High Temperature Brazing of Stainless Steel with Nickel-Base Filler Metals BNi-2, BNi-5 and BNi-7

Best results in Type 316 stainless steel butt joints are obtained when brazing with BNi-2 and BNi-5 filler metals is followed by heat treatment

BY E. LUGSCHEIDER AND K.-D. PARTZ

Introduction

The improved application of high temperature brazing (HTB) with nickel filler metals requires an exact knowledge of the dependence of brazed joint quality on the processing variables. These include brazing time, temperature, joint clearance, and heat treatment conditions.

A systematic investigation was undertaken with respect to the effects of these variables when joining Type 316 stainless steel using typical nickel-based filler metals. Three groups of filler metals were studied:

1. Phosphide stabilizing BNi-7.
2. Silicide-boride stabilizing BNi-2.
3. Boron and phosphorus-free BNi-5.

A wedge gap specimen for metallurgical investigation was developed to define the effects of brazing conditions and joint clearances on joint quality. Using two different brazing times, the influence of joint clearance on the stabilization of brittle phases in brazed joints was determined at the recommended brazing temperature ranges for the BNi-2, BNi-5 and BNi-7 filler metals. The improvement in brazed joint quality resulting from postbraze heat treatment was also tested, using time-temperature-braze cycles in combination with different heat treatment cycles.

The results of metallurgical investigations showed good correlation to fracture loads and tensile strengths of brazed butt joints. It was reasoned that a knowledge of the dependence of brittle phase stabilization on brazing cycles and joint clearance would make it possible to characterize HTB systems with regard to joint quality and strength.

Influence of Brazing Time, Temperature, and Clearance on Braze Quality

Investigation of the metallurgical behavior of Type 316 stainless steel when brazed with BNi-2, BNi-5, and BNi-7 filler metals involved an assessment of the braze structure. Using a resistance heated brazing vacuum furnace and a vacuum lower than 1.33×10^{-2} Pa (1×10^{-4} torr), it had been shown that maximum tensile strengths could be expected with joint clearances up to 100 μm, i.e., 0.004 in. (Ref. 1, 2, 3). Using a wedge gap specimen with 0 to 100 μm (0 to 0.004 in.) gap tapering and various brazing cycles, clearances were determined where damaging hard phases were not

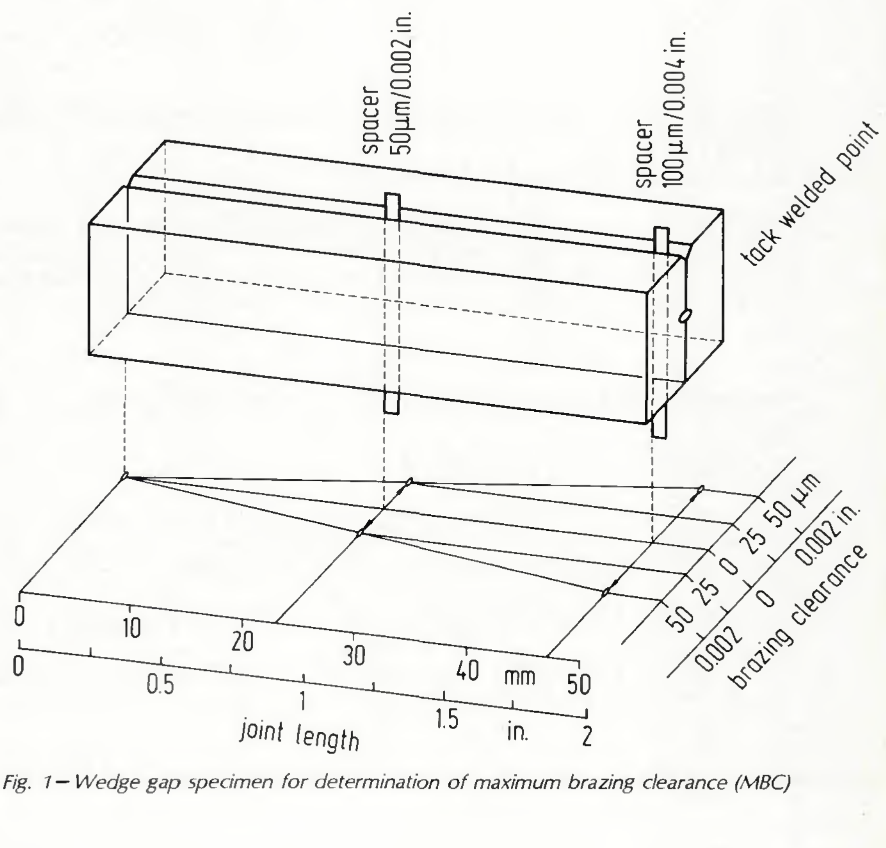

Fig. 1 — Wedge gap specimen for determination of maximum brazing clearance (MBC)

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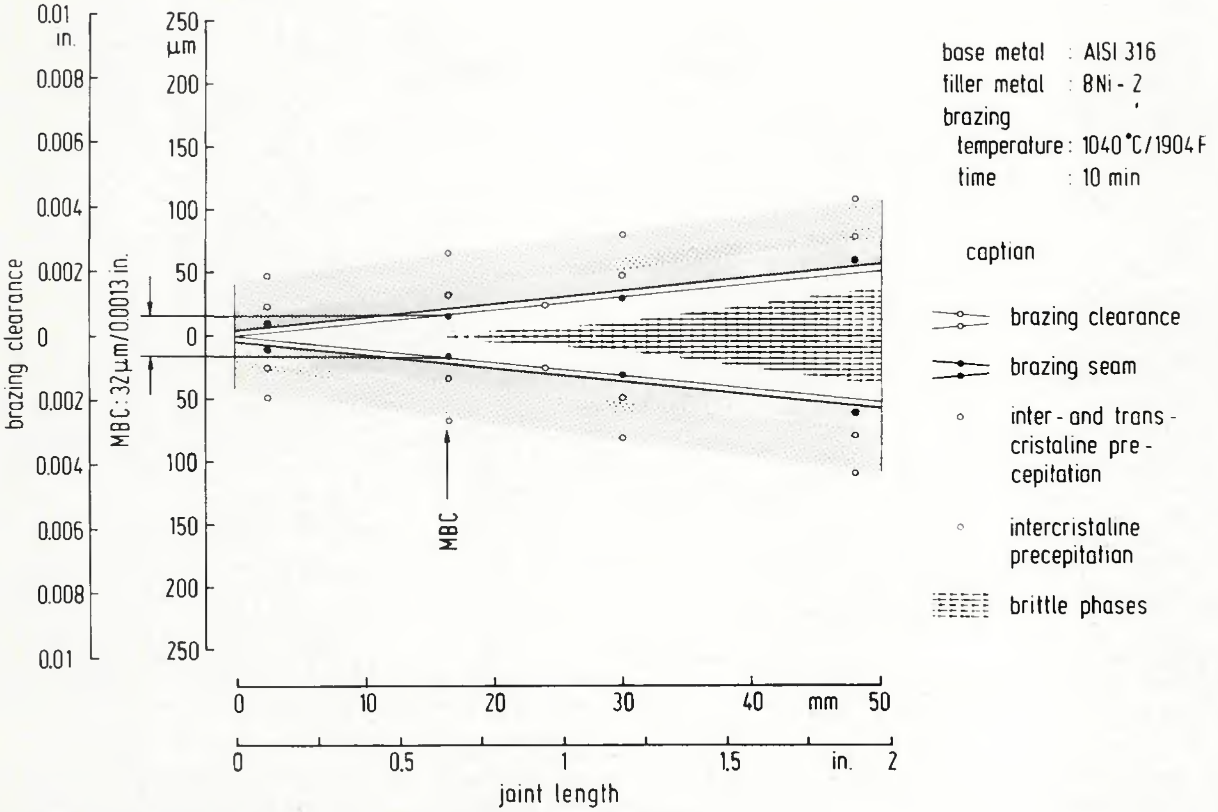

Fig. 2 — Wedge gap diagram with MBC at the beginning of brittle phase stabilization

observed in the braze.

Figure 1 shows the schematic for a prepared wedge gap specimen. The specimen consists of two spacers (one in the middle and one at the end) to set the gap while tack welding. The projection shows how the braze joint clearance can be calculated at any cross section through the specimen.

Using the projection of Fig. 1 at suitable magnifications, the degree of brittle phase stabilization is shown in a wedge gap diagram for a given set of brazing conditions — Fig. 2. In the wedge gap diagram, a distinction is made between areas free of brittle phases (white) and brittle phases containing seam sections (hatching). The beginning of brittle phase

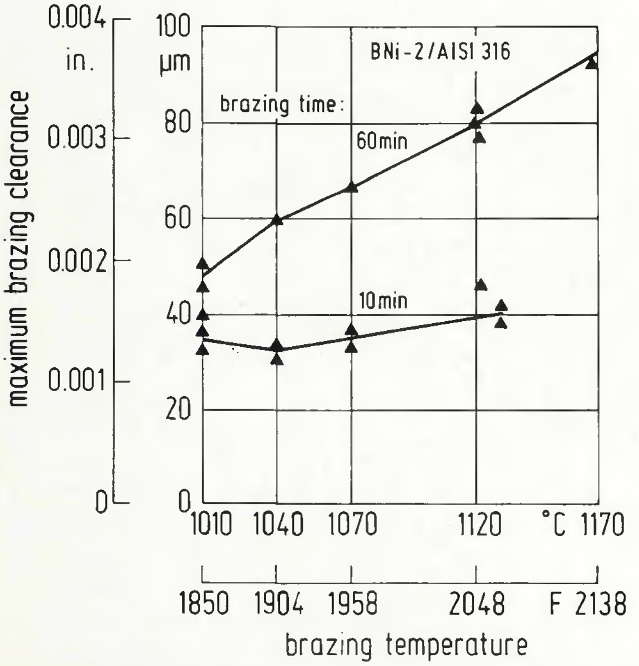

Fig. 3 — Dependence of MBC on brazing temperature and time for the BNi-2/Type 316 stainless steel brazing system

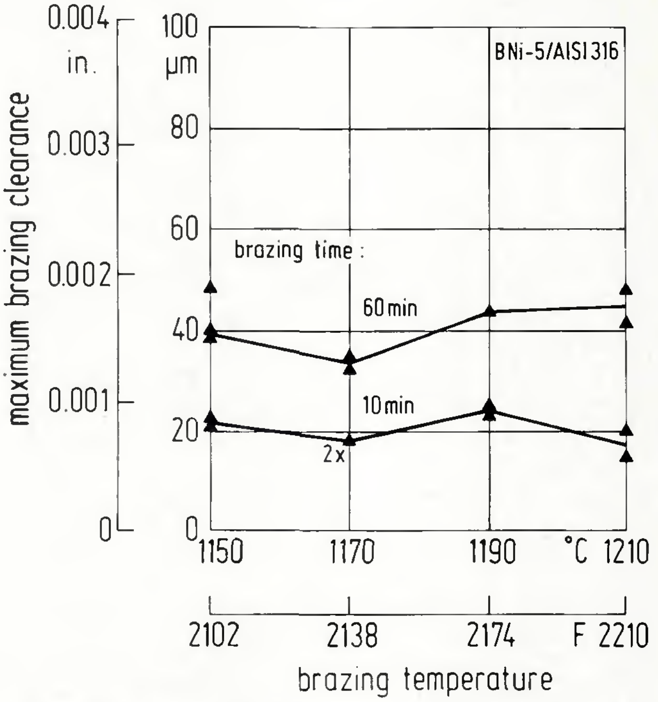

Fig. 4 — Dependence of MBC on brazing temperature and time for the BNi-5/Type 316 stainless steel brazing system

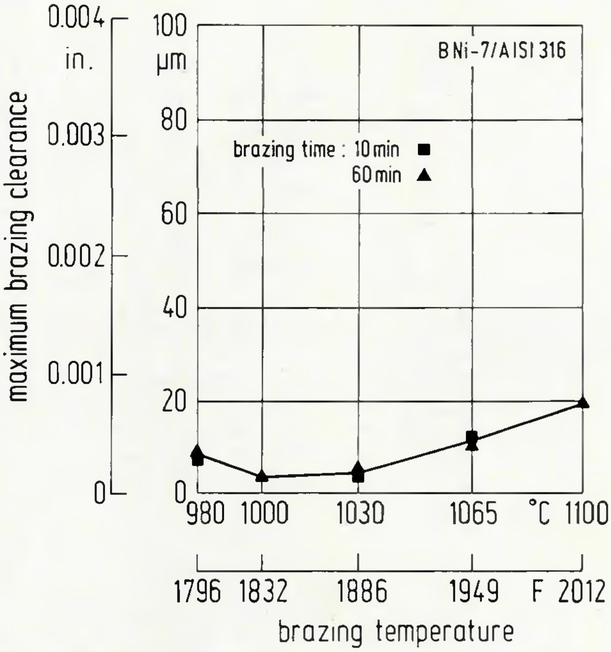

Fig. 5 — Dependence of MBC on brazing temperature and time for the BNi-7/Type 316 stainless steel brazing system

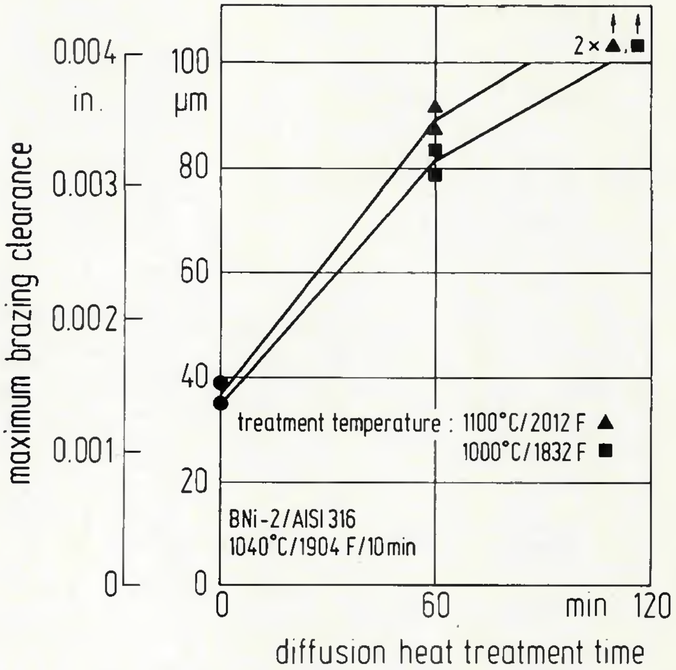

Fig. 6 — Improvement in MBC by heat treatment of Type 316 stainless steel joints brazed with BNi-2 filler metal for 10 min at 1040°C (1904°F)

stabilization marks the maximum brazing clearance (MBC) of the investigated steel filler metal combination for a given set of brazing conditions. The MBC is 32 µm (0.0013 in.) for the case illustrated in Fig. 2.

MBC dependence on brazing temperature was investigated in 30 and 50°C (54 and 90°F) steps, using two brazing times, i.e., 10 and 60 minutes (min), and using BNi-2, BNi-5 and BNi-7 filler metals to braze Type 316 stainless steel joints — Figs. 3, 4 and 5. All three illustrations indicate that brazing variables have a distinct influence on the stabilization of brittle phases and on joint strength.

In the temperature range investigated, the MBC for filler metal BNi-2 increases from about 50 µm (0.002 in.) to about 100 µm (0.004 in.) at a brazing time of 60 min and leads to a maximum MBC of about 40 µm (0.0015 in.) at a brazing time of 10 min. This means that stainless steel joints brazed with BNi-2 at a temperature of 1040-1070°C (1904-1958°F), as normally used in Europe, may have widely varying joint strengths if clearances range from 30 to 60 µm (0.0013 to 0.0022 in.), depending on brazing time.

The high sensitivity of BNi-5 joints to small brazing condition variations may be explained by the MBC decreasing from 50 µm/0.002 in. at 1190°C (2174°F) in 60 min to about 30 µm/0.012 in. at 1170°C (2138°F) in 60 min. This is a temperature difference of 20°C (36°F). Even the temperature of 1150°C (2102°F) results in MBCs of 45 µm (0.0019 in.). As with the MBC characteristic of BNi-2 brazed joints, the improvement of brazed joint quality at BNi-5 brazed joints using a longer brazing time, i.e., 60 min, is evident.

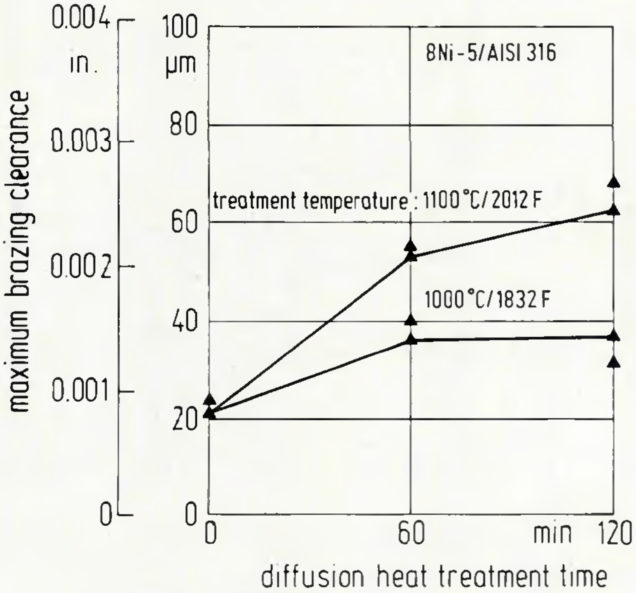

Fig. 7 — Improvement in MBC by heat treatment of Type 316 stainless steel joints brazed with BNi-5 filler metal for 10 min at 1190°C (2174°F)

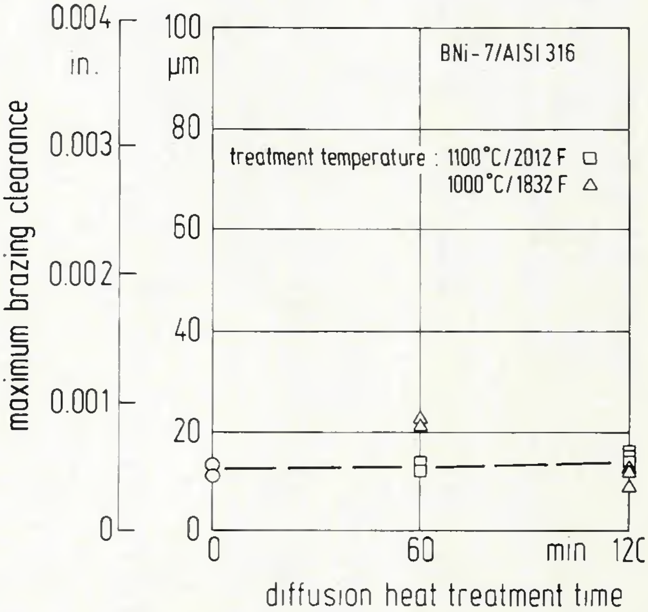

Fig. 8 — Change effected in MBC by heat treatment of Type 316 stainless steel joints brazed with BNi-7 filler metal for 10 min at 1065°C (1949°F)

Stainless steel joints, when brazed with BNi-7, provided a MBC of less than 10 μm (0.004 in.) over a wide temperature range. The elimination (by diffusion) of brittle phosphides resulting from the high phosphorus content of the filler metal is very difficult; increasing the diffusion time from 10 to 60 min does very little to decrease brittle phases.

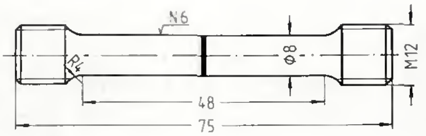

Fig. 9—Schematic of brazed butt joint tensile specimen (Ref. 6)

Improvement of Braze Properties by Heat Treatment

Figures 6, 7 and 8 depict the improvement in MBC that occurred when stainless steel joints brazed with BNi-2, BNi-5 and BNi-7 underwent heat treatment. The joints were first brazed at standard brazing temperatures for the three filler metals, i.e., 1040°C (1904°F) for BNi-2, 1190°C (2174°F) for BNi-5, and 1065°C (1949°F) for BNi-7. Heat treatment was then carried out at 1000°C (1832°F) and 1100°C (2012°F) for 60 and 120 min, respectively, in a resistance heated vacuum furnace with vacuum pressure lower than 1.33×10^{-2} Pa (1×10^{-4} torr).

An improvement in brazed joint metallurgy was demonstrated when brazing Type 316 stainless steel with BNi-2 and BNi-5 filler metal. Starting with an MBC of about 40 μm (0.0015 in.) in the BNi-2/Type 316 stainless steel brazing system and the previously described brazing conditions, an increase of MBC up to 80 μm (0.003 in.) at a heat treatment time of 60 min was found. This was nearly independent of heat treat temperature. A heat treatment time of 120 min leads to maximum brazing clearances of 100 μm (0.004 in.) and more. By comparing the time-temperature combinations of 1040°C (1904°F) at 10 min and 1000°C (1832°F) at 60 min for a MBC of 80 μm (0.003 in.) to 1040°C (1904°F) at 60 min for a MBC of 60 μm (0.0022 in.), it becomes evident that there is a possibility of achieving a better braze ("brazing seam" in Fig. 2) quality by using lower thermal stress in the base metal; this includes a lower grain growth and a higher load resistance.

Stainless steel joints brazed with BNi-5 filler metal at 1190°C (2174°F) for 10 min showed marked improvement in quality when heat treated. This improvement in quality was distinctly temperature-dependent. This was in contrast to similar BNi-2 joints.

The best postbraze heat treatment temperature for BNi-5 was found to be 1100°C (2012°F). A heat treatment time of 60 min leads to about 55 μm (0.002 in.) and a heat treatment time of 120 minutes to about 65 μm (0.0025 in.) MBC. The improvement of the qualities of the joint by a heat treatment temperature of 1000°C (1832°F) is comparatively low—Fig. 7.

Figure 8 shows that there is almost no improvement in quality when stainless steel joints brazed with BNi-7 are heat treated after brazing. The small MBC of the joints after heat treatment is nearly the same as in the as-brazed condition. Only heat treatment at 1100°C (2012°F) for 60 min results in a MBC of about 20 μm (0.0008 in.). These results help explain problems encountered in eliminating the brittle hard phases in high phosphorus alloy diffusion.

Tensile Strength Test Results

Brazed butt joint tensile specimens with parallel brazing clearances were tested to verify metallurgical findings. Tensile testing was carried out using the specimen illustrated in Fig. 9, and the tensile strengths of brazed butt joint specimens with parallel gaps of various brazing clearances are shown in Figs. 10 to 13. Also shown in Figs. 10 to 13 are the ultimate tensile strength of Type 316 stainless steel after different brazing heat treatments and the corresponding MBCs in a range of ± 10 μm (0.0004 in.).

A dotted area in Fig. 10 depicts an MBC of about 80 μm (0.003 in.) for two conditions: brazing at 1040°C (1904°F) for 10 min and heat treatment at 1000°C (1832°F) for 60 min; this is in keeping with the MBC characteristic for BNi-2 brazed joints indicated in Fig. 6. The tensile

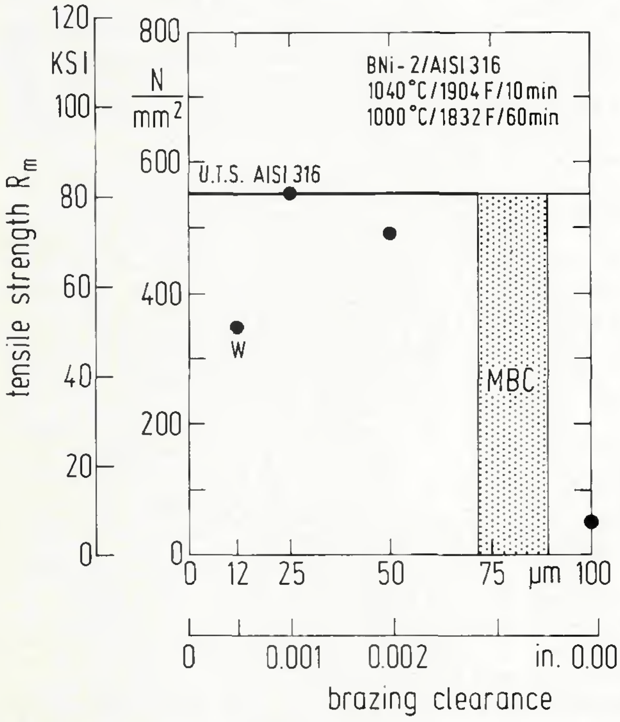

Fig. 10—Tensile strength test results obtained with the BNi-2 filler metal/Type 316 stainless steel butt joint specimen brazed at 1040°C (1904°F) for 10 min followed by heat treatment for 60 min at 1000°C (1832°F). W denotes wetting defect

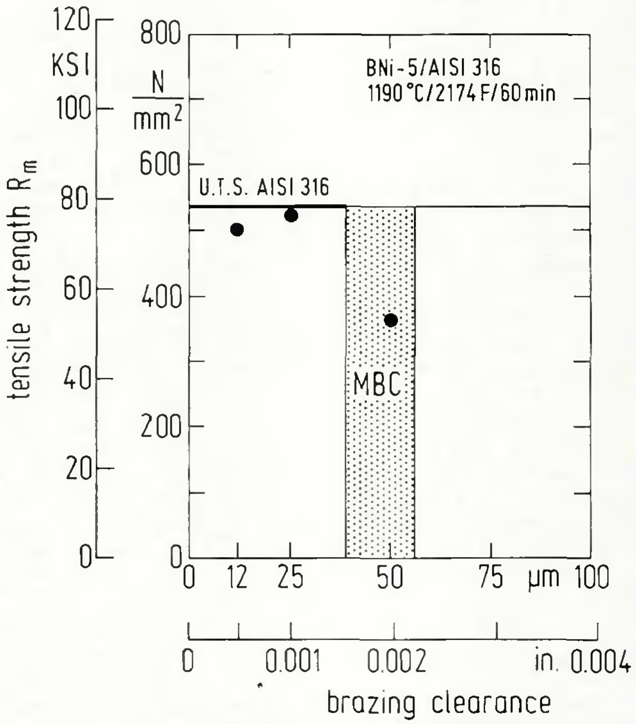

Fig. 11—Tensile strength test results obtained with the BNi-5 filler metal/Type 316 stainless steel butt joint specimen brazed at 1190°C (2174°F) for 60 min

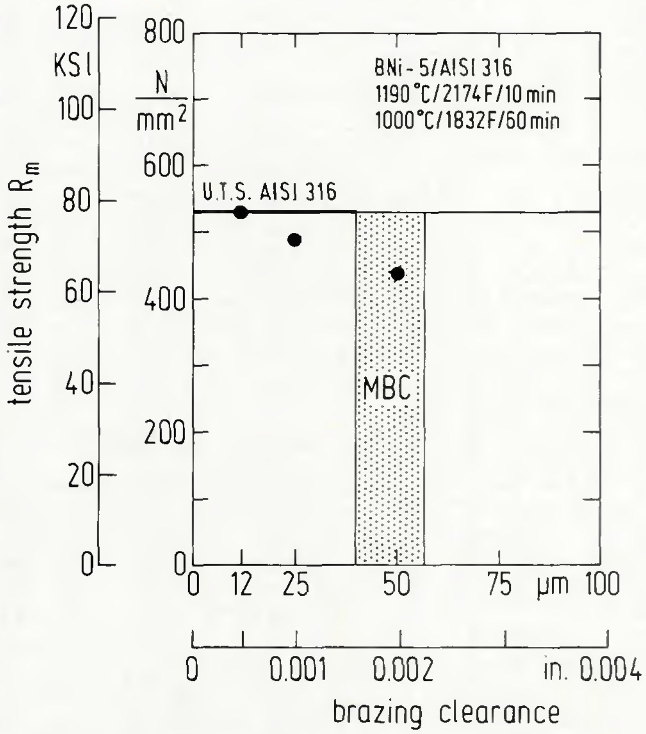

Fig. 12 — Tensile strength test results obtained with the BNi-5 filler metal/Type 316 stainless steel butt joint specimen brazed at 1190°C (2174°F) for 10 min followed by heat treatment at 1000°C (1832°F) for 60 min

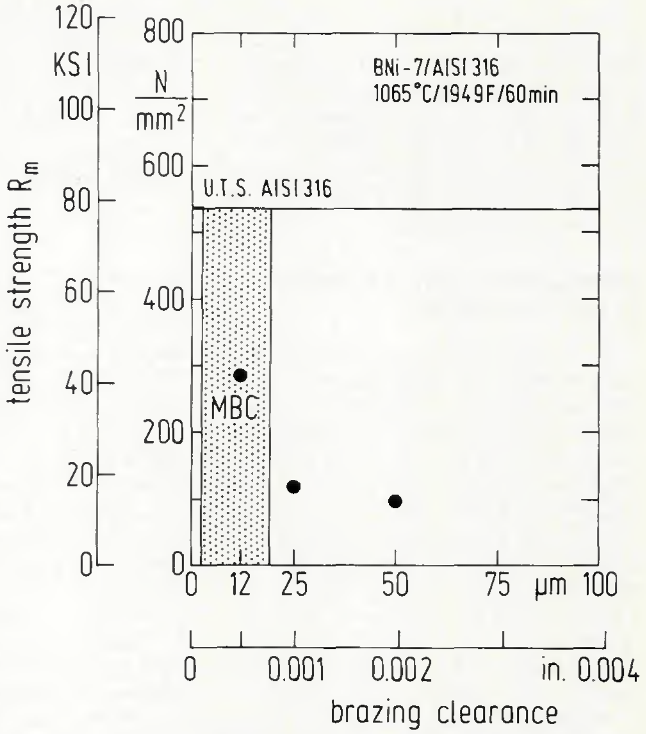

Fig. 13 — Tensile strength test results obtained with the BNi-7 filler metal/Type 316 stainless steel butt joint specimen brazed at 1065°C (1949°F) for 60 min

strength test results shown in Fig. 10 indicate that joints brazed using the same brazing/heat treatment conditions with a clearance below the MBC have a joint strength close to the ultimate tensile strength of the base metal. Higher brazing clearances than the MBC lead to low load resistance because of the hard phases contained in the braze.

The same relationship between MBC and tensile strength and MBC is shown in Figs. 11 and 12 for stainless steel joints brazed with BNi-5 filler metal under different brazing conditions. The BNi-5 brazed specimens with a brazing clearance lower than the MBC provided tensile strengths similar to the ultimate tensile strength of the base metal. A specimen brazed with a clearance of 50 µm (0.002 in.), i.e., close to the MBC, failed at lower fracture loads. In these instances, the strength was lowered by brittle hard phases in the braze.

Figure 13 shows that low tensile strengths were obtained when brazing stainless steel joints with BNi-7 filler metal; this confirmed the MBC characteristic determined for the same brazing conditions shown in Fig. 4.

Summary

Type 316 stainless steel joints brazed with BNi-2, BNi-5 and BNi-7 filler metals were investigated to determine the effects of brazing temperature, time, postbraze heat treatment, and brazing clearance on metallurgical quality and tensile strength. Brazed joint metallurgical investigations were carried out using a wedge gap specimen with a continuous, increasing clearance ranging from 0 to 100 µm (0 to 0.004 in.).

Maximum brazing clearances (MBCs) were determined for the following temperature ranges at 10 and 60 minute brazing times:

1. For BNi-2 filler metal — 1010 to 1175°C (1805 to 2147°F).
2. For BNi-5 filler metal — 1150 to 1210°C (2102 to 2210°F).
3. For BNi-7 filler metal — 980 to 1095°C (1796 to 2003°F).

Following the brazing of stainless steel joints for 10 minutes with BNi-2 filler metal at 1040°C (1904°F) and BNi-5 filler metal at 1190°C (2174°F), postbraze heat treatments at 1000°C (1832°F) for 60 minutes and at 1100°C (2012°F) for 120 minutes led to satisfactory improvements in joint quality, thereby implying an increase in MBC. Stainless steel joints brazed with BNi-7 filler metal were characterized by low MBCs, even when given postbraze heat treatment.

Metallurgical results defining the MBCs for the investigated filler metal/base metal combinations and brazing conditions were confirmed by the results of tensile strength tests carried out on brazed butt joints.

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