4.

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