

# Spreading and Aggressive Effects By Nickel-Base Brazing Filler Metals On the Alloy 718

*An experimental investigation with Ni-Mn-Si-Cu and both ASTM BNi-5 and BNi-7 brazing filler metals indicates that Ni-Mn-Si-Cu shows acceptable spreading as well as sufficient penetration to obtain satisfactory anchorage of the filler metal on the alloy 718 base metal*

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**ABSTRACT.** The spreading and the aggressive effects of three nickel-base brazing filler metals on the Alloy 718 has been determined. The three brazing filler metals are the ASTM alloy BNi-5, the Ni-Mn-Si-Cu alloy and the ASTM alloy BNi-7.

Brazing was carried out under a vacuum of  $10^{-4}$  Torr in the temperature and time range of each brazing alloy. Experimental results showed poor spreading for the ASTM alloy BNi-5 and acceptable spreading for the Ni-Mn-Si-Cu and the ASTM-BNi-7 alloys. The aggressive effects are weak for ASTM BNi-5 and Ni-Mn-Si-Cu alloys, but are strong for the ASTM alloy BNi-7.

## Introduction

Brazing has been an important and widely used joining process for several decades. The broadest applications of the process are found in mass-production industries such as the fields of appliance and automobile manufacturing. The acceptance of brazing in the aircraft and nu-

clear industry, however, has been slow because the brazed joints must possess severe heat and corrosion resistance requirements; to meet the needs of these industries, the filler metals have shifted from the silver alloy compositions and pure copper to the nickel-base compositions and exotic alloys containing gold, palladium and platinum.<sup>1-3</sup>

Nickel-base materials provide a wide variety of filler metals to meet many needs as to mechanical properties and heat and corrosion resistance qualities. The elements commonly used as alloying additions in the nickel-base brazing filler metals are chromium, silicon, boron, phosphorus, iron, manganese and copper. The primary function of chromium is to increase the oxidation resistance. The other elements add strength and lower the melting point of nickel to promote the wettability properties.

The alloying elements necessary to obtain the proper brazing characteristics of the filler metals are phosphorus, silicon and boron; they show different spreading and aggression in the form of diffusion into base metal and the erosion of it by filler metal. So at the beginning of experimental brazing, it is necessary to

estimate the spreading and aggressive characteristics of the brazing filler metal.

This paper examines the spreading and aggression behaviour of three different brazing nickel-base alloys on a high temperature resistance material, i.e., alloy 718.

## Theoretical Considerations

It is very important for a right knowledge of the spreading and the aggressive effects of the brazing filler metal to know what are the parameters that influence these phenomena. When two pieces of solid metal are joined by brazing, the liquid filler metal must flow between the two surfaces to be joined, ideally filling the entire overlap space between the two metal parts. The filler metal must, in addition, adhere to the parts so as to develop "joint strength." The process whereby the filler metal flows between the parts is capillarity and the process whereby it adheres to the parts is a function of solid solubilities,<sup>4 5</sup> i.e., of the "work of adhesion,"  $W_A$ . Both these processes are dependent upon the surface tension of the filler metal and the metal to be joined.

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Table 1—Chemical Composition of Base Metal, Alloy 718, %

Ni	C	Mn	Fe	S	Si	Cu	Cr	Al	Ti	Cb	Mo
52.5	0.04	0.20	18.5	0.007	0.30	0.07	18.6	0.40	0.90	5.0	3.1

performed for a surface area  $\sigma$  in  $\text{cm}^2$  at constant pressure  $p$ , temperature  $T$ , and molal concentration  $N$ , the surface free energy,  $\gamma$  is obtained:

$$\left(\frac{\partial G}{\partial \sigma}\right)_{p,T,N} = \gamma \quad (2)$$

which is expressed in ergs/cm<sup>2</sup>, i.e., dimensionally in dynes/cm as tension, and indicates a true thermodynamic property of the substance. In addition to this, an interfacial surface tension at the interface, where two species meet, exists. The condition for spreading of a liquid on any surface depends on the difference in chemical potential, in order to have that the spreading condition is given by  $dG < 0$ , i.e., any incremental change in the liquid surface will effect an equal change in wetted surface at the expense of non-wetted surface in order to have:

$$\left(\frac{\partial G}{\partial \sigma}\right)_{p,T} = \gamma_l + \gamma_{ls} - \gamma_s \quad (3)$$

It is possible to designate a spreading coefficient,  $S_{ls}$ ,<sup>6</sup> as the total differential  $dG/d\sigma$  that is:

$$S_{ls} = \gamma_s - (\gamma_{ls} + \gamma_l) \quad (4)$$

The adhesion between two species requires solid solubility to some degree between the two. The work of adhesion between the two species, i.e., the work,  $W_A$ , required to separate two such species joined by adhesion, is related to surface tension of the two species through the relation:

$$W_A = \gamma_a + \gamma_b - \gamma_{ab} \quad (5)$$

Since the work of cohesion of a single specie joined to itself is given:

$$W_C = 2\gamma \quad (6)$$

it is possible to obtain that:

$$S_{ls} = W_{ls} - W_l = W_A - W_C \quad (7)$$

and since spreading occurs when:

$$S_{ls} > 0 \quad (8)$$

by some simplifying assumption, condition for spreading of a liquid on a solid is that:

$$\gamma_s > \gamma_l \quad (9)$$

In addition to the spreading phenomenon, the filler metal migration occurs also for capillary action which is directly connected with the surface tension. In fact, capillary flow takes place because of a pressure difference which arises under the liquidus meniscus as a function of orthogonal radii of curvature,  $R_1$  and  $R_2$  where  $R_1$  is the radius of

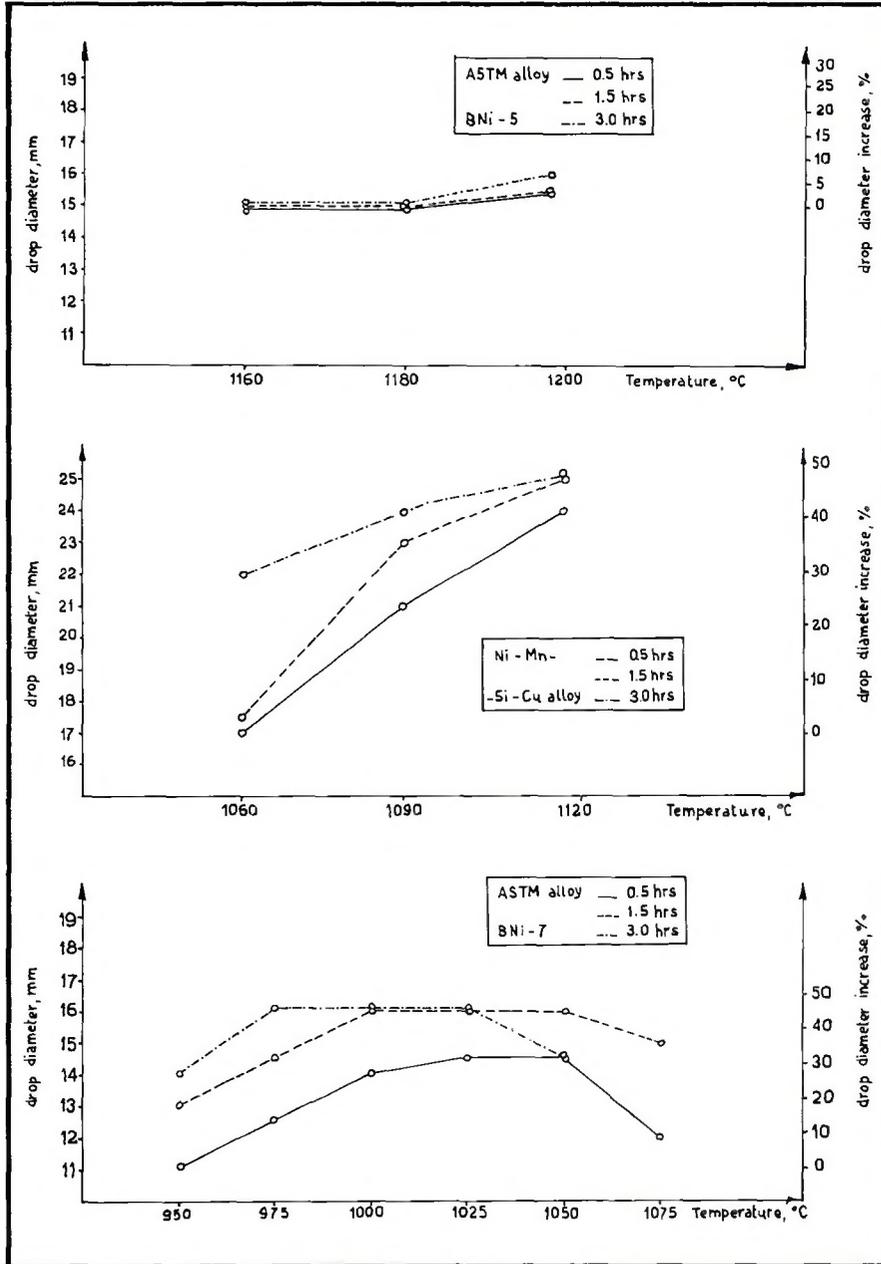


Fig. 1—Spreading measurements on the base metal by brazing filler metals

Physically, consider an atom within the body of a substance. It is surrounded by the other atoms and is subjected to forces of atomic attraction on all sides; thus it is in force equilibrium. At the free surface, however, there are no such attractive forces above the surface. Consequently, the resulting forces are situated on surfaces, and atoms tend inward toward the bulk of the materi-

al. This force field accounts for the tendency of any mass of liquid to seek a form of minimum surface to volume ratio, i.e., a sphere.

In thermodynamic language the Gibbs Free Energy,  $G$ , of any substance is given by the well known relation:

$$G = H - TS \quad (1)$$

where if the differentiation of  $G$  is

meniscus itself and  $R_2$  is perpendicular to it.

This pressure difference,  $\Delta P$ , generically related to chemical potential difference, is expressed through the well known relation:

$$\Delta P = -\gamma \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (10)$$

where  $\gamma$  is the interfacial energy between liquid and solid.

In essence this equation says that whenever there is a curved interface between two species, there will exist a pressure difference which will tend to move the boundary toward the center of curvature.

In the case of closely spaced flat plates,  $D$  cm apart, which would simulate a simple configuration of two plates to be joined by brazing, the radius of curvature along the line where liquid joins solid is infinite so that  $1/R_1=0$ , while for the meniscus itself, the curvature is given by the relation:

$$\frac{1}{R_2} = \frac{2}{D \cos \theta} \quad (11)$$

where  $\theta$  is the interfacial energy between the edge of the meniscus and the solid surface. For perfect wetting,  $\theta=0$  and  $\Delta P=-2\gamma/D$  so that the liquid would spread over the solid surface, continuing to spread until some other force caused it to stop.

One of this force is the penetration of the liquid filler metal into the base metal. The penetration may occur through the mechanisms of diffusion and erosion.<sup>8,9</sup> The diffusion occur prevalently through the migration of interstitial atoms i.e., atoms of relatively small atomic radii present in the filler metal, into the base metal along the grain boundary. When the interstitial atoms are along the grain boundary, they may migrate into the lattice of base metal, originating intermetallic compounds.

The elements of relatively large atomic radii, acting as substitutional atoms in the base metal, diffuse at a slower rate in the lattice of the base metal grains along the entire interface region. This migration involves nickel, chromium and silicon from brazing alloy and results in a complex solid solution (typically Fe-Cr-Ni-Si) at the interface region; this generally decomposes for cooling from brazing temperature to form an eutectoid mixture of solid solution and intermetallic compound.

Erosion is, instead, the dissolution of the solid base metal in the molten filler metal. Erosion and diffusion are undesirable because they reduce the effective thickness of the base metal and consequently the efficiency of the joined parts.

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

Alloy*	C	Mn	Si	Cu	Ni	Cr	P
ASTM BNi-5	0.10		10.0		70.9	19.0	
Ni-Mn-Si-Cu		23.0	7.0	5.0	65.0		
ASTM BNi-7	0.10				76.9	13.0	10

\*The Brazing Alloys were supplied by the Wall Colmonoy Corp. Detroit, Mich.

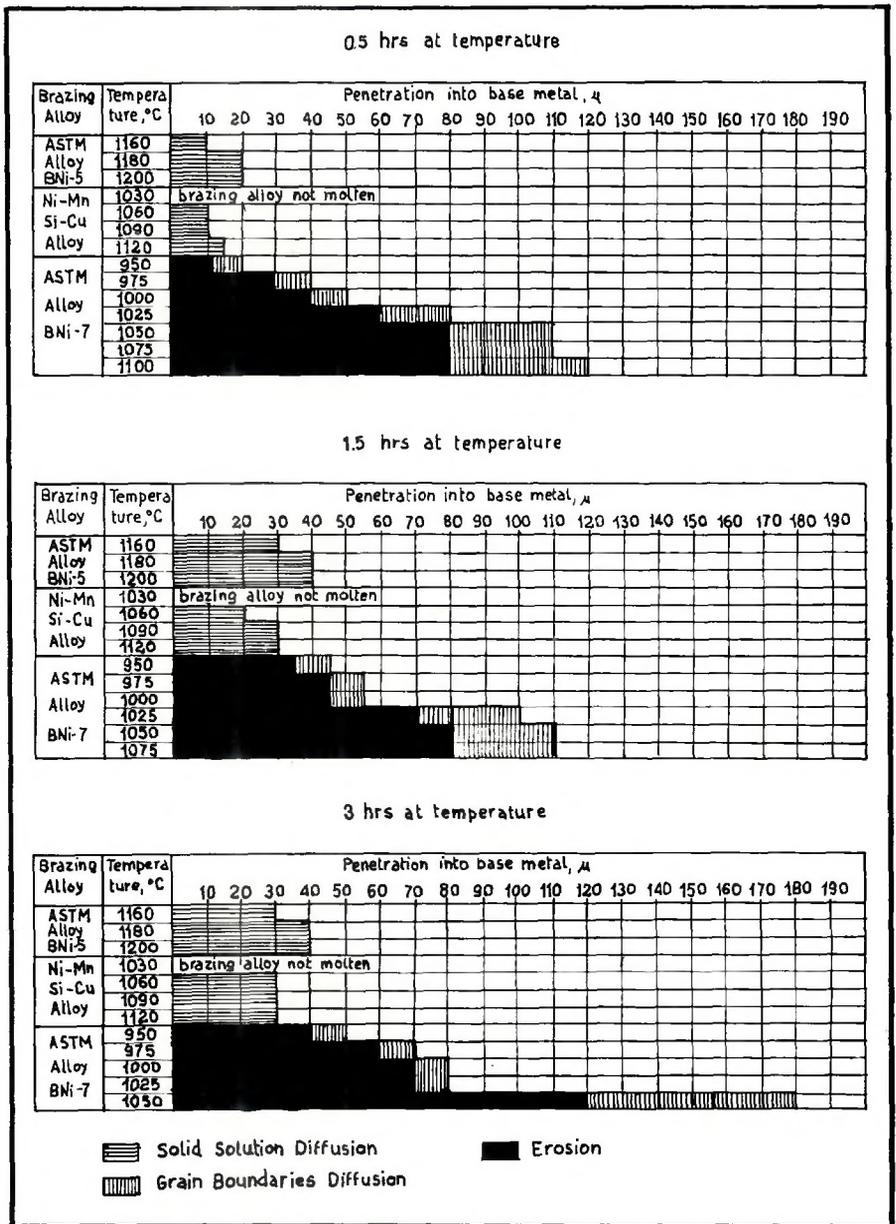


Fig. 2—Measurement of penetration into the base metal by brazing filler metals

### Material and Experimental Procedures

The scope of the investigation was to determine the spreading and the aggression of three different brazing alloys on the Inconel alloy 718.\* The chemical composition of this alloy is shown in Table 1. The three different brazing alloys were chosen in order to investigate the influence on the

spreading and aggression of alloying additions at different migration rate; 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 alloy 718. The spreading and aggression determinations were carried out at different brazing temperature for various time, heating the specimens un-

\*Inconel is registered trademark of the International Nickel Company, Inc.

der a vacuum of the order of  $10^{-4}$  Torr. The brazing temperatures were chosen in the brazing range of each filler metal. After heat treatment the drop filler enlargement was measured. After this determination, the specimen was sectioned to correspond to the center of the filler metal drop and the aggression determina-

tions were calculated as the penetration 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 Fig. 1. For the ASTM alloy BNi-5 it may be

seen that different brazing temperatures and different soaking times mean a small increase in spreading of the filler metal (less than 10% diameter increase for the entire brazing range). For the Ni-Mn-Si-Cu alloy, it may be seen that the brazing temperature and the soaking time have a great influence on the drop

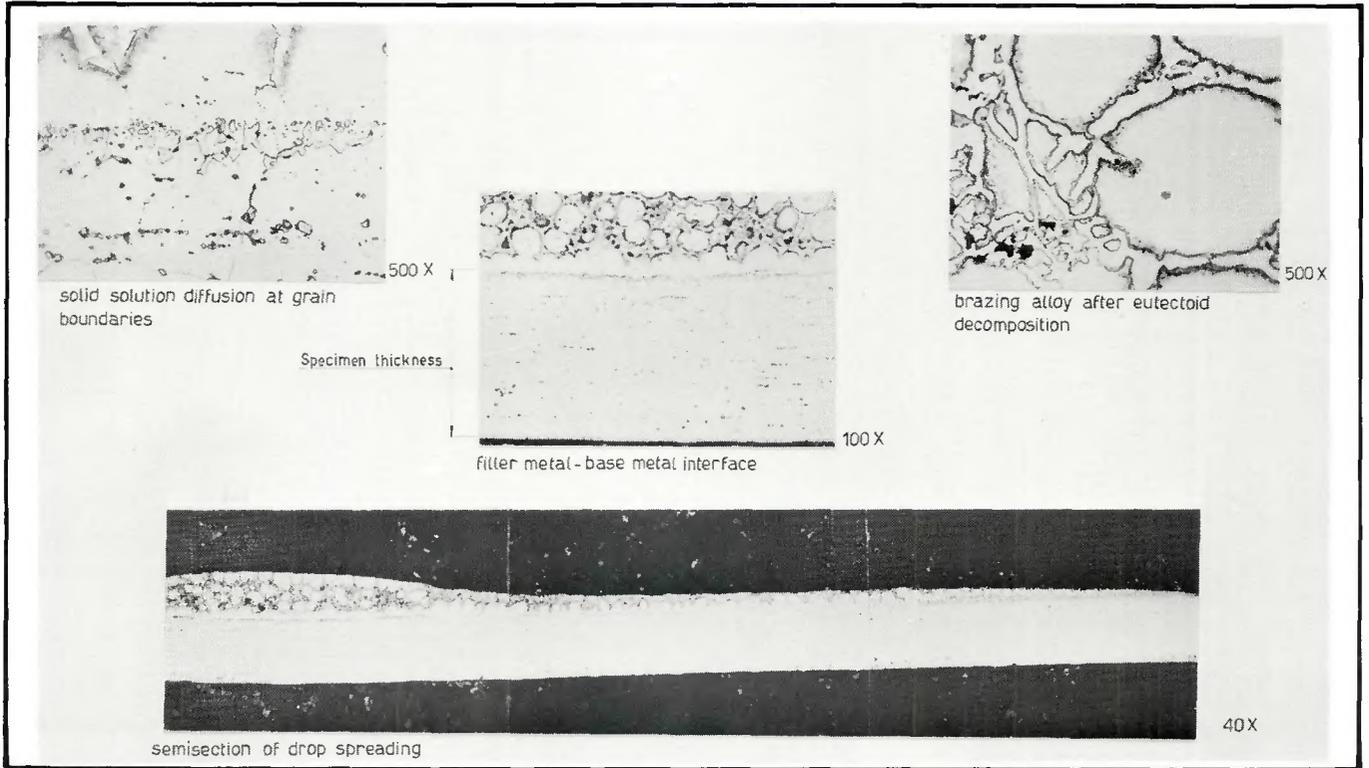


Fig. 3—Drop spreading. Base metal, alloy 718; filler metal, ASTM alloy BNi-5 — brazing treatment: 1200C, 3 hr,  $10^{-4}$  Torr vacuum (reduced 40% in reproduction)

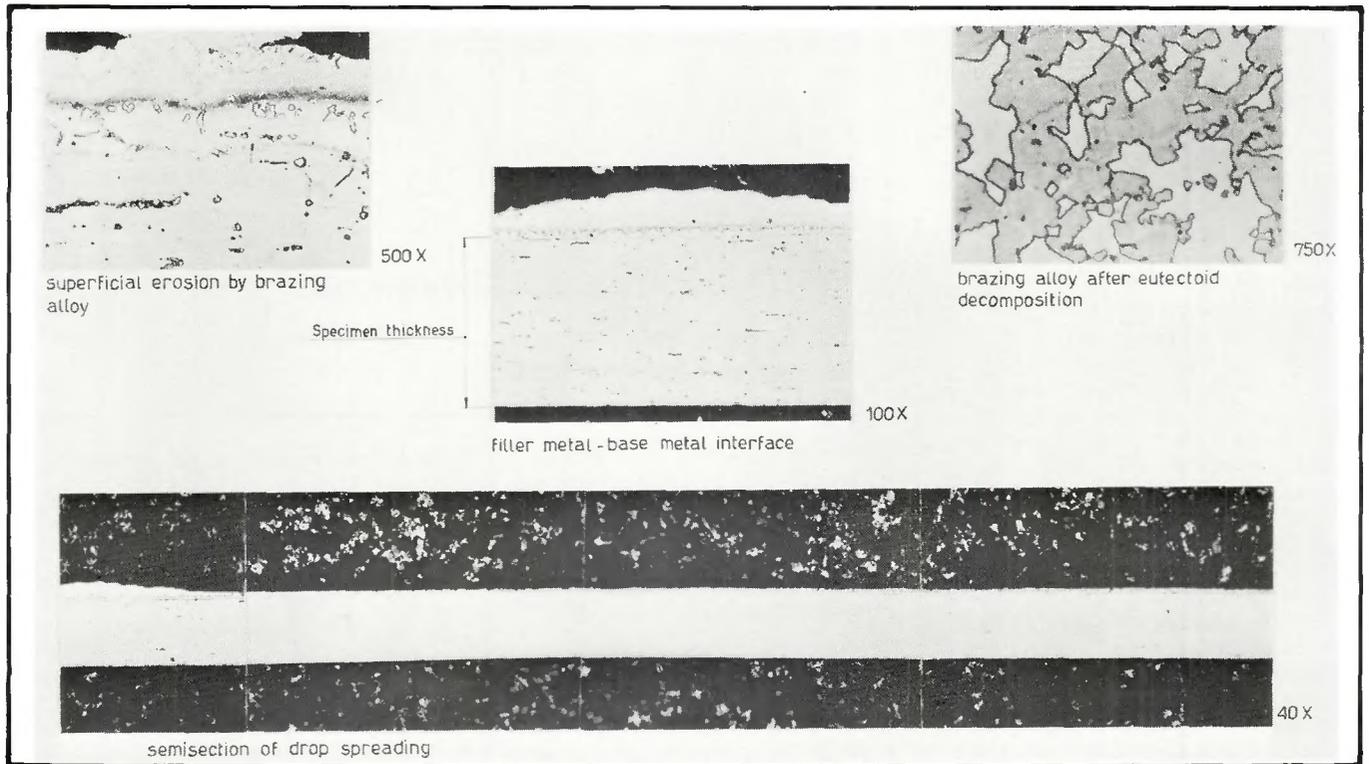


Fig. 4—Drop spreading. Base metal, alloy 718; filler metal, Ni-Mn-Si-Cu alloy; brazing treatment, 1120C, 3 hr,  $10^{-4}$  Torr vacuum (reduced 40% in reproduction)

spreading; in fact, for practical brazing time (0.5-1.5 hr.) the drop diameter enlargement is of the order of 40%. In addition it may be seen that the values of the spreading determinations are at high temperature less independent of the soaking time than at low temperature.

For the ASTM alloy BNi-7, it may be seen that the spreading effect has a saturation value for each time in a range of brazing temperature; in addition it is not needless to observe that spreading saturation occurs for each soaking time at different drop diameter. After spreading saturation is obtained, it is possible to observe a spreading decrease because the aggressive effects of the brazing alloy are prevalent on the wetting and spreading effects.

Concerning the aggressive effects, Fig. 2 summarizes the results obtained. For the ASTM alloy BNi-5, only a grain boundary diffusion of the brazing filler metal or of the compositions very similar to this, is evident (Fig. 3); the brazing filler metal undergoes an eutectoid decomposition with formation of roundish intermetallic compounds and solid solution. It is possible to see that the interfacial zone between the base metal and brazing filler metal is impoverished of the solid solution which is diffused into the base metal.

For the Ni-Mn-Si-Cu brazing alloy, a behavior very similar to that of previous alloy may be seen; also in this case it is possible to note the eutectoid decomposition and the solid so-

lution diffusion (Fig. 4). Since the silicon content of this alloy is less than that of the previous alloy, the diffusion zone is smaller.

For the ASTM alloy BNi-7, a more complicated situation is evident (Fig. 5). In this case, it is possible to see the eutectoid decomposition of the brazing filler metal in dendritic intermetallic compounds and solid solution (Fig. 5a). It is also possible to see the precipitation in base metal grains and at grain boundaries (Fig. 5b) and the grain boundary diffusion and precipitation (Fig. 5c). The net result of these effects is a great erosion of the base metal (Fig. 5d). It is clear that the greater diffusion rate of the alloying element present in the ASTM alloy BNi-7, i.e., the phosphorus, gives to this alloy a behavior more aggressive than that of the filler metals with silicon as alloying element.

### Conclusions

The following main conclusions can be drawn from the performed experiments:

1. ASTM alloy BNi-5 shows small spreading in the entire range of brazing temperature.
2. Ni-Mn-Si-Cu brazing alloy shows acceptable spreading in the entire range of brazing temperature.
3. ASTM alloy BNi-7 shows good spreading, but the spreading stops at a saturation value because the alloy diffusion hinders further spreading.
4. ASTM alloy BNi-5 and the alloy Ni-Mn-Si-Cu show penetration in

the range 10-40 microns for the entire brazing range; this penetration is enough to obtain a satisfactory anchorage of the filler metal on the base metal.

5. ASTM alloy BNi-7 shows a great penetration of the filler metal with erosion of the base metal. The zone affected by the filler metal is in the range 40-180 microns; consequently this filler metal can be used only when great penetration does not influence the performance and the efficiency of the brazed components.

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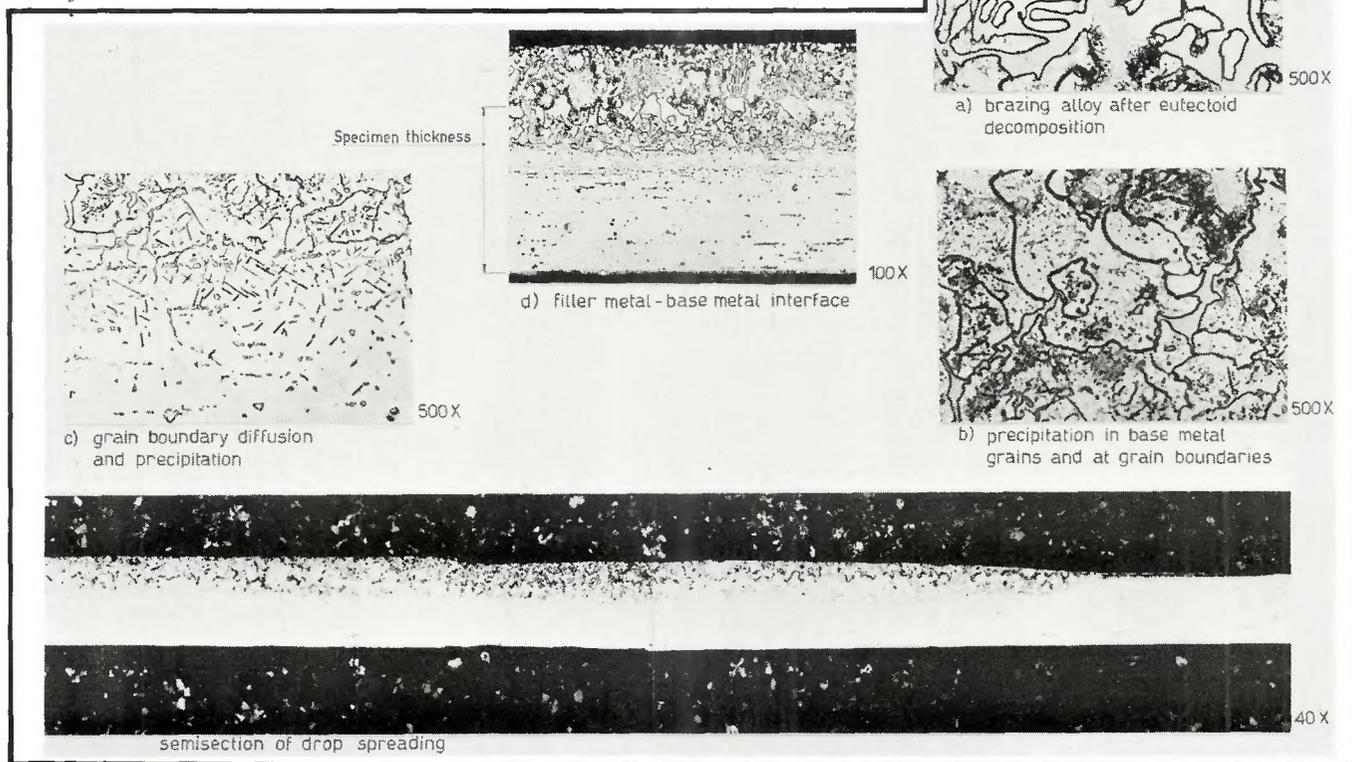


Fig. 5—Drop spreading. Base metal, alloy 718; filler metal, ASTM alloy BNi-7; brazing treatment, 1050C, 3 hr,  $10^{-4}$  Torr vacuum (reduced 40% on reproduction)