Behavior of Brazed Nickel Alloy Under Cyclic and Thermal Load

Filler metal microstructure and brazing faults are shown to influence the fatigue properties of high temperature brazed Nimonic 80A

BY U. DRAUGELATES AND K.-H. HARTMANN

ABSTRACT. Results of investigations are reported conducted on the fatigue behavior at elevated temperatures of high temperature brazed joints. It has been found out that the fatigue life of cylindrical specimens of a nickel-base superalloy (Ni-20Cr-Ti-Al) brazed with BNi-5 filler metal increased after postbraze heat treatment. However, at all test temperatures (RT, 600, 700 and 800 C, i.e., 1112, 1292 and 1472 F), failure on different stress levels appeared very broad.

Micro-faults in the brazed seam which act as crack initiation zones have been found to be a cause of this scattering. These faults have to be avoided in order to reach reliable values of fatigue strength needed for fail-safe design. The technological results are completed by fracture surface investigations to find out the failure mechanism in the brazed seam fatigued at elevated temperatures.

Introduction

One alternative process to the fusion welding of nickel-base superalloys is brazing. It may permit joining parts with large cross-section areas and complex contours, realizing a narrow gap width, and avoiding distortion and residual stresses as well as hot cracking problems and postweld heat treatment cracking problems related to several conventional welding processes. Therefore, much research and development has been expended on the application of brazing to nickel-superalloys. It has become apparent that successful brazing depends both on optimizing the process variables and selecting a specific filler metal composition. By this means, particular disadvantages like limited ductility of the seam, remelting if overheated, or weakness at high temperature service can be prevented.

Table 1—Base Metal and Filler Metal Compositions, Wt-%

Base material: NiCr20TiAl (Nimonic 80 A)	Brazing filler metal: BNi-5 Nicrobraz 30
72.14 Ni	70.9 Ni
20.0 Cr	19.0 Cr
4.0 Fe	10.0 Si
2.4 Ti	0.1 C
1.4 Al	
0.06 C	Melting point: 1080–1135 C

An effort has been made to determine the mechanical properties and failure criteria of brazed superalloys. The knowledge of this technological behavior is a presupposition for practical application of brazed structures. In addition to ultimate tensile properties, toughness creep-rupture behavior and fatigue strength are of particular interest for joints in high temperature service structure components.

In a great number of fatigue tests, the behavior of brazed nickel-base superalloy Ni-20Cr-Ti-Al with BNi-5-type filler metal at elevated temperature has been determined.[1,2] It has been observed that a wide scattering of the number of cycles to failure at the different stress levels occurred. Also, the fatigue strength for finite life at various test temperatures is apparently influenced by the melting conditions and the microstructure of the solidified filler metal. Thus, these aspects have been the subjects of comprehensive and thorough examination, the results of which are reported here.

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Experimental Procedure

The investigations have been conducted with cylindrical specimens corresponding to German Standard DIN 8525 with a diameter of 9 mm (0.35 in.). Certain experiments to determine surface effects with SEM were run with 4 mm (0.16 in.) diameter cylindrical, polished microspecimens.

The base metal was Ni-20Cr-Ti-Al. It was brazed with a Ni-Cr-Si-alloy corresponding to AWS specification BNi-5. The compositions of these alloys are shown in Table 1.

The brazing procedure has been carried out in a vacuum furnace at 5×10^{-5} torr with resistance heating. The brazing temperature was 1190 C (1994 F).

Postbraze heat treatment was carried out at a the temperature of 1100 C (2012 F) for 10 to 20 h in air. After quenching, age-hardening followed at

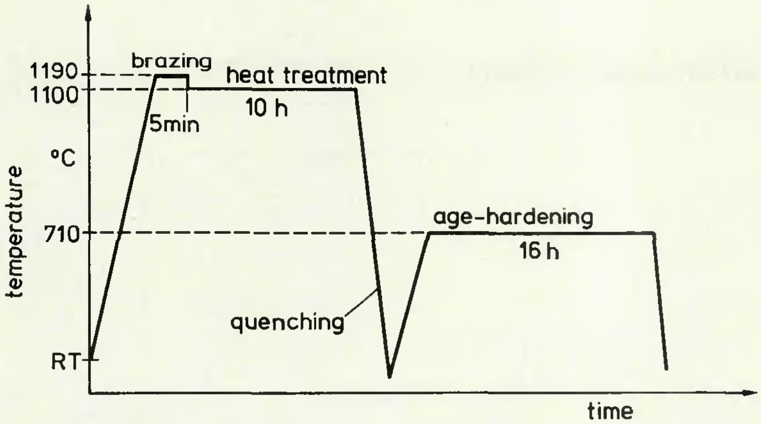


Fig. 1—Brazing and heat treatment procedure

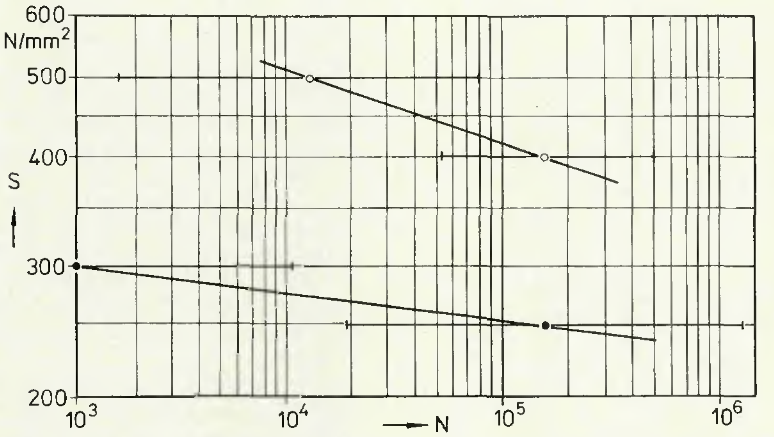


Fig. 2—Fatigue behavior of brazed joints—test temperature, RT, R = 0.1; heat treatment after brazing: ●—710 C/16 h/air; ○—1080 C/8 h/air and 710 C/16 h/air

710 C (1310 F) for 16 h in air—Fig. 1.

Fatigue tests were conducted with sine-shaped stress cycles at various stress levels with a frequency of 30 Hz. The stress ratio was determined as $R = \Sigma\ min/\Sigma\ max = 0.5$. The specimens were tested at 600, 700 and 800 C (1112, 1292 and 1472 F) in a tube furnace with resistance heating after remaining at test temperature for 1 h before cycling.

Discussion

Influence of Microstructure of the Filler Metal

The results of fatigue tests at RT happened to be poor compared to those for the base metal. Scattering of the number of cycles to failure was to a large extent at the tested stress levels—Fig. 2. As a result of thorough examination it was proved that the major reason for both low fatigue strength and wide scattering was the brittleness of certain microscopic areas in the brazed seam—Fig. 3.

In detailed examination, three modifications containing chromium, nickel and silicon have been identified. The microhardness of these phases depends on the chromium content and ranges up to 1350HV0, 005. The brittle phases hang together in an aged solid-solution matrix, building a continuous crack path. It has been proved then that added heat treatment after brazing, as shown in Fig. 1, causes solution and coagulation of the brittle phases and provides increased toughness of the seam,[1-3] which after this treatment looks like a diffusion welded zone—Fig. 4.

The single brittle phase existing with round shape is that associated with high hardness containing about 45% chromium and 11% silicon.[3]

The influence of the changed microstructure on the fatigue behavior is obvious—Fig. 2. The S-N-curve shows increased fatigue strength of the brazed joints and somewhat decreased scattering on the stress levels, on each of which twelve specimens were tested. The marks on the curves represent 50% survival probability and the scatter bands 10% to 90%, respectively. Consequently, all further experiments were conducted with specimens which had been heat treated after brazing at 1100 C (2012 F) for 20 h in air.

Fig. 3—Micrograph of a brazed seam

Fig. 4—Microstructure of brazed joint post-brazeheat treated

Results of Fatigue Testing at Elevated Temperatures

The one-stage fatigue tests were carried out with stress ratio R = 0.5 in the temperature range of 600 to 800 C (1112 to 1472 F). Experiments at 900 C (1652 F) were given up because of the extremely low strength below 250 $N\ mm^{-2}$. The results of tests at 600 C (1112 F) are plotted in Fig. 5. At each stress level at this temperature as well as at others, a quantity of eight specimens represents the statistically determined scatterband—Figs. 6 and 7.

With increasing test temperature, the expected value of endurance life decreases from about 450 $N\ mm^{-2}$ to about 190 $N\ mm^{-2}$. The fatigue strength, at which with 50% survival probability a fatigue life of 10^5 cycles will be reached, decreases from approximately 550 $N\ mm^{-2}$ to 500 $N\ mm^{-2}$ at 700 C (1292 F) and 400 $N\ mm^{-2}$ at 800 C (1472 F). The accelerated decrease of fatigue strength corresponds very well with the results of tensile testing at elevated temperatures. In the same modus, the scattering range is decreasing. The results of these fatigue tests correlate with that from the tested base metal Nimonic 80 A.[6] The endurance life of the brazed joints is additionally plotted in the Gerber's diagram with a mark on the broken line (P ± ⅓ P) for 2×10^6 cycles—Fig. 8.

On some stress levels, there happened to appear a specimen which supported an extremely low number

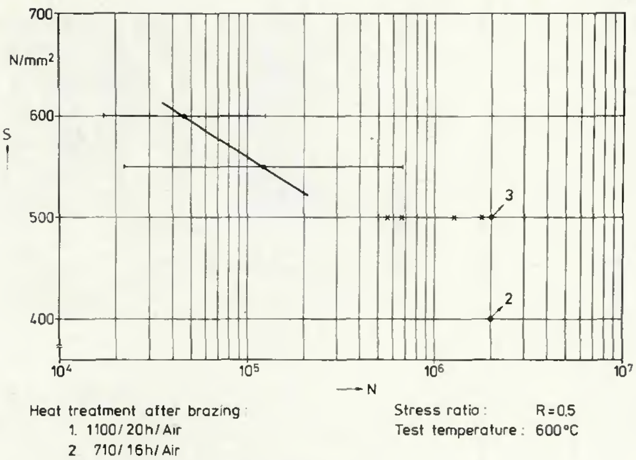


Fig. 5—S-N-curve for 600 C of brazed joints

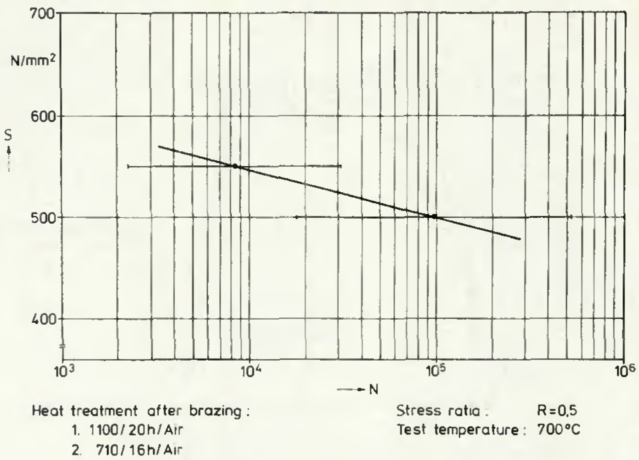


Fig. 6—S-N-curve for 700 C of brazed joints

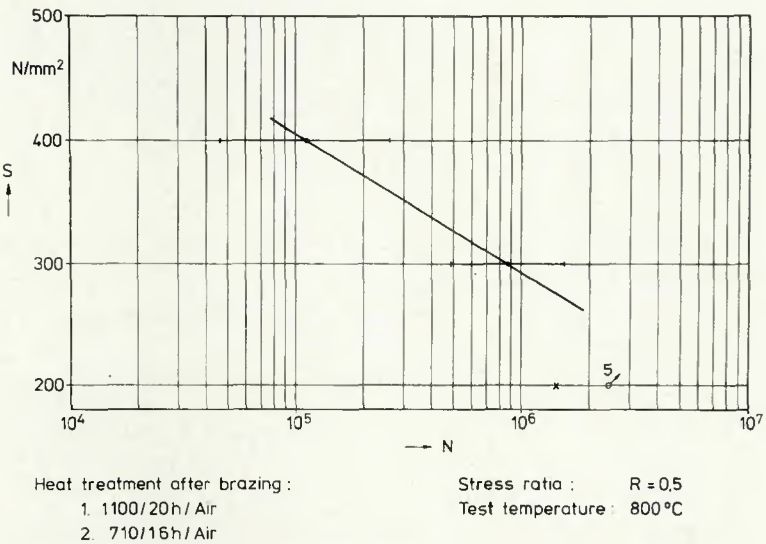


Fig. 7—S-N-curve for 800 C of brazed joints

of cycles to failure, e.g., 2 to 3 decades below the number of the other specimens at the same level. This fact suggested a detailed examination of the fracture surface to prove that these failures were caused by brazing faults at the edge of the specimens which acted like notches from where fatigue cracking started. Opened to the environmental gas attack in the furnace, they became visible by their oxidized surface.

In addition to this observation, the surface of the fracture specimens has been examined with SEM. Also, fracture surfaces, which did not show brazing faults at optical inspection (Fig. 9), contained more or less defects which need not be a separation or blow hole, as observed in Fig. 10.

By careful examination of the frac-

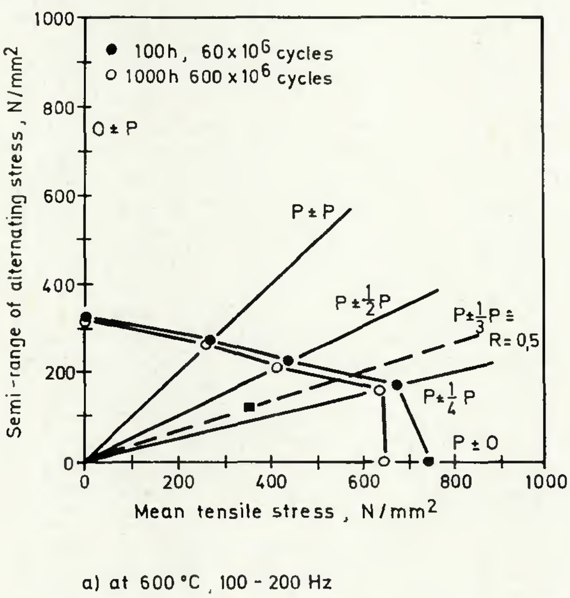
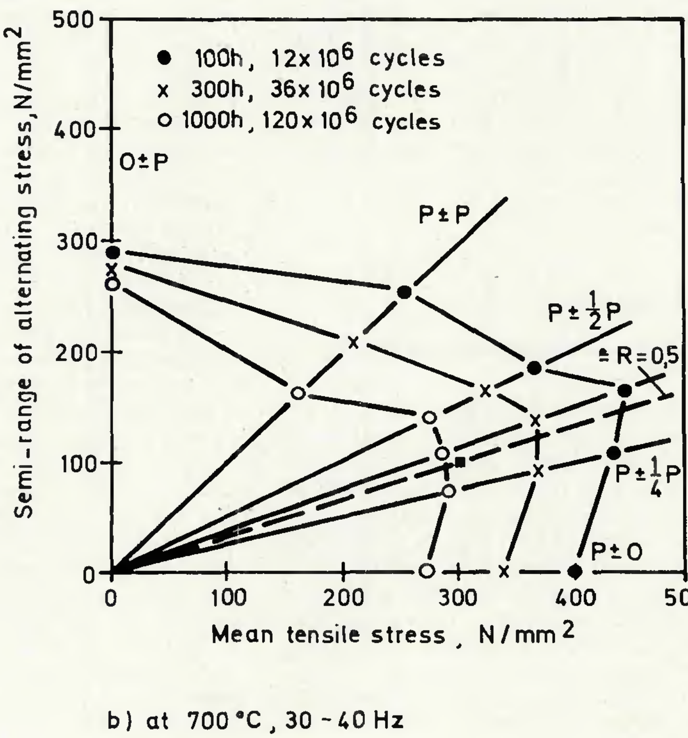


Fig. 8—Gerber's diagrams of Nimonic 80 A with fatigue life of brazed joints (2 × 10^6 cycles)



ture surface on fatigued specimens, a correlation could be shown between summarized fault area and cycles to failure—the larger the fault area, the lower fatigue life of the specimen. So the problem of fatigue behavior of brazed joints with this filler metal is predominantly determined by adhesive events within the filler metal; these events are caused by processing parameters as well as by the state of the braze alloy.

Investigation of Failure Mode

Observations made on filler metal fatigue fracture surfaces due to cycling at elevated temperatures correspond with the referred deformation and cracking behavior of nickel-base superalloys.[6,7] Crack initiation occurs mainly at microstructural defects on the polished surface of the specimen, on brazing faults in the cross section of

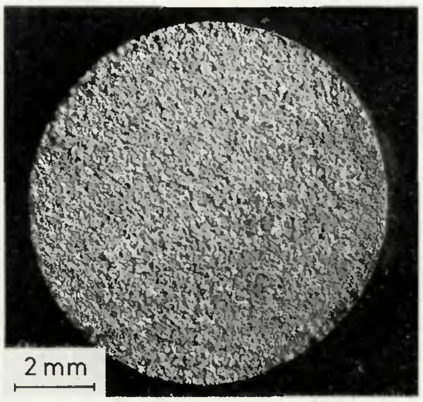


Fig. 9—Fracture surface of cycled specimen

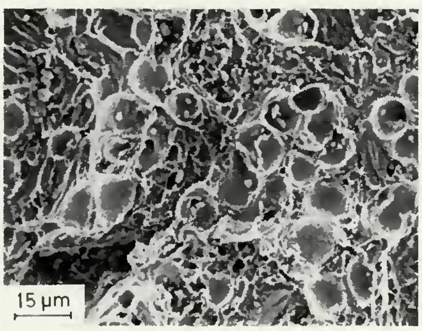


Fig. 10—Brazing fault on fracture surface

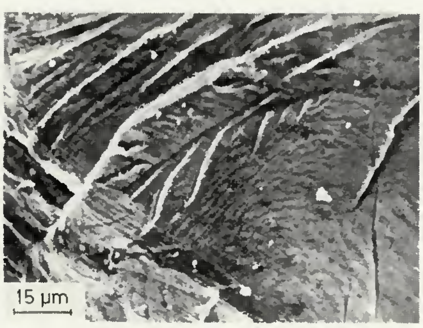


Fig. 11—Transgranular fatigue fracture

the seam, and on silicide inclusions within the filler metal. The different size of the defects determines the rates of both crack initiation and first propagation by which is caused the scattering range of fatigue life at different stress levels. It could be observed that crack initiation mostly occurred at microfaults in the seam due to the high stress concentration.

A crack may propagate transgranular or intergranular independently of the deformation mode. If intergranular initiation occurs "creep component" (which increases with increased temperature, hold time, and mean stress), transgranular cracking with the Stage I propagation mode (planar slip) is observed—Fig. 11. Sometimes even shear offsets appear on the transgranular fracture region—Fig. 12. Transgranular cracking in the Stage II propagation mode is produced by thermally or stress activated cross slip and climb eventually passing twin regions—Fig. 13. Finally intergranular crack propagation occurs with a rather faster rate up to overload failure—Fig. 14. The intergranular mode is widespread over the fracture surface supported by weak phases on grain boundaries at high temperatures.

Conclusion

The high temperature brazing of nickel-base superalloys with nickel-chromium filler metal appears to be a suitable process for practical application due to the tensile properties of the brazed joints, even at elevated temperatures. For this reason, the fatigue behavior of brazed Ni-20Cr-Ti-Al with BNi-5 filler metal at elevated temperatures was investigated, with a summary of results so far obtained as follows:

1. Fatigue life of this type of brazed joint can be effectively increased by postbraze heat treatment which can be combined with brazing and annealing procedure.
2. The fatigue strength of the brazed joints drops slowly with elevated temperature up to 800 C (1472 F).
3. The scattering of cycles to failure on the different stress levels and endurance life are predominantly influenced by brazing faults and microdefects which can be improved with optimum brazing procedure and filler metal.
4. Elevated temperature fatigue fracture of brazed joints has been observed in intergranular mode along grain boundaries as well as transgranular. The intergranular crack propagation mode is widespread on the fracture surface of the filler metal. Its initiation and propagation rate happens to be much faster than granular. The portion of intergranular fracture may be reduced by varied process parameters, metallurgical means, and/or certain treatments.

Acknowledgments

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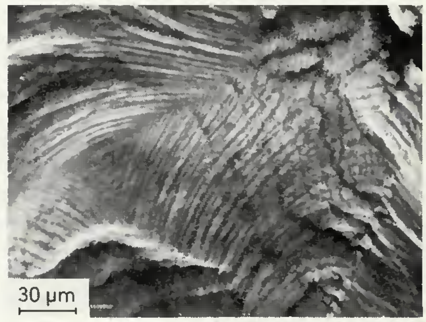

Fig. 12—Transgranular crack propagation

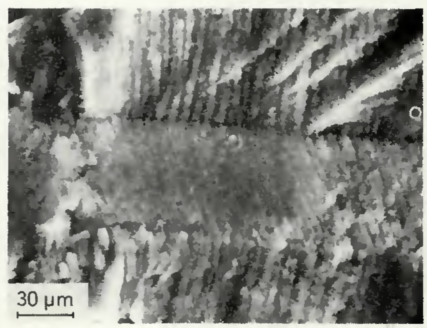

Fig. 13—Transgranular crack propagation

Fig. 14—Intergranular fatigue crack (top) and overload failure (bottom)

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