Spreading and Aggressive Effects By Nickel-Base Brazing Filler Metals on Stainless Steel

Little difference in wettability was observed in the stainless steels tested, but more aggressive penetration was evident in unstabilized AISI-304 than in stabilized AISI-321

BY I. AMATO, F. BAUDROCCO, AND M. RAVIZZA

ABSTRACT. Nickel-base materials provide a wide variety of brazing filler metals to meet many needs due to their mechanical, heat, and corrosion resistance properties. The characteristics of the nickel-base brazing filler metals differ mainly in the alloying elements added to promote spreading and wettability.

The wettability and the aggression of five nickel-base brazing filler metals on stabilized (AISI-321) and unstabilized (AISI-304) stainless steels have been determined.

The brazing filler metals BNi-1 and -2 have shown good spreading and high grain boundary diffusion properties. The BNi-5 and the Ni-Mn-Si-Cu filler metals have shown good wettability but poor solid solution diffusion properties, and the BNi-7 filler metal has shown good spreading and bonding properties. The unstabilized carbon content present in the stainless steel can enhance the agression of the nickel-base brazing filler metals.

Introduction

Brazing is assuming an ever increasing role in the manufacture of hardware utilized in different fields (aircraft, marine, military, nuclear, etc.). The severe service conditions have required the development of special nickel-base brazing filler metals[1–3] because of the good strength and corrosion resistance of these nickel alloys at high temperatures.

The alloying elements (silicon, boron, phosphorus, copper, etc.), added to the nickel in order to lower its melting point and to promote wettability, have also brought increased aggression by the brazing filler metal in the form of diffusion into and erosion of the base metal.[4–6]

I. AMATO is a Professor in Material Science, F. BAUDROCCO is Chief of the Metallography Laboratory, and M. RAVIZZA is Chief of the Heat Treatment Laboratory, at Fiat Sezione Energia Nucleare, Italy.

Paper to be presented at the Second International AWS-WRC Brazing Conference in San Francisco, Calif. during April 27-29, 1971.

At the present time, many nickel-base brazing filler metals are available. The determination of their wettability and their damaging effects on base metals, as a result of solution or penetration, is very important in choosing commercially available brazing filler metals for a given application. Although the nickel-base brazing filler metals are now widely used by the aircraft industry, where brazing of thin sections is a common practice, little information is available about the physical metallurgy of these brazing materials. The investigation reported here gives information on the physical properties and metallurgical change induced by five different nickel-base brazing filler metals on two stainless steels, i.e. AISI-304 and AISI-321.

Materials and Experimental Procedures

The base metals chosen for the investigation are AISI-304 and AISI-321 stainless steel. The chemical composition of these materials is shown in Table 1. The two stainless steels were chosen in order to investigate the influence of different forms of carbon content (stabilized and unstabilized) on the aggressive effects of the brazing filler metals.

The five different nickel-base brazing filler metals were chosen in order to investigate the influence of alloying additions that have different diffusion rates on wettability and aggression. The chemical compositions of the brazing filler metals are shown in Table 2.

A fixed amount (by weight) of filler metal was placed on a plate of the base metal. The spreading and aggression determinations were carried out at different brazing temperatures and times, heating the specimens under a vacuum in the order of 10^{-4} Torr. The brazing temperatures were chosen in the brazing range of each filler metal; after each heat treatment, the drop enlargement and the penetration of the filler metals were measured at the center of the drop. The summarized results are the average value of four determinations.

Results and Discussion

The results of the spreading determinations are summarized in Figs. 1 and 2.

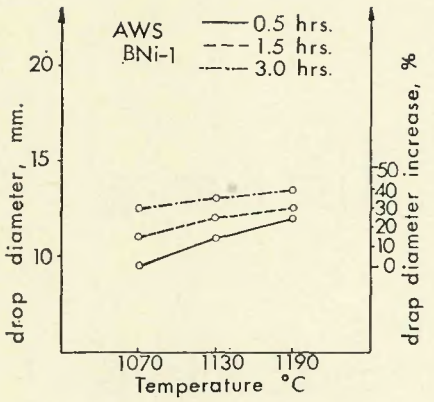
For BNi-1, it may be seen that increasing the brazing temperature and the soaking time produces a regular increase in the drop enlargement. Drop enlargements of 20–40% of the initial values show that the filler metal

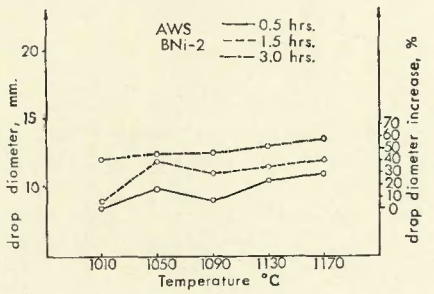
Table 1—Chemical Compositions of Base Metals, %

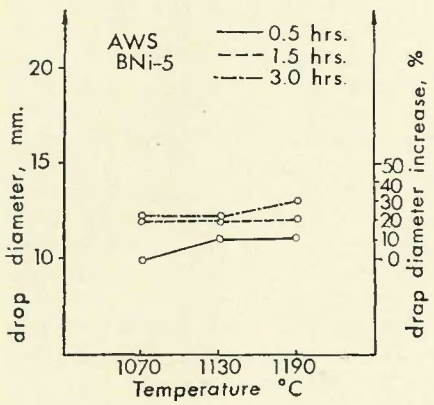
	C	Mn	P	S	Si	Cr	Ni	Ti
AISI 304	0.08	2.0	0.045	0.03	1.0	18–12	8–12	
AISI 321	0.08	2.0	0.045	0.03	1.0	17–19	9–12	5 × C min, 0.70 max

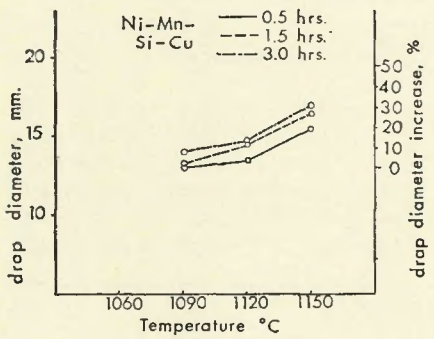
Table 2—Nominal Chemical Compositions of Brazing Filler Metals, %

Filler Metal	C	Fe	Mn	Si	Cu	Ni	Cr	P	B
AWS BNi-1	0.70	4.5	—	4.5	—	72.8	14.0	—	3.5
AWS BNi-2	0.06	2.5	—	4.5	—	83.5	6.5	—	3.0
AWS BNi-5	0.10	—	—	10.0	—	70.9	19.5	—	—
Ni-Mn-Si-Cu	—	—	23.0	7.0	5.0	65.0	—	—	—
AWS BNi-7	0.10	—	—	—	—	76.9	13.0	10.0	—









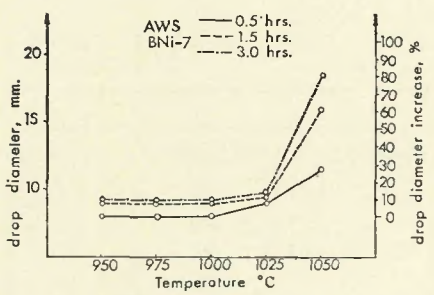


Fig. 1—Spreading measurements. Base metal—AISI 304 stainless steel

has good spreading properties for the two stainless steels under investigation.

The BNi-2 filler metal has a wider brazing temperature range than that of BNi-1. The spreading results show that maximum drop enlargement is reached at low temperatures in the brazing range. The spreading properties of these filler metals (20-60% of the initial value) are good for brazing applications.

In the BNi-5 filler metal, the presence of silicon as an alloying element instead of boron gives less spreading (i.e., wettability) than the BNi-1 and -2 filler metals. In fact, the drop enlargement for this filler metal in the brazing range is in the order of 10-30% of the initial drop value. The brazing filler metal Ni-Mn-Si-Cu shows spreading properties similar to BNi-5.

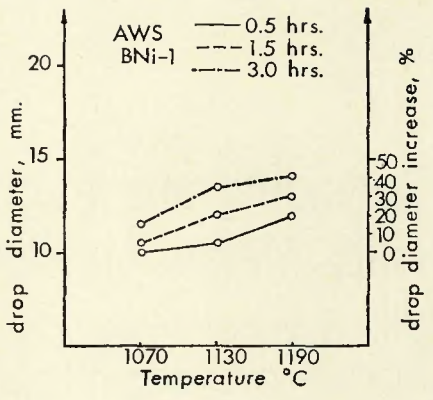
BNi-7 shows the highest drop enlargement among the brazing filler metals under investigation. It is interesting to observe that the wettability of this filler metal is enhanced through heat treatment at the maximum brazing temperature. In this case, a drop enlargement in the order of 60-80% of the initial drop value has been obtained. This particular behavior must be attributed to the presence of phosphorus as an alloying element.

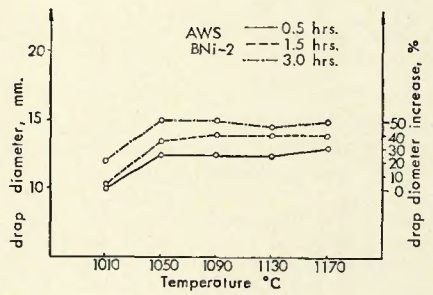
Concerning the aggressive effects, Figs. 3 and 4 summarize the results obtained. The aggression of the base metal by the brazing filler metals occurs through the mechanism of diffusion and erosion.[7] The diffusion begins through the migration of interstitial atoms, i.e., atoms of relatively small atomic radii, present in the filler metals. This migration occurs through the grain boundaries of the base metal and is called grain boundary diffusion.

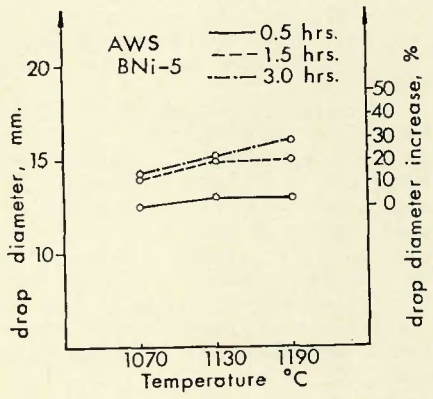
The elements of relatively large atomic radii diffuse at a slower rate in the lattice of the base metal grains along the entire interface region. This migration, which involves the formation of an interfacial solid solution, is called solid solution diffusion. The dissolution of the solid base metal by the molten brazing filler metal is called erosion.

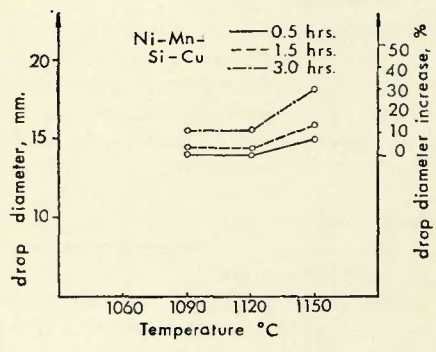
For BNi-1, a large grain boundary diffusion of the alloying element, in this case boron, in the base metal can be observed (Fig. 5). The molten filler metal undergoes an eutectoid decomposition with formation of intermetallic compounds and solid solution. It is possible to see that the filler metal-base metal interface shows a great impoverishment of the alloying elements. The grain boundary diffusion is enhanced in unstabilized stainless steel.

For BNi-2, a large grain boundary









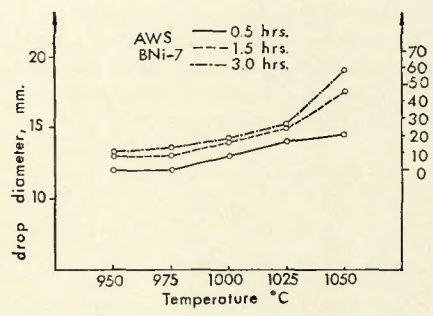


Fig. 2—Spreading measurements. Base metal—AISI 321 stainless steel

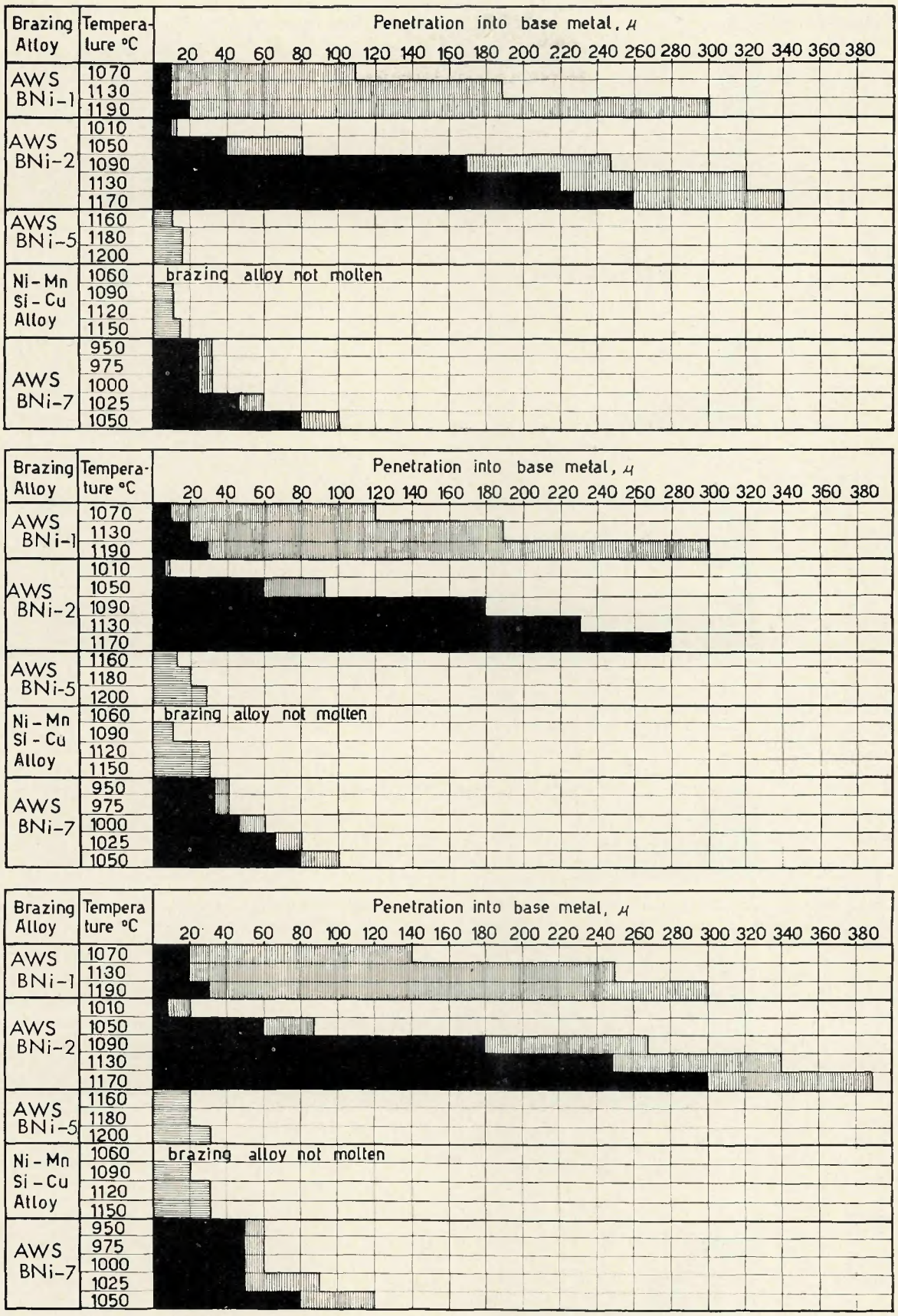
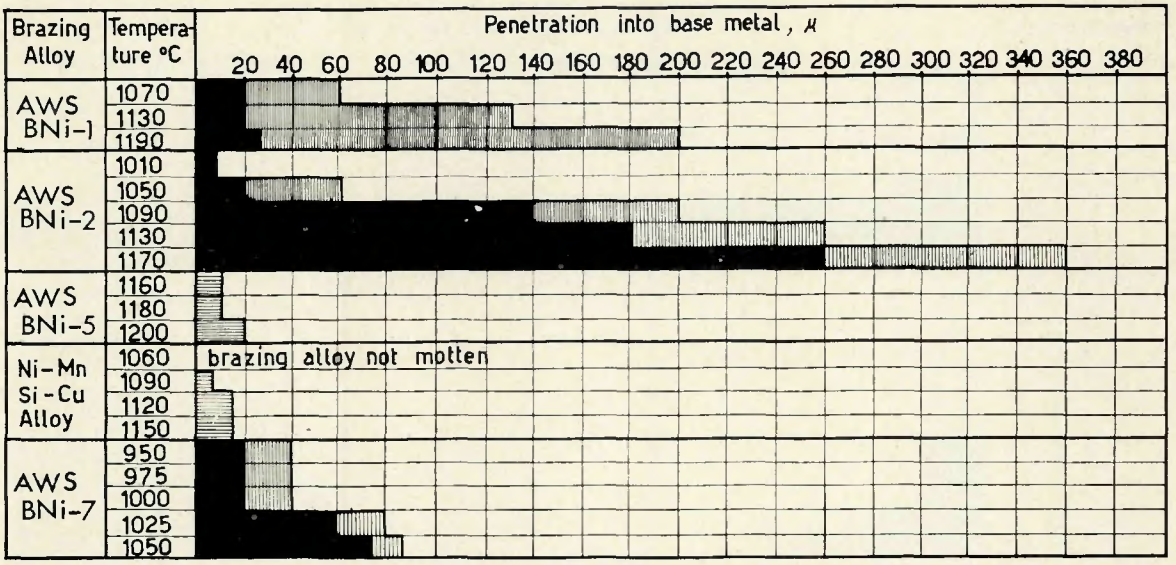
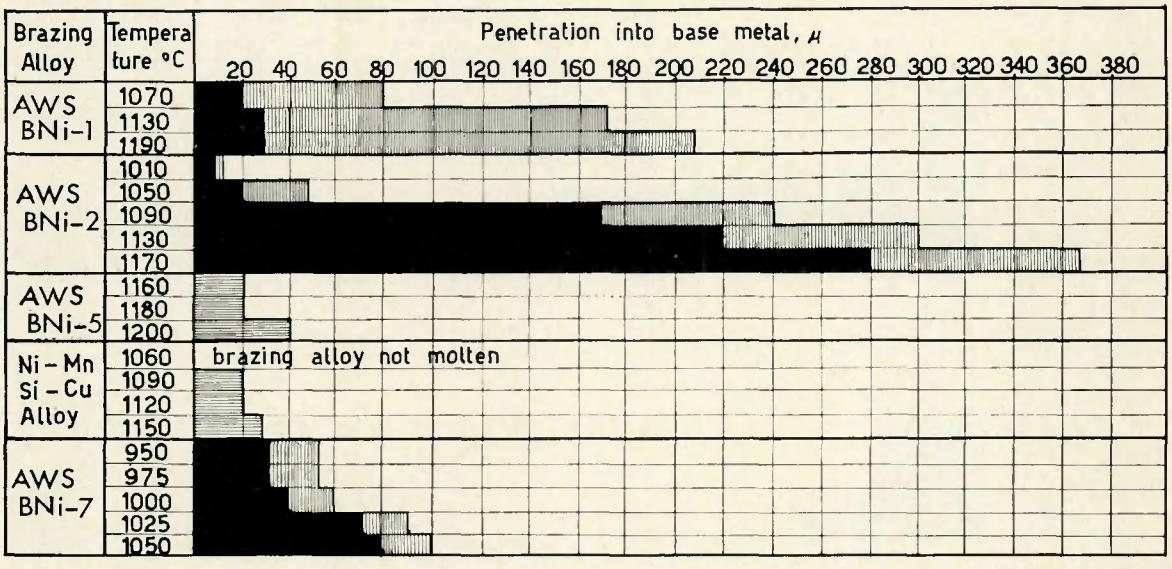
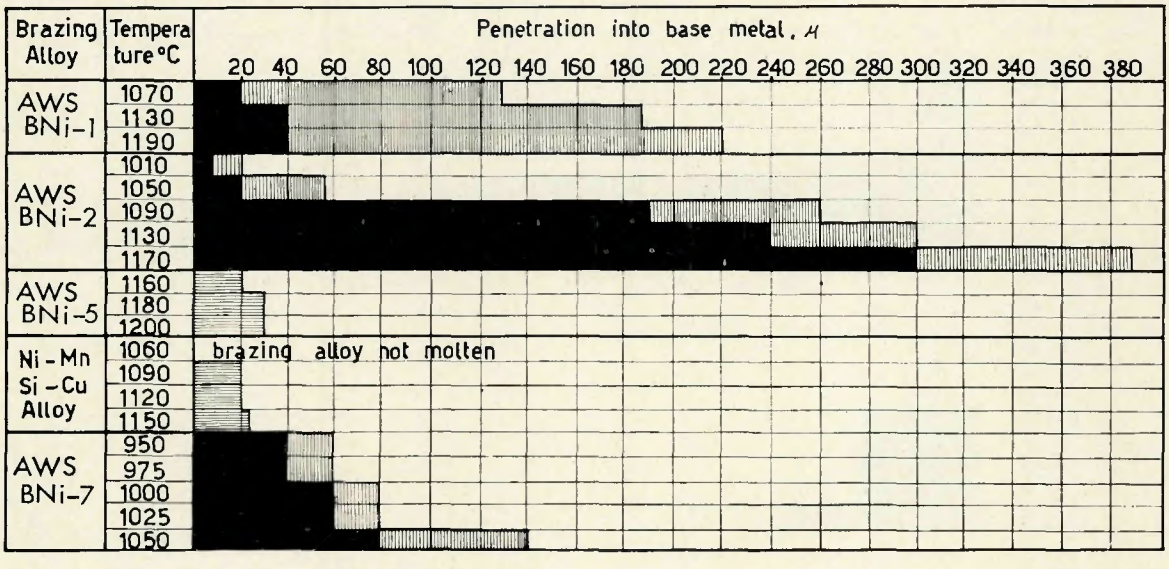


Fig. 3—Measurements of penetration. Base metal—AISI 304 stainless steel. Soaking time: A (top)—0.5 hr; B (center)—1.5 hr; C (bottom)—3 hr







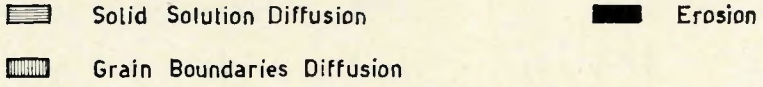


Fig. 4—Measurements of penetration. Base metal—AISI 321 stainless steel. Soaking time: A (top)—0.5 hr; B (center)—1.5 hr; C (bottom)—3 hr

Fig. 5—Drop spreading and penetration. Base metal—AISI 304; filler metal—AWS BNi-1; brazing treatment—1130° C, 1.5 hr; vacuum—10^{-4}—Torr: A (top left)—grain boundary diffusion and precipitation; B (top center)—filler metal-base metal interface; C (top right)—brazing alloy after eutectoid decomposition; D (bottom)—semisection of drop spreading

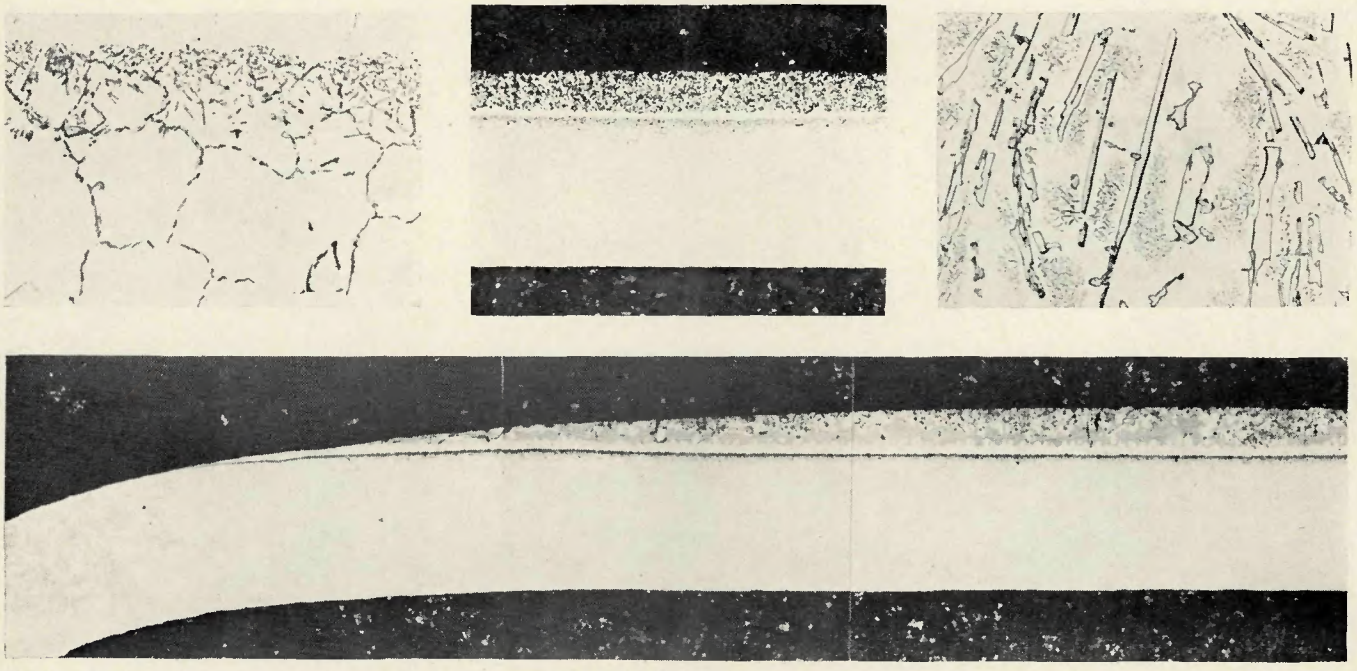


Fig. 6—Drop spreading and penetration. Base metal—AISI 304; filler metal—AWS BNi-5; brazing treatment—1090° C, 0.5 hr; vacuum—10^{-4} Torr. A (top left)—grain boundary diffusion and precipitation; B (top center)—filler metal-base metal interface; C (top right)—brazing alloy after eutectoid decomposition; D (bottom)—semisection of drop spreading

diffusion and erosion can be observed —Fig. 6. The eutectoid decomposition of the brazing filler metal takes the form of rod-like intermetallic compounds. The extent of this erosion is too great to adopt this filler metal for brazing thin structures.

For BNi-5, a small solid solution diffusion is the only effect obtained through the entire brazing cycle—Fig. 7. For Ni-Mn-Si-Cu, a small solid solution and erosion are the results of the aggressive effect of the brazing filler metal—Fig. 8.

For BNi-7, the aggressive effects, grain boundary diffusion and erosion are operative during the brazing cycle—Fig. 9. Enrichment of the phosphorus content at the base metal-molten filler metal interface and diffusion in the bulk material through the grain boundary, can be observed.

Conclusions

The following conclusions can be drawn from the observations carried out during the experiments:

1. BNi-1 and BNi-2 have good wettability, but the penetration is too high to use these alloys for brazing thin structures. For BNi-1, the aggression is attributed to grain boundary dffusion. For BNi-2, in addition to the grain boundary diffusion, a great erosion is present.

2. The BNi-5 and the Ni-Mn-Si-Cu filler metals have acceptable wettability and low penetration, occurring

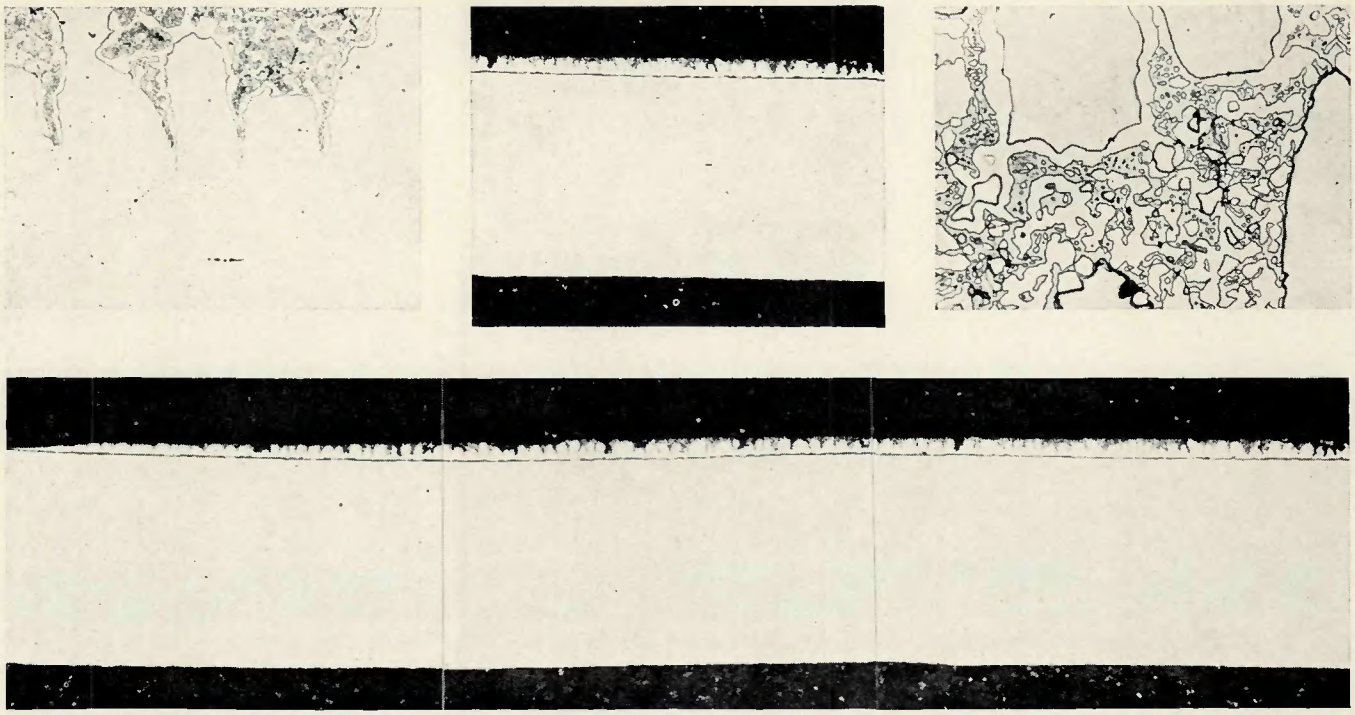


Fig. 7—Drop spreading and penetration. Base metal—AISI 321; filler metal—AWS BNi-5; brazing treatment—1090° C, 3 hr; vacuum—10^{-4} Torr. A (top left)—solid solution diffusion; B (top center)—filler metal-base metal interface; C (top right)—brazing alloy after eutectoid decomposition; D (bottom)—semisection of drop spreading

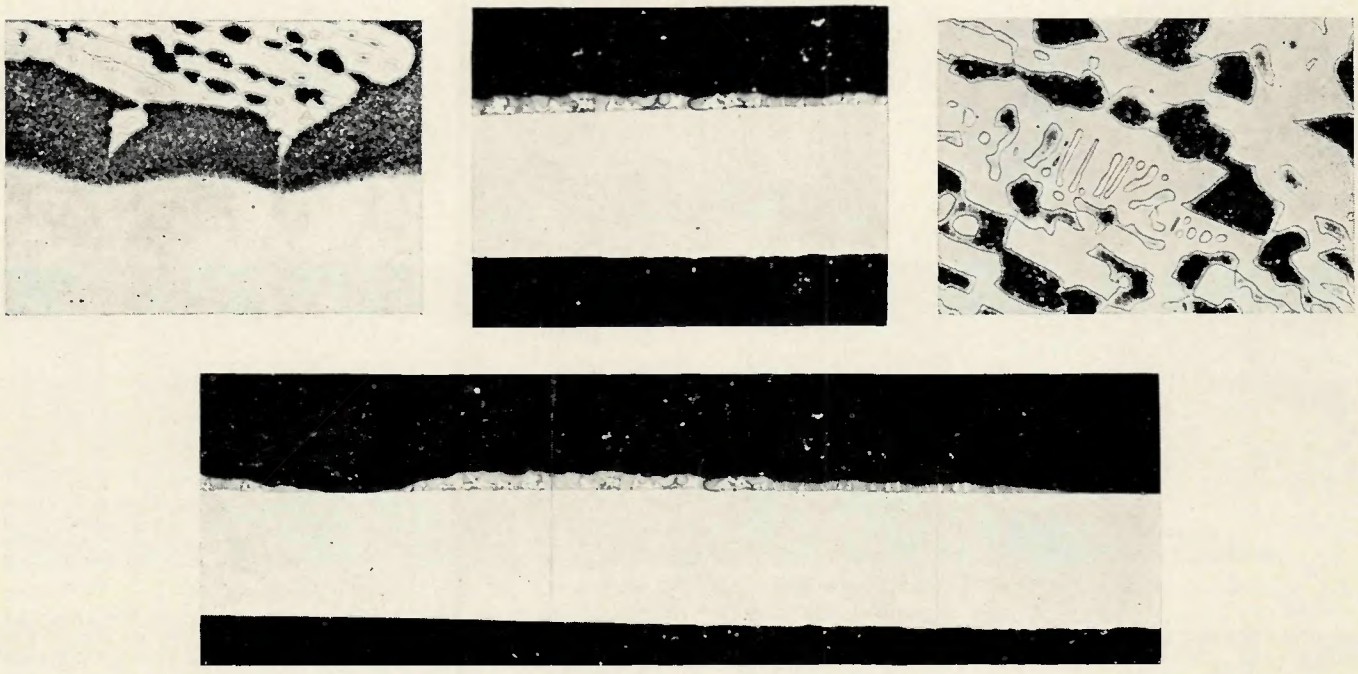


Fig. 8—Drop spreading and penetration. Base metal—AISI 304; filler metal—Ni-Mn-Si-Cu; brazing treatment—1120° C, 3 hr; vacuum—10^{-4} Torr. A (top left)—grain boundary diffusion and precipitation; B (top center)—filler metal-base metal interface; brazing alloy after eutectoid decomposition; D (bottom)—semisection of drop spreading

mainly by solid solution diffusion. These alloys are recommended for brazing thin structures.

3. BNi-7 shows a high wettability for brazing cycles carried out at high temperatures; and the aggression, which occurs through grain boundary diffusion and erosion, is intermediate between the BNi-1 and BNi-2 filler metals, and the BNi-5 and Ni-Mn-Si-Cu filler metals.

4. Concerning wettability, no great difference has been observed between the two stainless steel base metals. More aggressive penetration of the base metal by the brazing filler metal is observed in the unstabilized AISI-304 stainless steel than in the stabilized AISI-321 stainless steel.

References

1. Bell, G. R., "Brazing with Nickel-Base Alloys", paper presented at Spring Meeting of Welding Institute (1967)
2. Peaslee, R. L., "Stainless Brazing: A sophisticated joining method", paper presented at Autumn Meeting of Welding Institute (1964)
3. Rhys, D. W., and Betteridge, W., Metal Industry 6, 13 (1962)

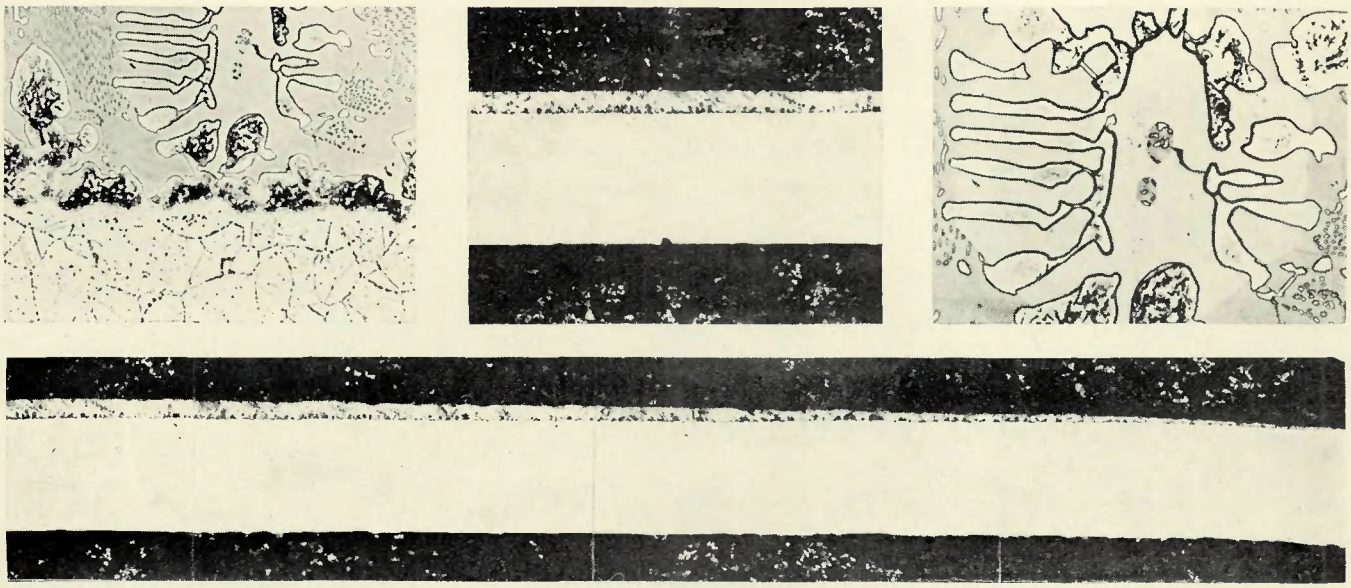


Fig. 9—Drop spreading and penetration. Base metal—AISI 304; filler metal—AWS BNi-1; brazing treatment—975° C, 3 hr; vacuum—10^{-4} Torr. A (top left)—grain boundary diffusion and precipitation; B (top center)—filler metal-base metal interface; C (top right)—brazing alloy after eutectoid decomposition; D (bottom)—semisection of drop spreading

4. Bredzs, N., and Schwartzbzrt, H., "Grain Boundary Penetration and Base Metal Erosion in High Temperature Brazing", WELDING JOURNAL, 41 (3), Research Suppl., pp. 129-s to 144-s (1962)

5. McDonald, A. S., "Alloys for Brazing Thin Sections of Stainless Steel", *Ibid.* 36, (3), Research Suppl., pp. 131-s to 140-s (1957)

6. Feduska, W., "The Nature of High Temperature Brazing Alloy-Base Metal Interface Reactions", *Ibid.*, 37 (2), Research Suppl. pp. 62-s to 73-s (1958) and "The Nature of the Diffusion of Brazing Alloy Elements into Heat-Resisting Alloy", *Ibid.*, 40 (2), Research Suppl. pp. 81-s to 89-s (1961)

7. Lamb, S., and Miller, F. M., "The Effects of Aggression by Nickel-Base Brazing Filler Metal", *Ibid.*, 48 (7), Research Suppl. pp. 283-s to 289-s (1969)

WRC Bulletin No. 159 Feb. 1971

"Welding of Maraging Steels"

by F. H. Lang and N. Kenyon

This report was prepared for the Interpretive Reports Committee of the Welding Research Council. A general description of the metallurgical conditions involved in welding maraging steels is followed by a detailed discussion of the usefulness of a variety of processes. Important parameters are discussed, procedures are recommended, and the properties that can be expected from the weld joints are outlined.

Bulletin 159 is $3.00 per copy. Orders for single copies should be sent to the American Welding Society, 345 E. 47th Street, New York, N.Y. 10017. Orders for bulk lots, 10 or more copies, should be sent to the Welding Research Council, 345 E. 47th Street, New York, N.Y. 10017.