Cracking Susceptibility and Microstructure of Ni-Cr20-Ti-Al Brazed Joints

Post braze annealing may restore toughness in joints where a brittle phase occurs during high temperature brazing with BNi-5 filler metal

BY U. DRAUGELATES, B. WIELAGE AND K. -H. HARTMANN

ABSTRACT. An investigation was conducted of the microstructure of brazed joints made in a high strength nickel alloy (Ni-Cr20-Ti-Al) using BNi-5 brazing filler metal. Light-optical and scanning electron microscopy supported by microscopic hardness testing revealed a brittle phase that may cause a loss of toughness unacceptable for certain applications.

With the aid of micrographs from sectioned specimens, the influence of heat treatment processing on the mechanical properties of the brazed joints was studied in order to correlate the behavior of individual zones in the microstructure. As a result of these investigations, future research will be concentrated on the brittle phases in the joint, to determine the effect of structural changes.

Introduction

For joining materials that are subjected to extreme thermal and mechanical stresses in service, high temperature brazing processes are being used more frequently. Research for a viable process for joining structural components from materials not weldable with common fusion processes has shown that high temperature brazing in vacuum or in a controlled environment is particularly suitable (Ref. 1). The proven shear and tensile strength of high temperature brazed joints produced with high melting point filler metal and high strength base metals having good elevated temperature characteristics is equaled by the long term static and dynamic properties of these joints (Refs. 2,3).

However difficulties arise with respect to repeatability when testing for technological properties of high temperature brazed joints. As a result of very high elastic properties and a high yield strength to ultimate strength ratio of the filler metal, it may be extremely difficult to maintain a propagating crack in this region during fatigue testing. The extent of these difficulties depends on the type of joint and the microstructure. The investigations of this dependence during experimental tests was conducted on brazed joints produced by inductive heating in vacuum. The base metal was a high strength Ni alloy, Nimonic 80 A, and the filler metal a Ni base alloy BNi-5.

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Materials

Base Metal

The base metal used in these experiments, Ni-Cr20-Ti-Al, is typical of the high temperature resistant alloys (Table 1). This alloy is characterized by good resistance to oxidation and corrosion as well as high fatigue strength at elevated temperatures. This high strength superalloy is structured on the Ni-Cr system and is alloyed so that some of the alloying constituents strengthen the matrix. The high aluminum content in combination with titanium

Table 1 — Base Metal and Filler Metal Compositions (wt %)

Base metal Ni-Cr20-Ti-Al (Nimonic 80A)		Filler metal BNi-5 (Nicrobraz 30)	
Ni	72.14	Ni	70.9
Cr	20.0	Cr	19.0
Fe	4.0	Si	10.0
Ti	2.4	C	0.1
Al	1.4	Melting range:	
C	0.06	1080-1135 C	

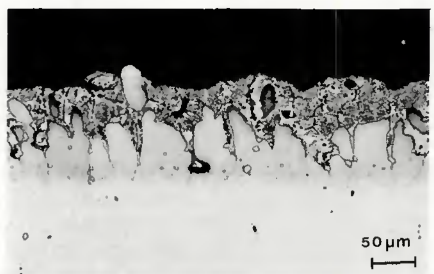

Fig. 1 — Micrograph showing a fractured cross section of a braze joining the Ni-Cr20-Ti-Al base metal (see Table 1) with BNi-5 filler. Conditions: vacuum, 10^{-5} torr; brazing temp., 1190 C; heat treatment before brazing, 1080 C/8 h/air cool; heat treatment after brazing. 710 C/16 h/air cool

leads to precipitations occuring as a result of the formation of intermetallic phases (Ref. 4).

In addition to the presence of these phases, carbide phases at grain boundaries arise during heat treatment processing. These new phases influence the deformation characteristics of the joint so that the proportion of grain boundary slip and therefore also the elongation before fracture increases (Ref. 5).

Although this base metal can be used in applications at service temperatures up to 1000 C, adequate deformation under mechanical loading is only obtained at temperatures up to 850 C. Joints with satisfactory tensile strength can be made with electron beam and gas shielded arc welding processes as well as with the high temperature brazing process. However, precautions should be taken during all thermal processing to employ a shielding gas to ensure that oxidation of Ti and Al is minimized.

Brazing Filler Metal

The well known Ni base alloy, BNi-5 (Table 1), is used primarily for joining high strength materials in turbine installations and especially in nuclear engineering. In addition to possessing high mechanical and thermal load carrying capacity and high temperature resistance, this alloy, unlike Cu and Ag base alloys, presents no problems in vacuum environment as a result of its low vapor pressure. For this reason, as well as the fact that it alloys well with other elements, nickel is present in this type of brazing filler metal. The Ni content also ensures a joint with satisfactory corrosion resistance.

The desirable property of resistance to embrittlement at elevated temperatures is for critical applications in nuclear engineering of particular significance. However, when used with large brazing gaps, this filler material exhibits severe embrittlement. In addition to this undesirable characteristic, the exact maintenance of the prescribed brazing temperature of 1190 C is recommended, in order to avoid the formation of brittle phases and the rapid diffusion of these phases along grain boundaries in the base metal microstructure.

Metallography

The metallographic investigation of the brazed joints was conducted on heat treated specimens. From the cross-sectioned specimen of a fractured brazed joint (Fig. 1) the following observations can be made:

1. The fracture is completely confined to the fine structured braze constituent, which is mainly orientated in the center of the braze gap. From the results of the investigations by De Paoli and Colbus (Ref. 5), it can be assumed that for this base and filler metal combination the fine structured microstructure consists of silicides.

2. The second constituent in the joint is a lightly etched phase which is heavily concentrated at the sides of the brazed gap. It is difficult to distinguish this phase from the microstructure of the base metal, and even the grain boundary configurations in each region are similar.

3. Lightly etched particles in the joint cause a diversion of the crack advancement during fracture.

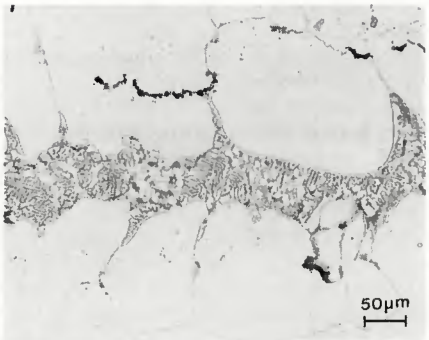

Fig. 2 — Micrograph showing cross section of brazed joint; materials and conditions same as in Fig. 1

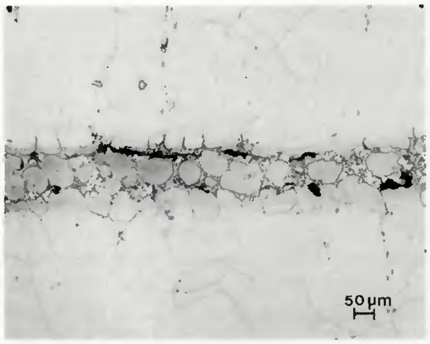

Fig. 3 — Micrograph of a brazed joint showing separations and various phases; materials and conditions same as in Fig. 1

With respect to brazed joints, it is possible for various phases to be present. In Fig. 2, a phase which is very similar to that in Fig. 1 is evident. In the center of the joint, the fine structured constituent is strongly protruding into the lighter phase.

However it is also possible for an alternative phase to exist, Fig. 3. The lighter phase, which as before is primarily to be found at the sides of the joint is also present in the form of large grains in the center ot the joint. Although these grains appear to be embedded in the fine structured brittle constituent, this separation is not always clearly defined. However it is apparent, that separations in the joint are almost completely confined to the fine structured region.

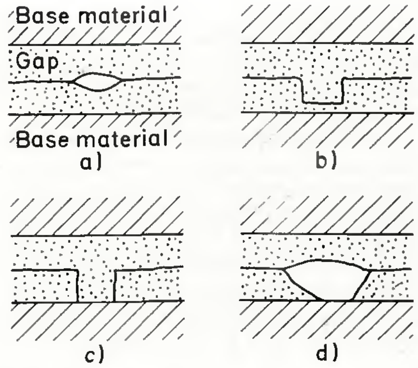

Fig. 4 — Schematic representation of faults found in the brazed joints

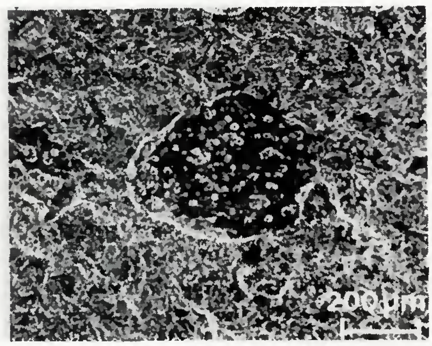

Fig. 5 — Scanning electron micrograph of fractured braze surface showing a so-called "blow hole"

Fractography

The examination of fracture surfaces from tested brazed specimens was done with a stereo microscope. While at the center of the specimens a relative smooth fracture surface was observed, at the outer edges a heavily roughened surface prevailed. In general, four distinct fracture characteristics were discernable and these are schematically represented in Fig. 4.

In Fig. 4 (a) a void exists, the surface of which has a bright metallic appearance. Picture (b) shows plateau-forming protrusions of considerable size. The plateaus rise very abruptly from the surrounding surface. In this case the fracture surface lies in the braze, whereas in (c) the fracture is at the base metal-braze interface. The surrounding surface of these fractures is oxidized and machine marks from a prior grinding operation are distinguishable. It can be assumed that insufficient bonding during the brazing process occurs, and during the post brazing heat treatment oxidization results.

A failure as a result of adverse surface tension effects is illustrated in Fig. 4 (d).

Investigations with an electron scanning microscope permit a better understanding of the fractured surfaces. In Fig. 5, a so called "blowhole" in the fracture surface, and in

Fig. 6 a bonding failure are shown respectively. The fracture surface, the transition zone and the base metal are clearly distinguishable in Fig. 6.

The transition region reveals a surface appearance characteristic of as-solidified material that is totally unaffected by the fracture. The appearance of a typical fracture surface is shown in Fig. 7. Although plastic deformation is evident at certain locations, the dominating surface characteristic is of a brittle fracture.

Effects of Thermal Processing

The results of the investigations using scanning microscopy, supported by microscopic hardness testing and light-optical microscopic examination of microstructures, lead to the conclusion that in the case of a rapid crack propagation in the braze, the fracture is essentially related to the brittleness of the intermediate phase. It is also possible that this phase adversely influences the toughness of the joint. Heat treatment processing at high temperatures and over long periods affects the formation and distribution of this brittle phase (Ref. 6).

In order to investigate these processes, specimens were subjected to an annealing temperature of 1000 C with holding times of 10 h (Fig. 8) and 57 h (Fig. 9). The variations in microstructure of the brazed joint in the as-brazed condition and after heat treatment processing are obvious. A redistribution of the brittle phase occurs as a result of annealing.

In order to assess the effect on the mechanical properties of the brazed joints, microhardness testing across the joint was done after each heat treatment (Fig. 10). Whereas hardnesses up to 9000 N/mm^2 were recorded during measurements on the brittle phase, the hardness of the annealed braze was measured to be 3400 N/mm^2. This value is only slightly higher than the hardness of the base metal, which is approximately 2600 N/mm^2. Similar results have been previously reported (Ref. 6).

Conclusions

For practical applications, high temperature brazed joints in Ni based alloys using the filler material BNi-5 are of considerable importance. Apart from the fact that these joints are economically produced, these brazed connections exhibit good mechanical properties at elevated temperatures. However as a result of the formation of a brittle phase in the joint microstructure, which even persists after heat treatment processing, these joints are not suitable for many applications. The toughness of the joints however can be considerably improved by heat treatment. The aim of the next investigations is to determine a series of post brazing heat treatments which result in optimum toughness in the braze while the tensile properties of the base metal are unaffected.

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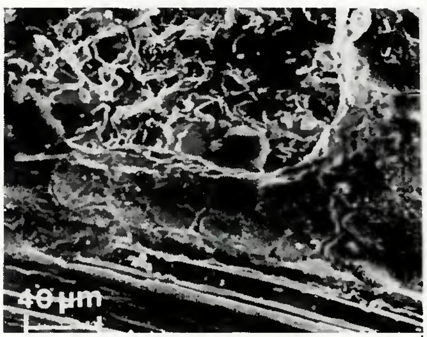

Fig. 6 — Electron micrograph of a bonding failure in a brazed joint

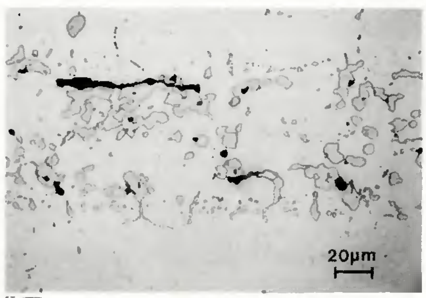

Fig. 8 — Microstructure of a brazed joint made under the same conditions as in Fig. 1, but followed by annealing at 1000 C for 10 h and air cooled

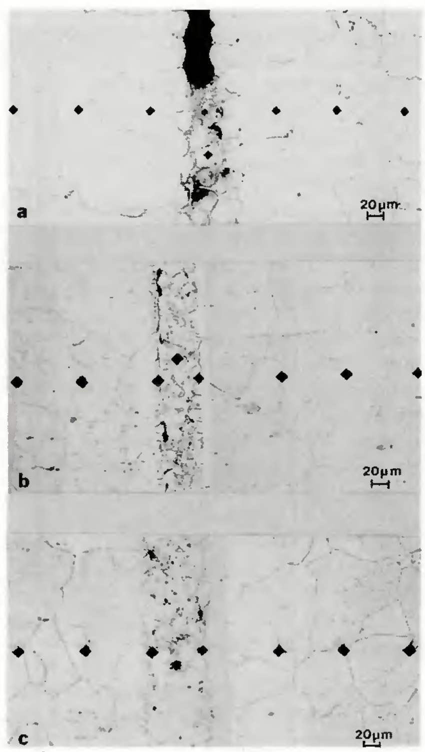

Fig. 10 — Hardness traverses made on brazed joints after three different post braze heat treatments: (a) with conditions same as in Fig. 1; (b) with conditions same as Fig. 1, but followed by annealing at 1000 C for 10 h and air cooled; (c) with conditions same as Fig. 1, but followed by annealing at 1000 C for 57 h and air cooled

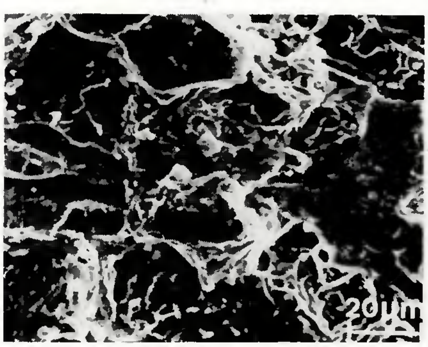

Fig. 7 — Electron micrograph of a typical fracture appearance of a brazed joint

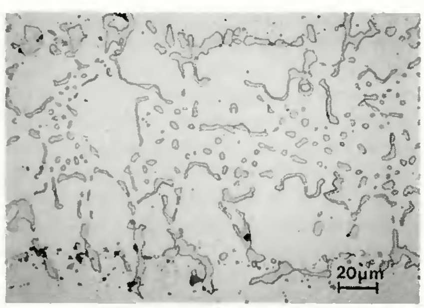

Fig. 9 — Microstructure of a brazed joint made under the same conditions as in Fig. 1, but followed by annealing at 1000 C for 57 h and air cooled

WRC Bulletin 201 December 1974

1. "The Submerged Arc Weld in HSLA Line Pipe — A State-of-the-Art Review"
by P. A. Tichauer

The submerged arc weld in HSLA line pipe is examined by briefly reviewing the metallurgy of high-strength low-alloy steels and then considering how the welding process affects this metallurgy. Particular emphasis is given to the influence of thermo-mechanical processing and to the role of micro-alloy additions as they relate to strength, grain size and toughness. The metallurgy of the weld is contrasted to that of the base plate, and some recent investigations are reviewed. The influence of consumable selection is considered, and some recommendations for further study are made.

2. "Experience in the Development and Welding of Large-Diameter Pipes"
by M. Civallero, C. Parrini and G. Salmoni

The production of X70 pipes up to 30 mm wall thickness with high base-material toughness has become necessary and possible today. In the choice of the most suitable type of steel, the mill and field weldability problems have been considered, as well as the weld-joint toughness requirements.

Of the experimental solutions, the best appears to be a control-rolled dispersoid steel, with extra-fine structure (mostly acicular type) with reduced pearlite and controlled inclusions. This steel, welded with the normal double-pass submerged arc techniques, allows one to achieve good toughness in the heat-affected zone, and to improve weldability compared to conventional steels. By further improving the type of flux on the basis of the theories developed, and by widening the knowledge of the effects of chemical composition (correlation between chemical composition, liquid-and-solid, austenite-to-ferrite transformation and final structures), it is believed possible to improve the low-temperature toughness up to the 10 kg/cm^2 level at temperatures down to -40 C, in wall thicknesses up to 30 mm.

3. "New Development in Weldability and Welding Technique for Arctic-Grade Line Pipe"
by E. Miyoshi, Y. Ito, H. Iwanaga and T. Yamura

In this study, low-temperature burst tests were performed on 48-in. diameter × 1-in. thick × 8-ft long line-pipe specimens of a 1% Ni steel recently developed and produced by controlled rolling. Notches twice the size of the largest allowable defect in API Std. 1104 were incorporated in the longitudinal weld seam. Test data were assessed by a COD approach. Two heat inputs were used in welding the specimens. A special GMA welding technique was developed for the lower heat input. It was found that the lower heat input was the best method of improving the fracture toughness of the weld.

4. "Technology of Wires and Electrodes for Welding High-Strength Pipe"
by J. Grosse-Wordemann

During the past few years, developments have led to steel grades with improved mechanical properties and reduced carbon content, compared to the previously known carbon-manganese grades. The new steels have improved weldability and API grades X60, X65 and X70 are already in use. The development of X80 is close to completion. This paper reviews the latest technology in developing suitable filler metals for welding these high-strength line-pipe steels.

5. "Preliminary Evaluation of Laser Welding of X-80 Arctic Pipeline Steel"
by E. M. Breinan and C. M. Banas

Single- and dual-pass laser welds were made in an alloy steel currently being evaluated for potential Arctic gas pipeline applications. The laser welds exhibited excellent overall mechanical properties and a Charpy shelf energy greater than 264 ft-lb, which is substantially above that of the base material. Dual-pass welds exhibited a ductile-to-brittle transition temperature below -60 F. Increased shelf energy was attributed to a reduction in the visible inclusion content of the fusion zone while transition temperature was shown to be strongly dependent upon fusion-zone grain size.

Paper (1) was prepared for the Subcommittee on Line-Pipe Steels of the Weldability (Metallurgical) Committee of the Welding Research Council. The other four papers were presented at a session sponsored by this subcommittee during the 1974 AWS Annual Meeting.

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