Properties of High Temperature Brazed NiCr20TiAl-PdNi40 Joints

Precise knowledge of the behavior of high temperature brazed joints as influenced by service conditions is mandatory for correct application

BY H.-D. STEFFENS AND H. LANGE

ABSTRACT. The dependence of joint properties on the structure and chemical composition of the brazing zone is demonstrated on Nimonic 80A alloy joints brazed with the palladium-base brazing filler metal PN1 (60 wt% Pd, 40 wt% Ni) under high vacuum by inductive heating.

The joints exhibit good mechanical properties and thermal characteristics, especially with respect to ultimate tensile strengths and fatigue behavior. Metallographic examinations and microprobe analysis show extensive diffusion at the joint interface during the brazing process. This mutual diffusion of alloying constituents directly results in a decrease of the melting point of the Nimonic alloy adjacent to the interface, so that melting occurs at the brazing temperature.

Long time annealing leads to an equilibrium composition between brazing filler metal and base metal. Furthermore the associated grain growth and the reduction in hardness as a result of diffusion processes causes a nominal decrease in mechanical strength. The influence of thermal treatments on tensile strength is clearly revealed in a short motion picture film, which shows a part of an investigation of temperature effects on tensile stressed micro-test specimens in a hot-stage microscope.

Introduction

The application of high temperature brazing in practice not only requires investigations of the mechanical properties but also must consider how the crystalline structure and chemical composition of the joint materials will influence these properties. This was revealed during investigations of brazed joints made of the heat resisting alloy Nimonic 80A joined with the high temperature brazing filler metal PN1 (Fig. 1).

Test Materials and Brazing Procedure

The base metal employed is a typical superalloy with excellent resistance to corrosion and good strength at elevated temperatures (Ref. 1). As a result of its contents of titanium and aluminum, which form the γ'-phase $Ni_3(TiAl)$, the alloy is artificial age hardenable. However, these alloying constituents necessitate special joining techniques. After solution heat treatment this superalloy is weldable by some methods. When there is a need to keep metallurgical influences to a minimum, high temperature brazing is called for. Therefore, Nimonic 80A was used for these investigations to show that vacuum brazing is a supplementary and sometimes the only satisfactory method for joining high alloy materials.

In the large field of high temperature brazing filler metals, the high-melting palladium-nickel-combination PN1, which has already proved suitable for joining other alloys, was selected (Ref. 2). As can be seen from the equilibrium phase diagram for Pd-Ni (Fig. 2), PN1 brazing filler metal freezes instantaneously to a homogeneous structure with fcc lattice (Ref. 3). This brazing alloy is characterized by a low vapor pressure and is therefore very suitable for high temperature brazing in vacuum.

The brazing procedure was carried out using an approved high frequency generator in high vacuum of 5×10^{-5} torr at 1290 C (Ref. 4). In order to have a minimum of thermal influence on the base metal structure, the brazing time was kept as short as possible.

Results and Discussion

Mechanical Properties Vs Test Temperature

Joints made of base metal Nimonic 80A and brazing filler metal PN1 exhibit good mechanical properties at

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elevated temperatures (Fig. 3). Typical test values show an ultimate tensile strength of about 100 daN/mm^2 (142 ksi) (see footnote) at room temperature, and at 500 C a tensile strength of 85 daN/mm^2 (120 ksi). In addition, the fatigue behavior is acceptable. For instance, with 100,000 load cycles for a 50% survival, the fatigue strength is 35 daN/mm^2 (50 ksi) at room temperature and 28 daN/mm^2 (40 ksi) at 500 C.

In all test specimens, the fatigue crack started in the braze metal, while propagation of the crack occurs partly in the braze and partly in the base metal adjacent to the interface. The fatigue properties of the joints primarily depend on the type of brazing filler metal.

Effects of Thermal Processing

In general, high temperature brazed joints find application in components at elevated service temperatures. These conditions, which usually apply over long periods of service, result in a forced equilibrium diffusion process of elements in the base metal and the brazing filler metal. Therefore, investigations were carried out to determine the effect of various heat treatments on joint properties.

Mechanical Strength Results. While the base metal properties may show an improvement as a result of precipitation hardening, the braze metal obviously suffers because of these heat treatments. Thus, with an annealing process of 1000 h at 800 C, the tensile strength of the brazed joints decreases by 20%. The fatigue behavior also diminishes as a result of the heat treatment (Fig. 4).

Crystalline Structure. As previously mentioned, the high temperature brazing filler metal is a homogeneous solid solution. The micrograph reveals this structure as the dark region (Fig. 5). However, the equilibrium state near to the interface, is disturbed due to the influence of mutual migration of elements of base metal and PN1 filler metal affecting the melting point of the base metal. The resulting molten zone, into which the grain boundaries of the Nimonic alloy encroach, corresponds to the light areas in the micrograph. The dark lines between the base metal and this region can be assumed to be the boundary of the molten zone.

After heat treatment at 800 C for 100 h, the diffusion process results in a balanced state, as is evident by the absence of discrete zones in the as-brazed micrograph. Furthermore, this annealing has left the base metal in a fully hardened state, which is revealed by the irregular dark coloration of the crystallites.

After 1000 h at 800 C, there is evidence of a tendency towards grain boundary diffusion, and precipitants are visible at the grain boundaries of the base metal. The micrograph shows a partial agglomeration inside the brazing gap. With chemical etchants, it is not possible to detect grain boundaries in the braze (Fig. 5).

However, with the use of hot-stage microscopy the grain formation can be observed (Fig. 6). At relatively low temperatures (800 C) the thermal etching process does not clearly

Base material	Brazing filler metal
Ni Cr 20 Ti Al (Nimonic 80A)	Pd Ni 40 (PN 1)
Bal. Ni 20,0 Cr <4,0 Fe 2,4 Ti 1,4 Al 0,06C	60Pd 40Ni Melting point: 1237 °C
Weight %	

Fig. 1 — Test materials

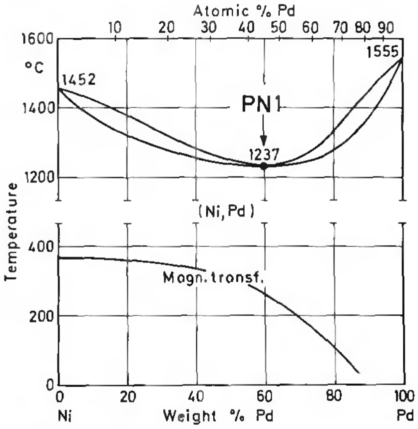

Fig. 2 — Palladium-nickel equilibrium diagram

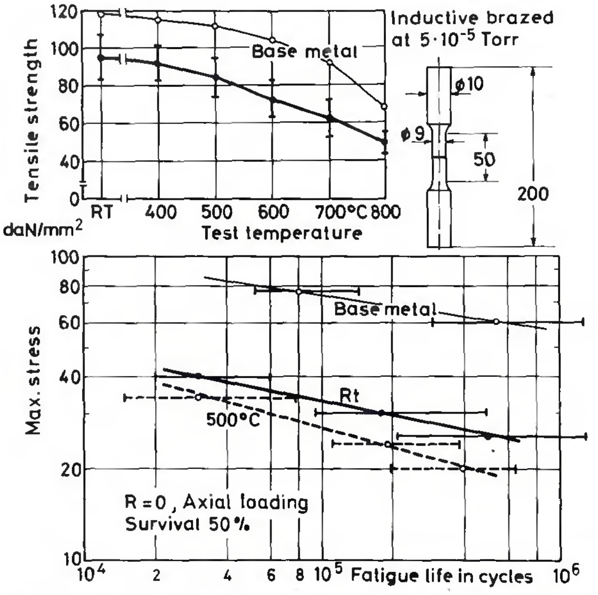

Fig. 3 — Mechanical properties of Nimonic 80A-PN1 brazed joints

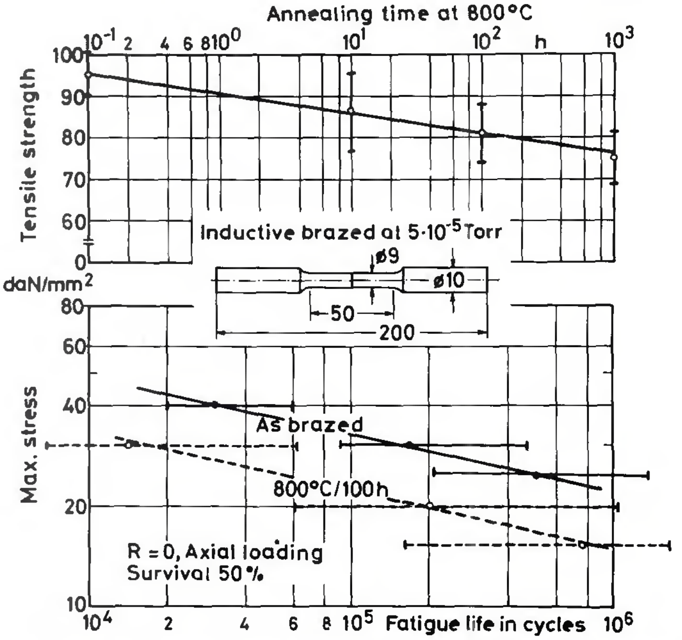

Fig. 4 — Mechanical properties of Nimonic 80A-PN1 brazed joints after heat treatment

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(The author uses the dekanewton daN for numerical convenience, although the SI suggests deka be avoided where possible — ed.)

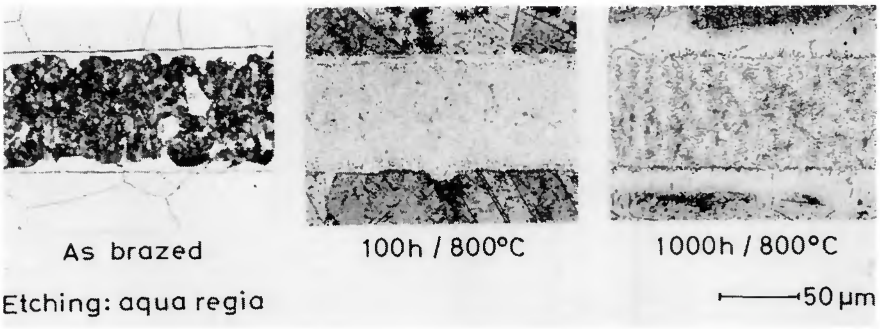


Fig. 5 — Micrographs of Nimonic 80A-PN1 brazed joints

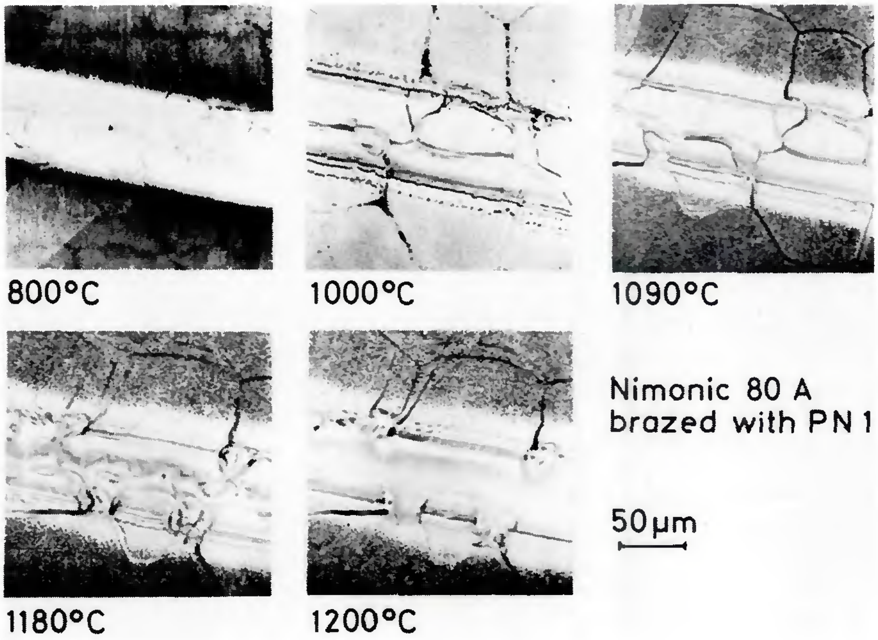
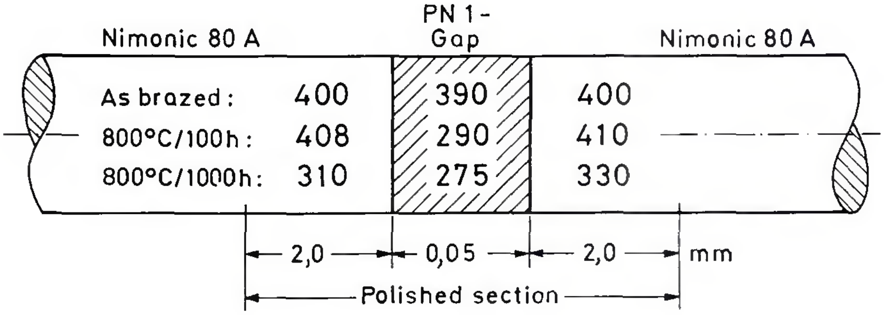


Fig. 6 — Thermal etching of a brazed joint



Mean hardness values indicated

Fig. 7 — Microprobe analysis of brazed joints

show this phenomenon; however, at higher temperature (up to 1000 C) the grain structure is distinctly revealed. It is of interest to note that the grain orientation in the brazing filler metal aligns itself with the crystalline structure in the base metal, to the extent that grain boundaries extend from one region to the other. It has been concluded that metallurgical compatibility between these materials is the reason for this growth pattern. On increasing the temperature to 1180 C, melting of the PN1 brazing filler metal starts to occur at grain boundary intersections, and finally, general melting occurs in the middle of the brazed gap.

The micrographs also show the grain growth in the palladium base brazing filler metal as a function of the increasing temperature. This is the main reason for the decrease in mechanical properties at elevated service temperatures.

Microprobe Analysis. In Fig. 7, it can be seen that during the brazing process, palladium diffuses to a depth of about 10 microns (0.0004 in.) into the Nimonic alloy. As a result of the high brazing temperature of 1290 C, in spite of the short brazing time, the concentration gradient decreases, with the palladium content in the middle of the gap dropping from 60% (PN1 composition) to 45%. On the other hand, nickel diffuses from the base metal into the braze metal.

This migration of elements in both directions produces Ni-Pd-alloys at the interface, with melting points near the brazing temperature. These new compositions account for the molten regions during the normal brazing process.

Annealing at 800 C for 1000 h leads to excessive diffusion, as evidenced in the palladium composition trace. Of particular importance in this system is the distribution of alloying elements titanium and aluminum in the base metal and brazing filler metal, before and after heat treatment. The precipitants γ'-phase $Ni_3(TiAl)$ have been shown to be the reason for the good mechanical behavior of Nimonic 80A. During heat treatment titanium and aluminum diffuse out of the base metal and lead to a weakening in this region. The result of long term annealing is a general decrease in microhardness (Fig. 8) in sympathy with the mechanical strength of the joints.

Microcinematographic Investigation

To show the influence of thermal structural changes on the joint mechanical strength, microcinematographic investigations were carried out (Refs. 5 and 6). In this film is presented the elastic and plastic behavior of the high temperature brazed Nimonic 80A-PN1 joints subjected to tension. As brazed, annealed at 800 C for 100 h, specimens, including those containing braze faults, were investigated at 500 C with a constant loading velocity of 8 mm/h.

The specimens which are provided with two opposed large-radius notches are uniformly pulled apart in a special tension device arranged in an atmosphere of highest-purity argon. The largest amount of deformation occurs at the smallest cross-section in which the braze gap, acting as a notch, is located. It is at this point that the strain behavior in the elastic and plastic ranges is cinematographically recorded up to fracture at approximately 500X magnification.

The first plastic deformations visible started in the base metal (Fig. 9a). The rupture occurs in the zones next to the interface of the brazing filler metal (Fig. 9b), depending on the heat treatment and braze faults.

Conclusions

With respect to high temperature brazed Nimonic 80A-PN1 joints, it has been shown that the brazing process involves considerable intermetallic diffusion, and that the mechanical strength of these joints is strongly influenced by postbraze heat treatments. In the present investigations, excessive grain growth and decrease in hardness in the brazing filler metal as a consequence of thermal treatments resulted in a marked decrease in joint mechanical properties.

It can be concluded for joints in other material combinations produced by the high temperature brazing process that optimum joint quality can only be obtained by a careful consideration of the service conditions such as type and magnitude of mechanical loading, service temperature and time, and the environment.

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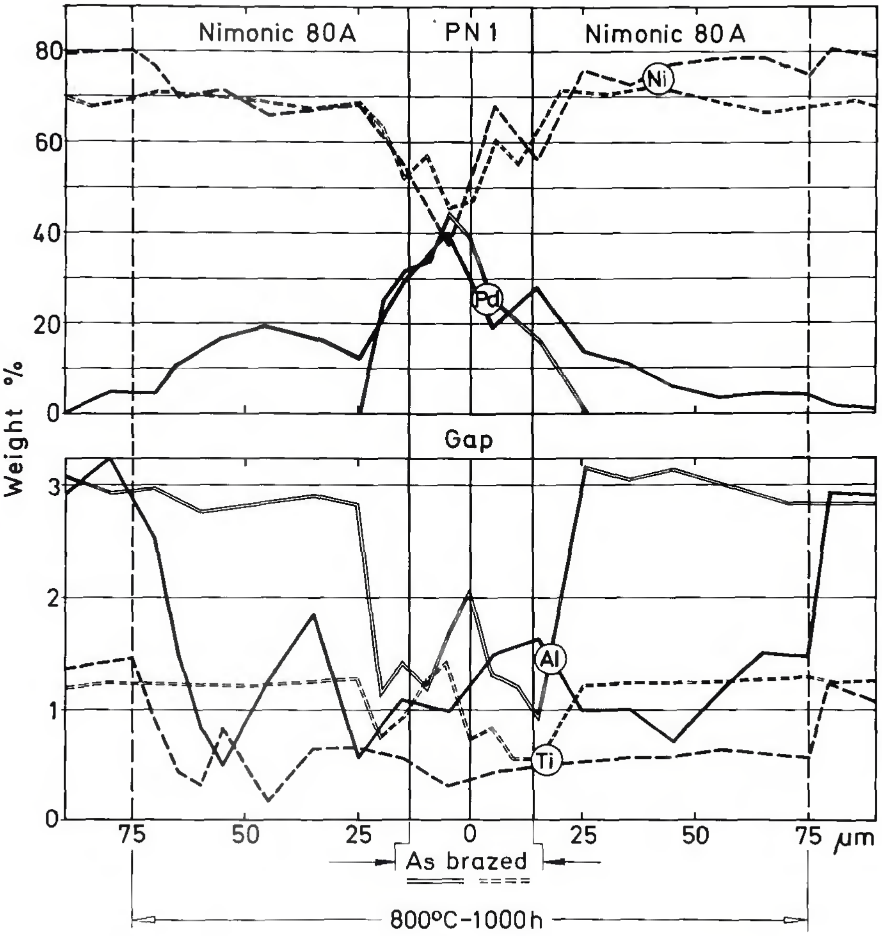

Fig. 8 — Micro-hardness of brazed joints ($HV_{0.1}$)

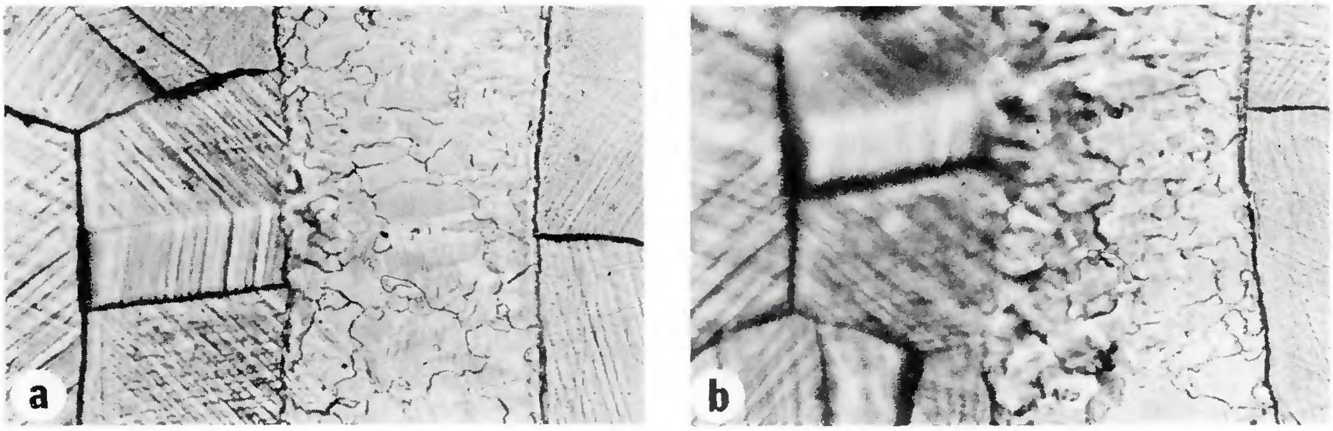

Fig. 9 — Micrographs of a tensile-stressed as-brazed Nimonic 80A-PN1-joint. Joint clearance 60 microns (0.0024 in.); test temperature 500 C; load direction horizontal

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"Submerged Arc Weld Hardness and Cracking in Wet Sulfide Service"

by D. J. Kotecki and D. G. Howden

This study was undertaken to determine:

(1) The causes of higher-than-normal hardness in submerged-arc welds in plain-carbon steels

(2) The levels of strength or hardness which will not be susceptible to sulfide-corrosion cracking

(3) Welding procedures which will assure that nonsusceptible welds will be produced.

Concentration is primarily on weld metal, though some consideration to the weld heat-affected zone is given. The study covered a two-year period. The first year was concerned with a macroscopic view of the weldments. In that first-year study, some inhomogeneities were observed in weldments which are not obvious in a macroscopic view of the weldment. It appeared likely that these inhomogeneities could affect the behavior of the weldment in aqueous hydrogen-sulfide service. Accordingly, their presence and effects were investigated during the second year.

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WRC Bulletin
No. 185
July 1973

"Improved Discontinuity Detection Using Computer-Aided Ultrasonic Pulse-Echo Techniques"

by J. R. Frederick and J. A. Seydel

The purpose of this project, sponsored by the Pressure Vessel Research Committee of the Welding Research Council, was to investigate means for obtaining improved characterization of the size, shape and location of subsurface discontinuities in metals. This objective was met by applying computerized data-processing techniques to the signal obtained in conventional ultrasonic pulse-echo systems. The principal benefits were improved signal-to-noise ratio and resolution.

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