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Corrosion of BAg Brazed Joints in Stainless Steel

Study relates corrosion resistance of joints made in two types of stainless steel, using three BAg filler metals, with several properties of the materials involved

By I. KAWAKATSU

ABSTRACT. Corrosion of lap joints in stainless steel brazed with three silver alloy filler metals have been studied with respect to the following properties:

1. The wetting properties of two types of stainless steels
2. The joint strength of brazements and the change of strength due to wet corrosion
3. Type of corrosion at the brazed joints
4. Measurement of electrode potential of silver alloys, and the relation between electrode potential and corrosion rate
5. Liquation due to capillary flow of molten silver alloy filler metals into the narrow clearance between base metals
6. The observation of diffusion phenomena at the interface between the silver alloy filler metal and the base metal by x-ray microanalyzer

Introduction

It is most important for industry that an investigation be made of the corrosion properties of brazed joints, especially in the case of stainless steel brazed silver alloy filler metals. There are several reports concerning such corrosion behavior, but only a few papers have treated the subject systematically. The author investigated the corrosion properties of two types of stainless steels, AISI types 304 and 430, brazed with the silver alloy filler metals BAg-1, BAg-3, and BAg-7.

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Four corrosive agents were examined for corrosion tests: (1) nitric acid, (2) hydrochloric acid, (3) sodium hydroxide and (4) sodium chloride. Each agent was used in a 5% aqueous solution at room temperature.

Experimental Procedure

Base metals and silver alloy filler metals used for the experiment are shown in Table 1. Each specimen was prepared by ordinary torch brazing with a proprietary low temperature flux at about 150 F above each melting point. Shape and dimension of lap joint test pieces are shown in Fig. 1a.

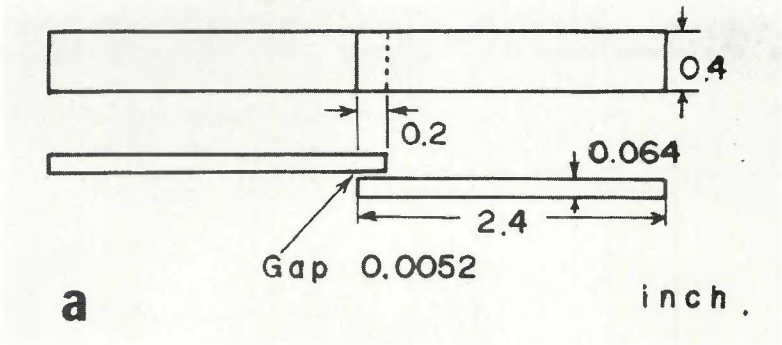
Appearance of the brazed joints after 5% NaCl solution are compared in Fig. 1b; that is, surface of AISI 430 joint is covered with brown hydroxide formation, on the other hand AISI 304 without these products.

Prior to the experiment, the wettability of the two types of stainless steel with the BAg filler metals was determined by spreading tests. These tests showed that wetting of AISI 304 is a little better than that of AISI 430 due to the nickel content of the type 304.

Joint Strength and Interface Structure

Before testing joint strength, we examined the interface structure of types 304 and 430 brazed joints, and we observed clearly different structures between the two, as shown in Fig. 2. In the case of type 430, no remarkable diffusion zone is recognized. On the other hand, spike-shaped dendrites line up along the interface between base metal and filler metal in type 304.

Figs. 3 and 4 show characteristic x-ray image of BAg-1 brazed joints in



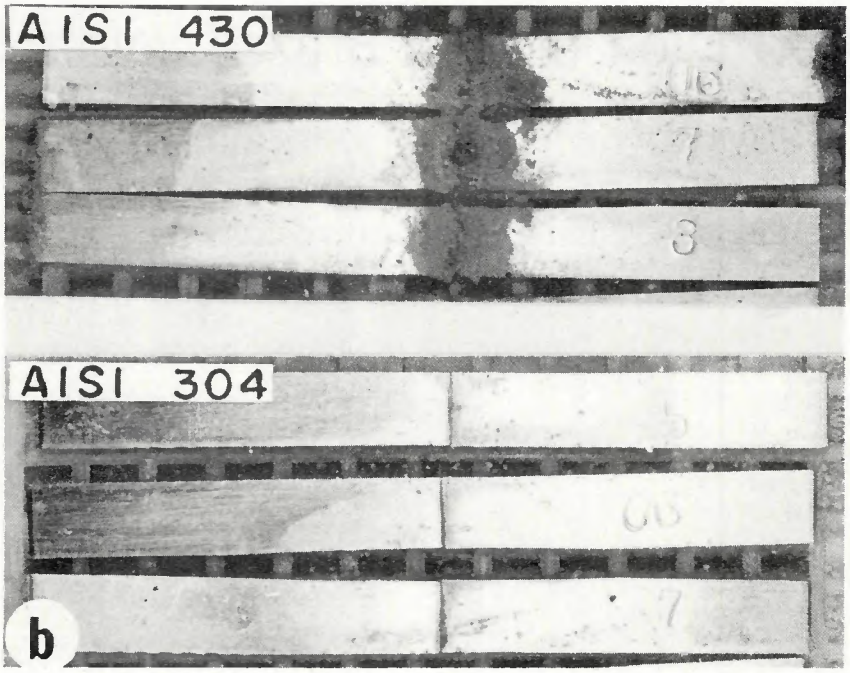


Fig. 1—(a) Details of lap joint. (b) Appearance of brazed specimens after corrosion in 5% sodium chloride solution

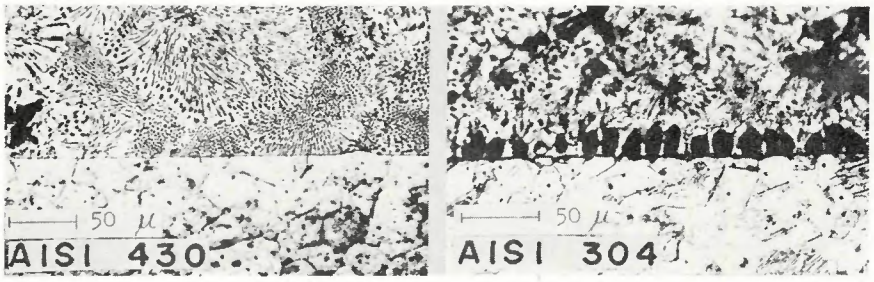


Fig. 2—Interfacial structure of two stainless steels brazed with BAg-1

Table 1 — Base Metals and Filler Metals Used in This Study

Base metal	Composition (wt %) C	Si	Mn	Ni	Cr	Fe
AISI 430	0.12	0.75	1.0	—	16.0-18.0	Bal
AISI 304	0.08	1.0	2.0	8.0-11.0	18.0-20.0	Bal

Filler metal	Composition (wt %) Ag	Cu	Zn	Cd	Ni	Sn	Melting Range, C
BAg-1	45	15	16	24	—	—	605-620
BAg-3	50	15.5	15.5	16	3	—	630-690
BAg-5	45	30	25	—	—	—	675-745
BAg-7	55	22	17	—	—	5	620-650

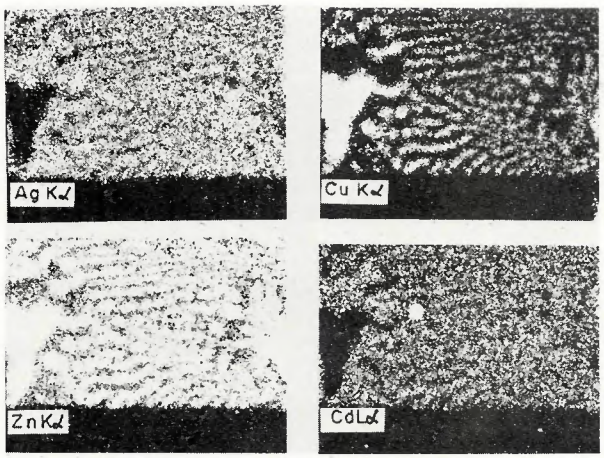


Fig.3—Characteristic x-ray image of BAg-1 brazed on type 430 stainless steel

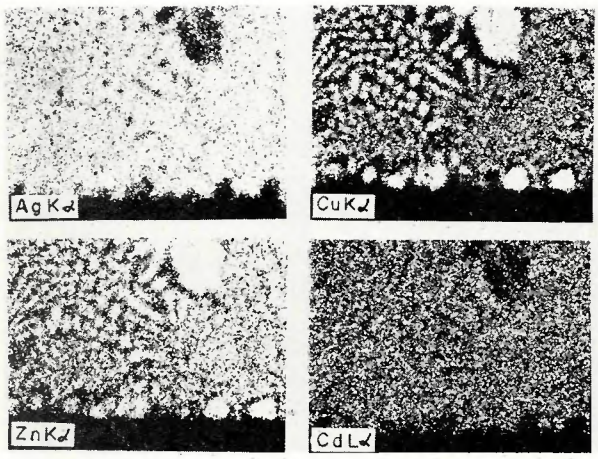


Fig. 4—Characteristic x-ray image of BAg-1 brazed on type 304 stainless steel

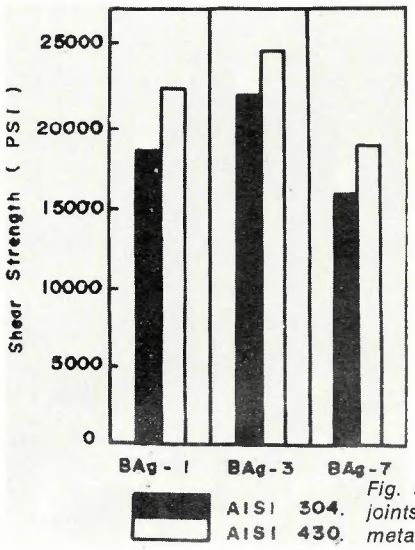


Fig. 5—Shear strength of stainless steel joints brazed with three silver alloy filler metals

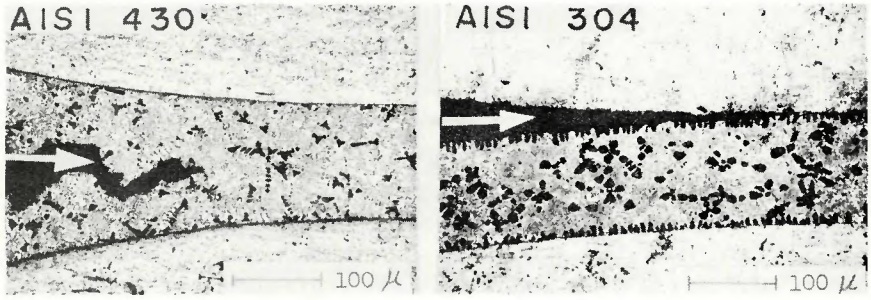


Fig. 6—Two modes of rupture encountered in testing BAg brazed joints in (left) type 430 and (right) type 304 stainless steel

types 430 and 304. The latter indicates that the black spike-shaped dendrite in type 304 is composed mainly of copper and zinc rich alloy phase. And we can see also by these x-ray microanalyses, that the structure of quaternary elements in BAg-1 consists of pseudo binary eutectic of Ag-Cd phase and Cu-Zn phase.

That the strength of the type 430 lap joint is 10 to 15% stronger than the type 304 with the three silver alloy filler metals is shown in Fig. 5. With respect to the kinds of silver alloy filler metals used, the joint strength of BAg-3 is the strongest and that of BAg-7 is the weakest. This is clearly observed on micrographs of ruptured joints, as shown in Fig. 6.

Thus, in the case of type 430, rupture occurred within the filler metal itself, but in type 304, the crack propagated along the boundary between the base metal and the filler metal. The reason why the joint strength in type 304 is a little poor compared with that of 430, can be explained by the ruptures shown in Fig. 6.

Corrosion Tests

Regarding the corrosion tests, we tried to confirm the dependence of the corrosion rate on the shear strength of the brazed joint. The lap jointed test pieces used for the experiment are 0.064 in. thick, 0.4 in. wide, and 2 in. long, and clearance was 0.0052 in. When we dipped these test pieces in corrosion media, such as 5% nitric acid, hydrochloric acid and sulphuric acid, the shear strength of the brazed joints fell rapidly.

These results are shown in Figs. 7, 8 and 9. The rupture time of type 304 in each of the above corrosive solutions was one week in nitric acid, two weeks in hydrochloric acid and sulphuric acid. On the other hand, after 100 days no failure can be seen in sodium hydroxide solution, as shown in Fig. 10. In general, corrosion resistance of type 430 is not as good as in the case of 304. It is an interesting fact that the corrosion resistance of silver alloys brazed stainless steel joints is unexpectedly poor in 5% sodium chloride solution as shown in Fig. 11. Most of the specimens were corroded out within one month or so.

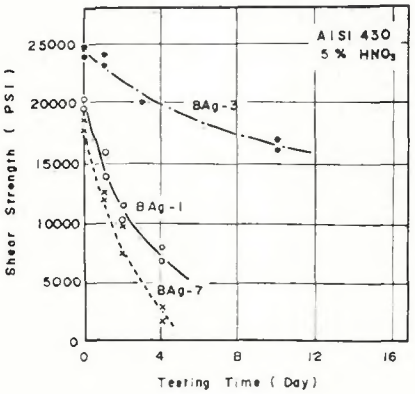
Throughout the corrosion tests on the various silver alloy filler metals, BAg-7 showed the highest corrosion resistance and BAg-1 the lowest.

Types of Corrosion

Microstructures at the corroded brazed joints are shown in Figs. 12 and 13. In the case of type 430, which has a ferritic structure corrosion occurred on the base metal side. On the other hand, in type 304 which has an austenitic structure, corrosion proceeded along the interface between brazing alloy and base metal forming a thin gap.

Electrode Potential Measurements

To make clear the mechanism of attack by sodium chloride solution,



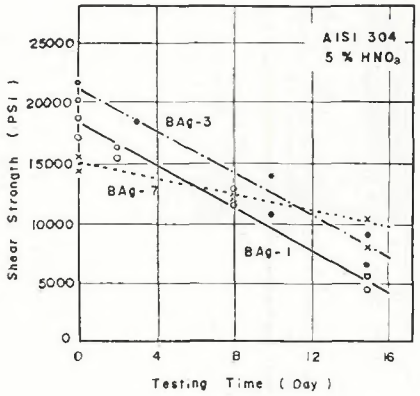
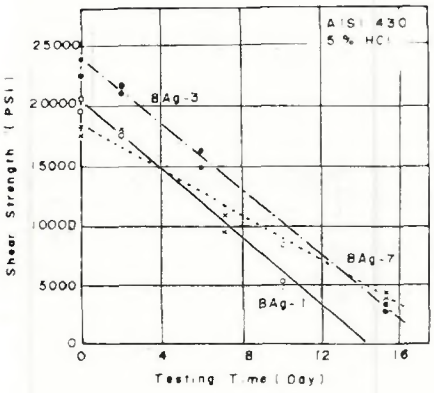


Fig. 7—Shear strength of BAg brazed stainless steel joints after corrosion in 5% nitric acid solution



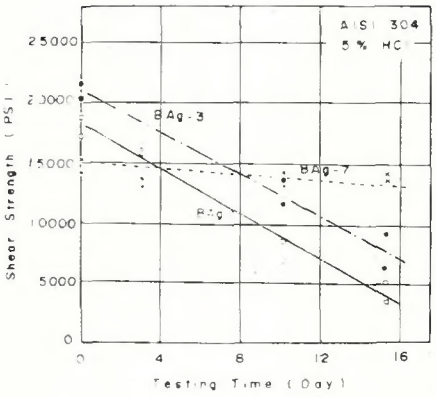
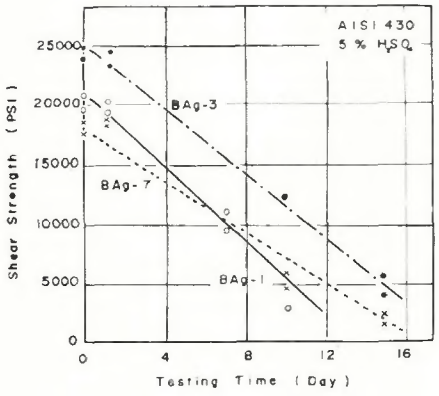


Fig. 8—Shear strength of BAg brazed stainless steel joints after corrosion in 5% hydrochloric acid solution



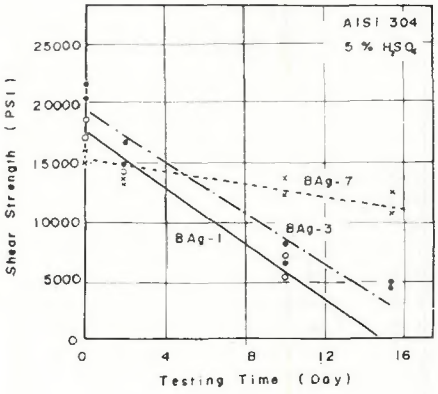
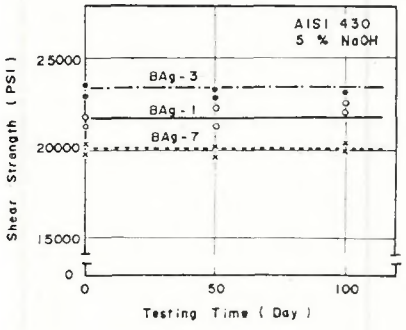


Fig. 9—Shear strength of BAg brazed stainless steel joints after corrosion in 5% sulfuric acid solution



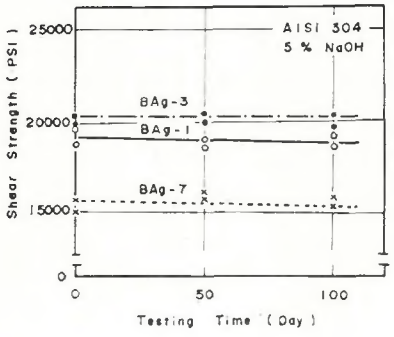


Fig. 10—Shear strength of BAg brazed stainless steel joints after corrosion in 5% sodium hydroxide solution

we measured the electrode potential of various silver alloys, including a few brazing alloys in 5% sodium chloride solution saturated calomel cell at 27 C. The results of experiment are shown in Figs. 14 and 15. The potential values of the three brazing alloys are as follows:

BAg-1	−260 mV
BAg-3	−220 mV
BAg-7	−217 mV

As to the dependence of the corrosion rate on the kind of silver alloy filler metal, the corrosion rate is the highest in BAg-1 and the lowest in BAg-7. This behavior seems to have a close relation with the abovementioned electrode potential.

At the same time, the electrode potentials of the silver base binary alloy series Ag-Cu, Ag-Zn, Ag-Cd, Ag-Sn and Ag-Cu-Ni were investigated. Each potential value obtained helped to explain the relative corrosion established by the test results.

Among the binary series of silver alloys, Ag-Cu and Ag-Sn alloys show a little anodic potential compared with pure silver. On the other hand, Zn and Cd contents in silver make it more anodic as seen in BAg-1. Nickel additions in Ag-Cu make it a little cathodic; therefore, in the case of BAg-3, the nickel component is beneficial for corrosion resistance.

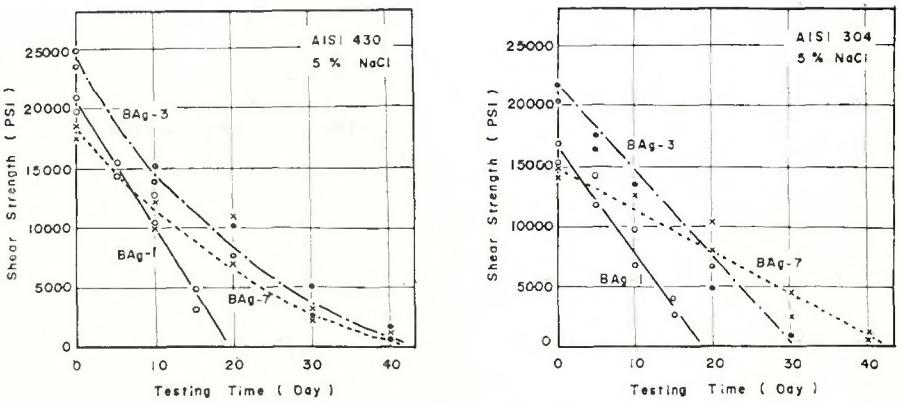


Fig. 11—Shear strength of BAg brazed stainless steel joints after corrosion in 5% sodium chloride solution

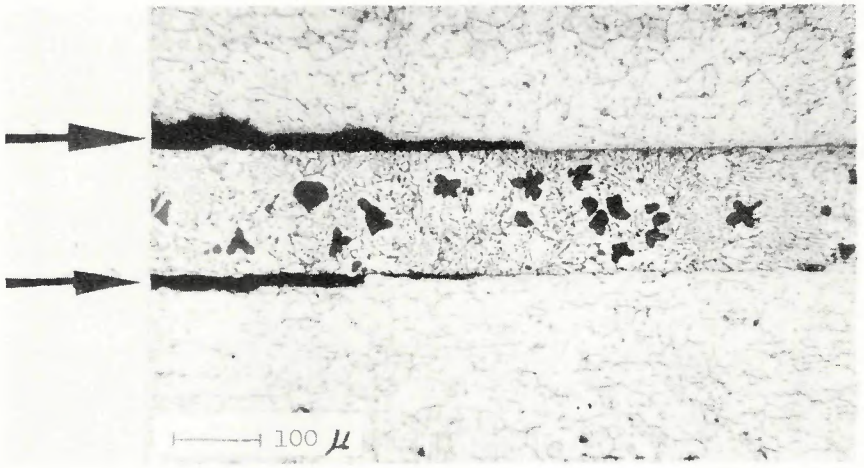


Fig. 12—Interfacial corrosion of type 430 stainless steel joint brazed with BAg-1

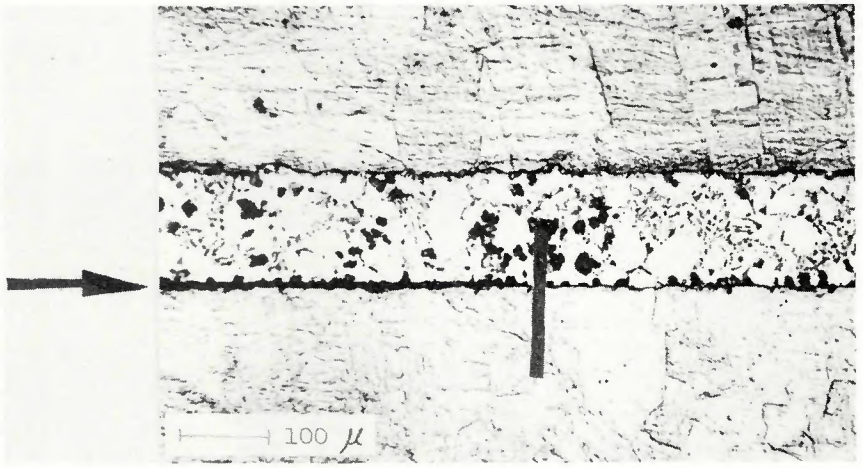


Fig. 13—Interfacial corrosion of type 304 stainless steel joint brazed with BAg-3

Liquation with BAg-3

In the case of lap brazed joints, when face fed BAg-3 filler metals flow into the thin gap of base metals from one end (for instance, with gap thickness of 0.004 in. and gap length of 0.125 in.), liquation of the nickel content was distinctly observed in micrographs, as shown in Fig. 16; moreover its amount was measured by x-ray microanalysis.

That the corrosion resistance of joints brazed with BAg-3 seems so poor in the test result shown in Fig. 11, is explained by this liquation of nickel content. To eliminate liquation by BAg-3 brazing filler metal, a joint was brazed with BAg-3 using the insert method (preplacement), instead of the face feed and flow method.

From this experiment it became clear that the insert method evidently improves this defect of BAg-3. Results shown in Fig. 17. Figure 18 illustrates the difference between the flow method (face feeding) and the insert method (preplacement).

X-Ray Microanalysis at the Interface

Addition of nickel in BAg-3 is considered beneficial for corrosion resistance because it may concentrate at the interface between stainless steel and filler metal, and therefore prevent the decrease of corrosion resistance owing to the depletion of nickel or chromium in this region.

As can be seen clearly from Figs. 19 and 20, nickel undoubtedly concentrates in the region of the interface, and contributes to corrosion resistance of both types 304 and 430.

Figure 21 shows the line scanning across the interface of type 304 brazed with BAg-1 and type 430 with BAg-7. From this experiment, we learned that chromium diffuses into the brazing filler metal, and that subsequently, the chromium-depleted

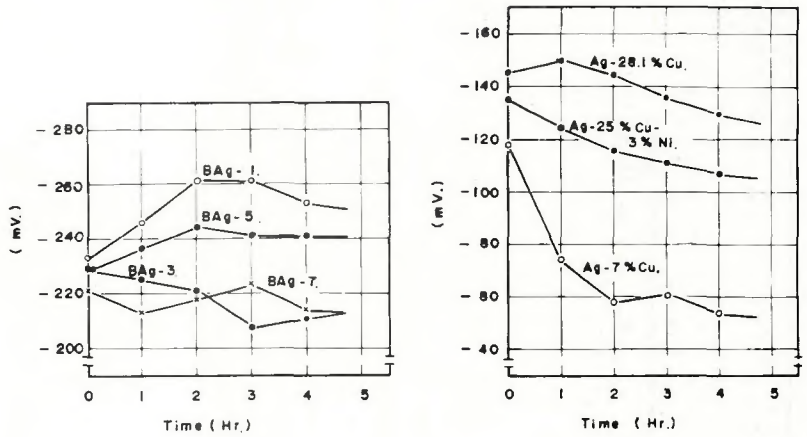


Fig. 14—Electrode potential of various silver alloys in a 5% sodium chloride solution

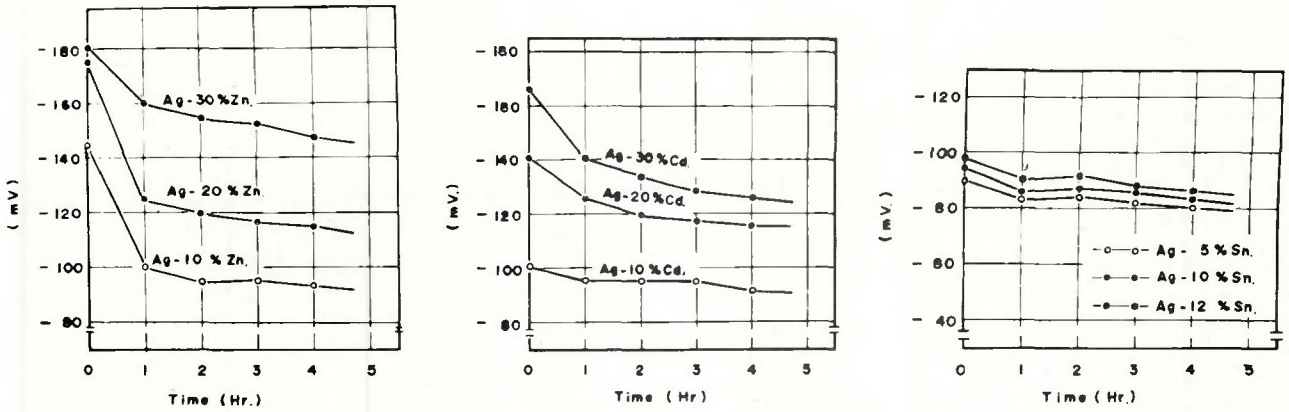


Fig. 15—Electrode potential of Ag-Zn, Ag-Cd and Ag-Sn alloys in 5% sodium chloride solution

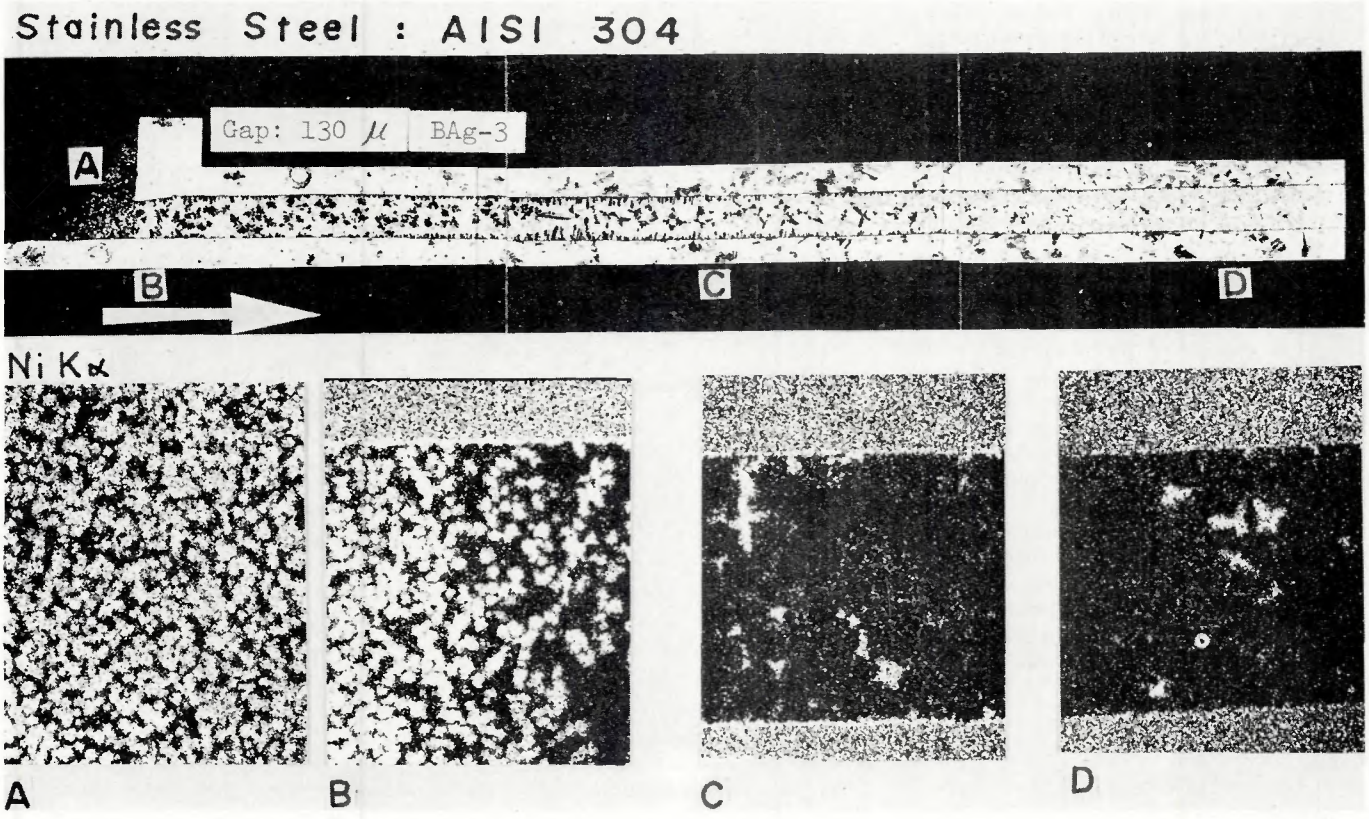


Fig. 16—Liquation with flow of BAg-3 filler metal into type 304 stainless steel joint. Nickel concentration revealed by x-ray microanalysis

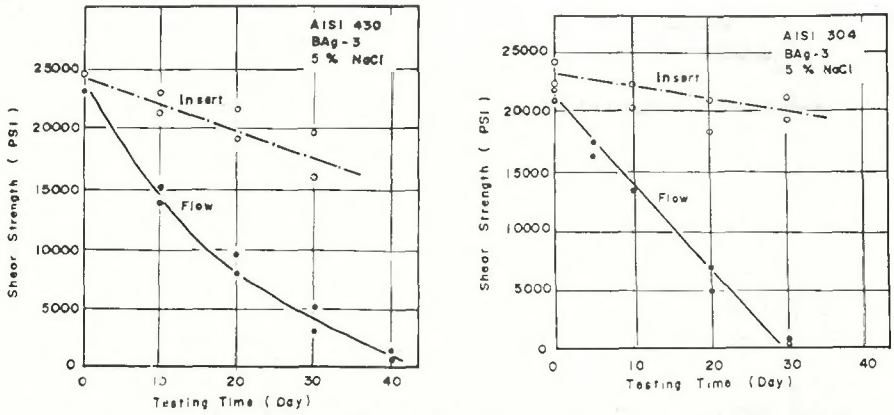


Fig. 17—Comparison of shear strengths (hence corrosion rates) obtained with insert (preplaced filler metal) and flow (face-fed filler metal) methods in 5% sodium chloride solution

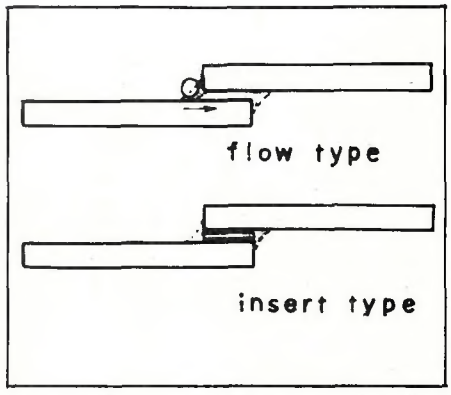


Fig. 18—Lap joints illustrating flow type (face fed) and insert type (preplaced) methods of adding filler metal

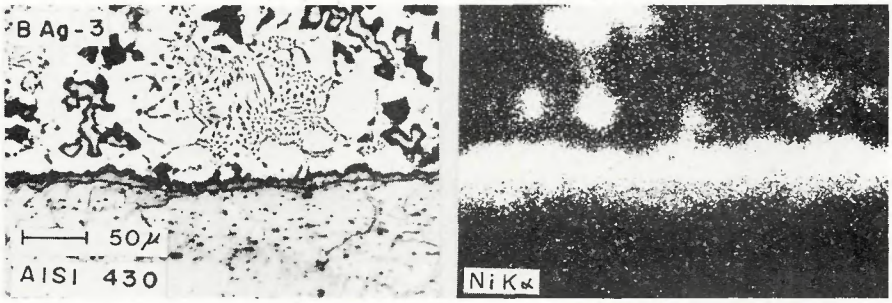


Fig. 19—(left) Microstructure at interface of brazed joint and (right) nickel concentration revealed by x-ray microanalysis

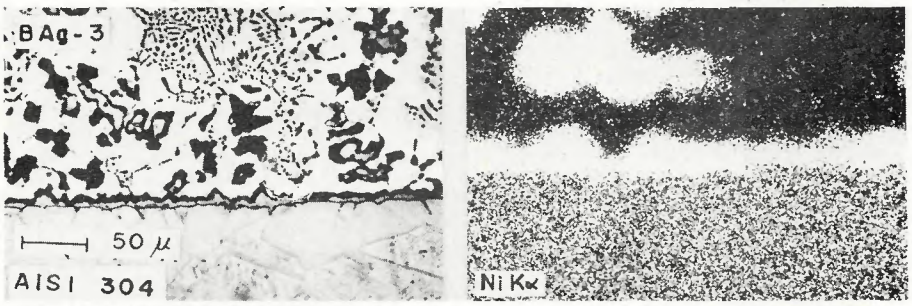


Fig. 20—(left) Microstructure at interface of brazed joint and (right) nickel concentration revealed by x-ray microanalysis

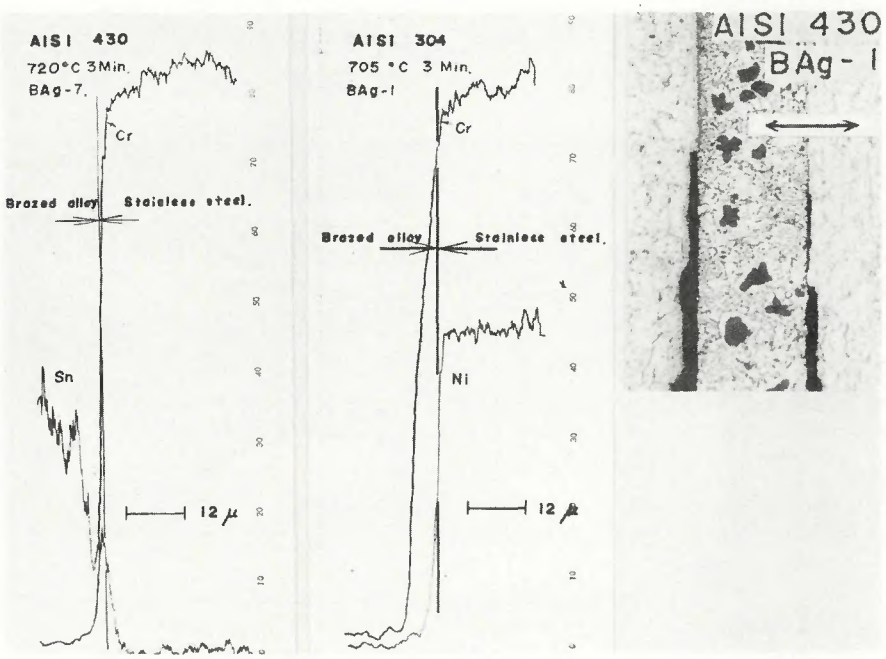


Fig. 21—Scanning traces by x-ray analysis of indicated elements. Micrograph at right shows typical location of scan with respect to joint subject to interfacial corrosion

zones at the surface of the base metal evidently decrease its corrosion resistance.

Summary

BAg brazed joints in stainless steel do not have high corrosion resistance in sodium chloride solutions. Even type 304 joints suffer interface corrosion and will be corroded out in about one month.

BAg-3 is noted as a suitable brazing filler metal for stainless steel, but it shows remarkable liquation of nickel when it is face fed to the gap between two base metals. We found it makes the joint less corrosion resistant in a salt solution, and to eliminate such liquation, it is better to insert the filler metal in the gap between the base metals.

Electrode potential measurement and x-ray microanalysis were carried out, and these test results served to explain various phenomena.

Acknowledgement

Thanks are due to my assistant Mr. M. Abe who has earnestly arranged experimental data.

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