Development of a Composite Brazing Wire

During brazing, a phosphorus-bearing brazing filler metal with a powder core and outer metallic shield completely fuses into an homogeneous alloy and subsequently behaves like a conventional BCuP-type filler metal

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Nearly anybody in the brazing profession is used to a guaranteed supply of high quality brazing filler metals in those dimensions and shapes which are most suitable for various specific applications. However, from a metallurgical point of view the near eutectic structure of many of these materials makes them difficult candidates for the highly efficient production methods used in the modern wire industry.

Such materials contain a high percentage of brittle intermetallic compounds. Consequently, they are usually hard and of low ductility at room temperature. This is especially true for the phosphorus-bearing brazing filler metals of the BCuP series, which are widely used for brazing copper in the manufacture of heat exchangers, in the electrical industry and in other applications. Although they are very ductile and easy to form at higher temperatures, severe attack on conventional tool materials by the phosphorus prevents the use of high-temperature forming processes such as extrusion. On the other hand, phosphorus-bearing filler metals are very brittle at room temperature. Therefore, the high speed drawing and forming machines used for the production of "ordinary" metals such as copper or aluminium wires cannot be employed in their manufacture. It is probably no great error to assume that a large percentage of the cost of these brazing filler metals in wire form is caused by the special forming operations needed for their manufacture.

Fig. 1—The composite brazing filler metal wire consists of a powder core, which is tightly enclosed by a metal sheath

After various unsuccessful attempts by the authors to markedly improve the production economics of BCuP type wires by the existing wire making technology, a completely new approach led to the development of composite brazing filler metal wires. The new wires resemble basically the well-known flux cored welding rods and can likewise be produced by a high speed forming operation. Although development work concentrated on a brazing filler metal with 7% phosphorus, the concept of composite brazing filler metal wires outlined in this paper can in principle be applied to any filler metal.

The paper describes the structure of the newly developed composite brazing filler metal wires and various factors leading to the trial manufacture of a filler metal wire with a total composition of Cu-7%P-5%Sn. The paper discusses its melting and brazing characteristics as well as the properties of joints brazed with it.

Concept of Composite Brazing Materials

Conventional brazing filler metals are melted at least two times: once when the alloy is produced from its individual elements or by adding a mother alloy to the base metal, and a second time during brazing. The development of composite brazing materials started from the basic idea that it should be possible and more economical to perform these two melting operations simultaneously during brazing.

According to this concept, the individual constituents of the brazing filler metal are intimately mixed and placed in the joint area. Upon heating to the brazing temperature, the individual elements diffuse into each other. The process of equilibration by diffusion is strongly accelerated after the constituent with the lowest melting temperature has melted. Finally, complete fusion of the mixture leads to an alloy, which not only has the required composition but also has the same properties as a conventional brazing filler metal.

The viability of this basic concept was checked in initial experiments using various mixtures of copper and phosphorus or Cu-P alloy powders. Figure 2 compares the flow characteristics of commercial BCuP-2 with that of a powder mixture having the same total composition. In this experiment the powder was compacted to 65% of its bulk density. Heating was carried

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out in a furnace for about 4 min.

Figure 2 shows that the compacted powder completely fused and that spreading over the copper substrate is similar for both materials. However, melting and flow of the powder mixture required a higher temperature. This is due to the complex diffusion processes, which precede fusion and which are necessary to decrease the melting point of the high melting constituent (in this case the copper powder). Further investigations showed that the melting temperature of powder mixtures can be decreased in the following ways:

1. Increasing the compaction of the powder mixture to increase the contact of its constituents.
2. Selecting powders with low melting points.

These results served as a basis for extending the concept outlined above to brazing filler metal wires.

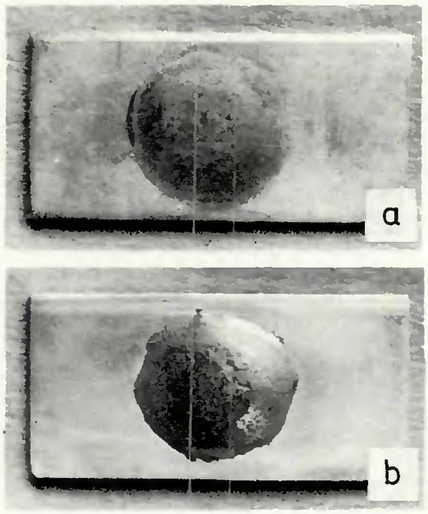


Fig. 2—Spreading characteristics of (a) BCuP-2 filler metal and (b) a compacted power sample heated in a furnace at 800 and 830 C respectively

Development of Composite Brazing Wires

The Structure

The newly developed composite brazing wires consist essentially of a powder core, which is tightly enclosed by an outer metal sheath—Fig. 3. Although various configurations can be visualized for such a composite wire, the one shown in Fig. 3 was selected mainly because of its ease of fabrication. Here the sheath tape is wrapped around the core in the length direction of the wire. An overlap of between 90 and 180 deg ensures a tight enclosure of the core and protects the core powder against deterioration during storage. It also provides the wire with the necessary stiffness for easy handling during the brazing operation.

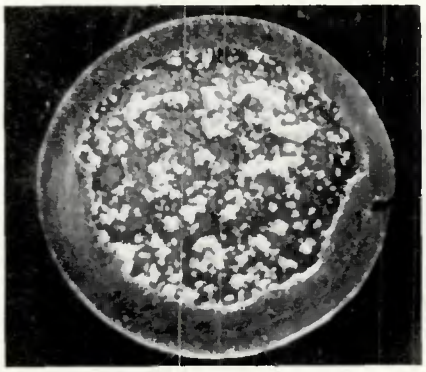


Fig. 3—Cross section of composite brazing wire. ×26

The core contains those elements of the brazing filler metal which cause embrittlement of the conventional alloy. It thus may consist mainly of copper plus phosphorus or Cu-P alloy powders. Additional elements required for certain brazing operations can also be included in this powder mixture. On the other hand, the outer sheath is made from a copper or copper alloy tape.

During brazing the composite wire has to fuse into an homogeneous alloy. Therefore, its brazing characteristics are determined—as for the powder mixtures discussed above—by the compaction of the core during fabrication and by a suitable selection of the sheath and core materials.

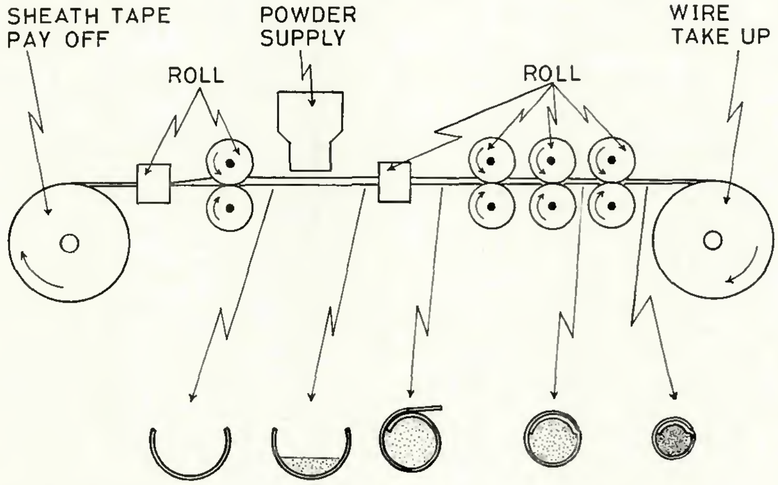


Fig. 4—Schematic illustration of manufacturing process

The Production Process

The composite brazing filler metal wire was manufactured by a continuous roll forming process—Fig. 4. Here the sheath tape is first formed into a U-shape, which receives the core powder. Feeding of the core powder is synchronized with the tape speed to ensure a constant composition of the final wire. Subsequently, the edges of the tape are formed to the required overlap. The final rolls reduce the wire to its desired diameter and provide for the necessary compaction of the core.

Figure 5 shows the change of core compaction and wire composition during roll forming of the composite filler metal wire to progressively smaller diameters. It is seen that the compaction of the core increases with decreasing wire diameter, and a density of up to 80% of the bulk density can be obtained. On the other hand, the composition of the wire stays constant, indicating that the sheath and core deform homogeneously during rolling. Thus the composition of wires with various diameters is uniquely determined by the compositions and weight ratios of the sheath and core materials.

Experiments showed that the mini-

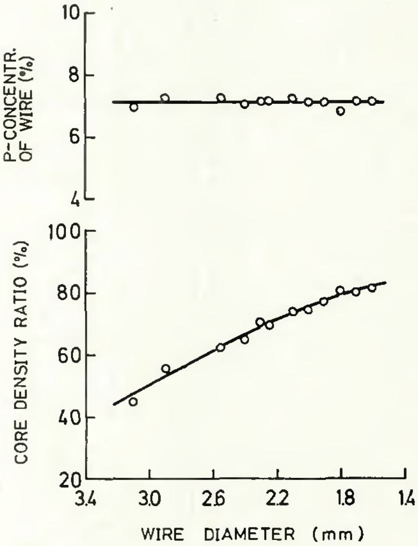


Fig. 5—Change of composition and core compaction during roll forming of composite brazing wire. Core density is given in percentage of bulk density

Table 1—Composition and Thermal Properties of Various Composite Brazing Filler Metal Wires and Commercial Brazing Filler Metals (the standard composite wire was used for a detailed evaluation of brazing characteristics)

	Sheath material			Brazing filler metal					
		Melting temp., C		Composition, %					
Type of filler metal	Composition	Solidus	Liquidus	P	Ag	Sn	Cu	Melting temp.,[c] C	Solidif. temp., C
Composite wire A[a]	Pure Copper	1083	1083	7.0	—	—	Bal.	845	706
Standard composite wire[a]	Cu-8%Sn-0.02%P	880	1020	7.0	—	4.6	Bal.	785	669
Composite wire B[b]	Cu-2.5%P	714	1010	7.0	—	—	Bal.	754	704
BCuP-2	—	—	—	7.0	—	—	Bal.	726	708
BCuP-3	—	—	—	7.0	5.0	—	Bal.	691	676

[a] Core is Cu-15%P alloy powder.
[b] Core is Cu-8%P alloy plus pure phosphorus powder mixture.
[c] Shows the temperature at which the filler metal starts to flow when heated in a furnace to 900 C.

mum core compaction ratio for easy handling and favorable brazing characteristics is 60% of the bulk density. Therefore, it is recognized from Fig. 5 that all wire diameters smaller than 2.6 mm (0.10 in.) can be produced from the same initial combination of sheath and core materials.

The Sheath Material

As can be expected from the initial experiments with powder mixtures, the melting point of the sheath material has a strong influence on the melting temperature of the composite brazing wires. This is evidenced by the data in Table 1, which show this dependency for three selected sheath materials. Although all three materials showed good flow after fusion at their respective temperatures, the obvious choice of a copper tape can only be employed if the higher brazing temperatures are of no concern. In order to obtain brazing temperatures similar to the reference BCuP-2 filler metal, alloy tapes have to be used. In consideration of commercial availability, the phosphorus bronze was selected as standard material for the composite brazing filler metal wire.

The thickness of the sheath also influences the time required for fusion of the composite wire and thus the brazing temperature. However, roll forming of the tape gets to be difficult for very thin tapes. Furthermore, a certain tape thickness is required to provide sufficient stiffness to the wire. Best results were obtained with a sheath tape of 0.2 mm (0.0079 in.) thickness.

The Core Material

The core of the composite brazing wire contains phosphorus and enough copper to balance the overall composition. Initial experiments with a mixture of copper and phosphorus powders gave inconsistent and high brazing temperatures. Good results were obtained, however, with Cu-P alloy powders having a phosphorus content of 8% or 14% depending on the total amount of phosphorus required. Small additions of either copper or phosphorus powders can be made to the basic alloy powder for adjusting the total composition without impairing the brazing characteristics of the wire.

The particle size of the core powder has little influence on the brazing characteristics, but it has to be small enough to allow sufficient compaction during roll forming. In all experiments powders finer than 100 mesh (particle size smaller than 149 μ) were used and found satisfactory.

The Standard Composite Brazing Filler Metal Wire

The results obtained during the development of the composite brazing wire showed that, by choosing the appropriate sheath and core materials, these wires can be tailored to meet specific needs. However, in order to study their properties in greater detail, a standard composite wire was selected and manufactured under closely controlled conditions on a trial basis. In this way larger amounts of wire with constant and homogeneous properties were obtained.

The standard composite brazing filler metal wire was manufactured from the following materials:

1. Sheath material: phosphorus bronze (Cu-8%Sn-0.2%P).
2. Size of sheath tape: 0.2 mm × 15 mm (0.0078 in. × 0.59 in.).
3. Core powder: Cu-15%P.
4. Core compaction: 80% of bulk density.

The total composition of the resulting wire is given in Table 1 and may be compared with the corresponding values of the conventional BCuP-2 and BCuP-3 brazing filler metals. The use of a phosphorus bronze for the sheath tape resulted in a total tin content of 4.6% in the composite wire.

Properties of Standard Composite Brazing Filler Metal Wire

Melting Behavior

Table 1 compares the melting and solidification temperatures of clad composite wires with those of the conventional filler metals. In obtaining

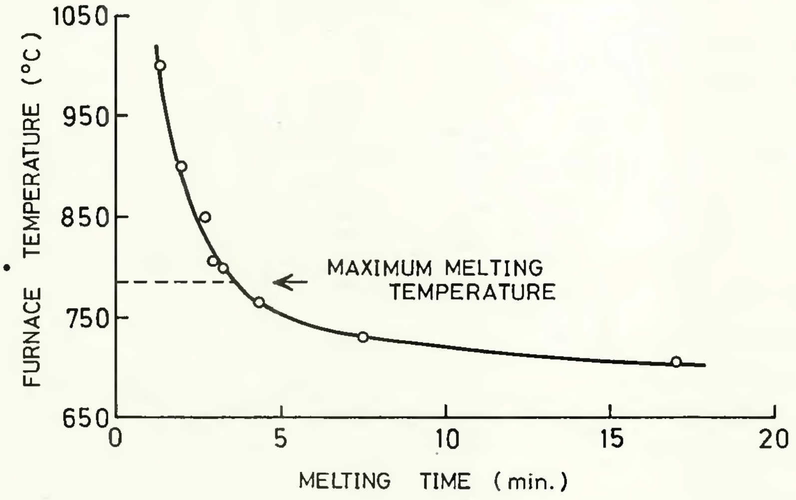


Fig. 6—Time required to melt the standard composite brazing wire at various furnaces temperatures. Below the maximum melting temperature the furnace temperature corresponds to the melting temperature of the wire

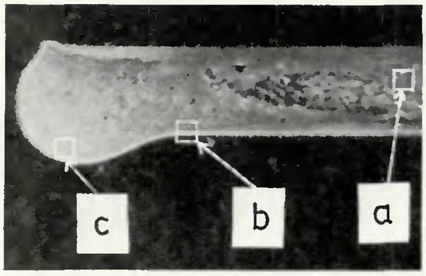


Fig. 7—Transverse cross section through a standard composite brazing wire, the tip of which had been melted in an acetylene torch. ×9 (reduced by 28% on reproduction)

these data, small samples of the various filler metals were placed on a copper substrate heated in a furnace of 900 C (1652 F). By continously monitoring the temperature of the samples, their melting temperature was determined to be that temperature at which they started to flow over the substrate. During subsequent air cooling, the temperature at which the filler metals completely solidified was measured.

Two important characteristics of the composite brazing filler metal wires can be deduced from the data in Table 1. First, the melting temperature of these wires is lower than the melting temperatures of the respective sheath materials. This indicates that, during heat-up, diffusion between the core and the sheath causes a pronounced reduction of their melting points. Further, the solidification temperatures of the composite brazing wires are much lower than their melting temperatures.

Composite wires containing only phosphorus solidify at the same temperature as the BCuP-2 alloy. The lower solidification temperature of the standard composite brazing filler metal wire is due to its tin content. This result proves that, after their various components are melted, the composite brazing wires completely fuse into a homogeneous alloy having a solidification point specific for its total composition.

Since diffusion processes play a great role for the melting of the composite brazing wires, their melting temperatures depend on the heating time. To investigate this time-dependency, small samples of the standard composite brazing wire were heated in a furnace to various temperatures. The time required to completely melt the samples and the melting temperature were recorded. The results plotted in Fig. 6 show that the composite brazing wire has a maximum melting temperature of 785 C (1445 F).

Setting the furnace at a higher temperature results in decreased melting times only because less time is required to heat the samples to their maximum melting temperatures. However, complete melting of the composite brazing wire could also be realized at temperatures below 785 C (1445 F). In this case the samples had to be kept at the furnace temperature for times which strongly increased with decreasing temperatures. For very long holding times, the melting temperature even approaches the solidification temperature of the molten alloy.

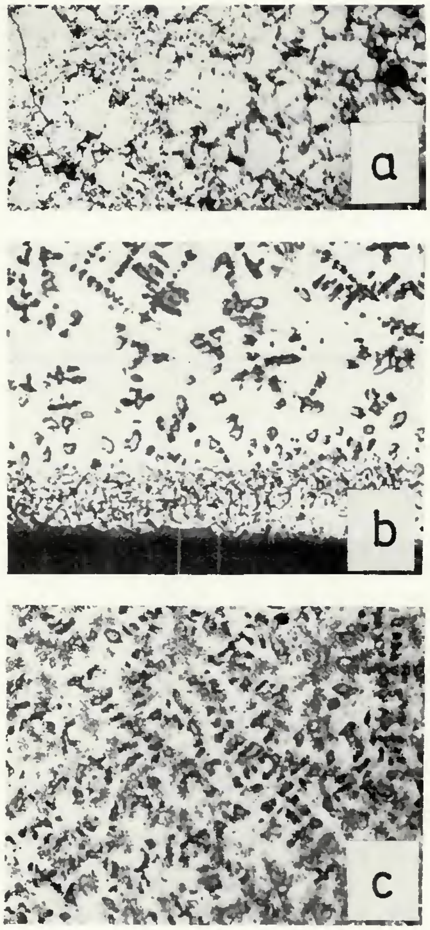


Fig. 8—Micrographs of selected areas of the sample in Fig. 6 showing various stages of melting the composite brazing wire: (a) powder core; (b) reaction between molten core and sheath tape; (c) structure of completely alloyed wire tip. ×150

These results, also, are a direct consequence of the diffusion processes which precede melting of the composite brazing wire and cause a reduction of the melting point of the sheath material. Thus, in order to melt the composite wire at lower temperatures, a greater amount of diffusion is required. Melting times are also increased by the influence of decreasing temperatures on the diffusion rate.

The processes leading to the melting of the composite brazing wire were further studied by examining the cross section of a wire sample, the tip of which had been melted by a torch—Figs. 7 and 8. The temperature gradient which existed along the axis of the wire allows the simultaneous observation of the various stages of melting. It is recognized that melting starts in the core material and, subsequently, the sheath progressively dissolves in the molten core. Since the sheath tape has better heat conductivity than the compacted core powder, initial melting of the core occurs in the region adjacent to the sheath. Therefore, the reactions between the core and the sheath will start even before the whole core has melted.

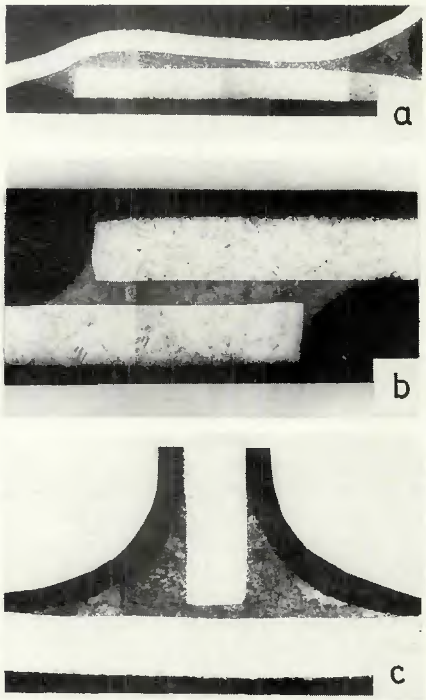


Fig. 9—Examples of joints brazed with the standard composite brazing wire

The micrographs in Fig. 8 show that dissolution of the tape occurs by attack along the grain boundaries and that small particles of tape material are floating into the molten core. At the tip of the wire a droplet of homogeneous alloy has formed. Its structure is similar to that of a conventional brazing filler metal. Investigations of a large number of samples confirmed that the sheath material completely dissolves and alloys with the core material.

The melting behavior demonstrated in Fig. 7 is important for the successful application of the clad brazing wire. As melting proceeds from the core outwardly into the sheath, the molten core is contained by the sheath tape until complete fusion takes place. This ensures that during brazing the flow of the filler metal occurs only after complete alloying.

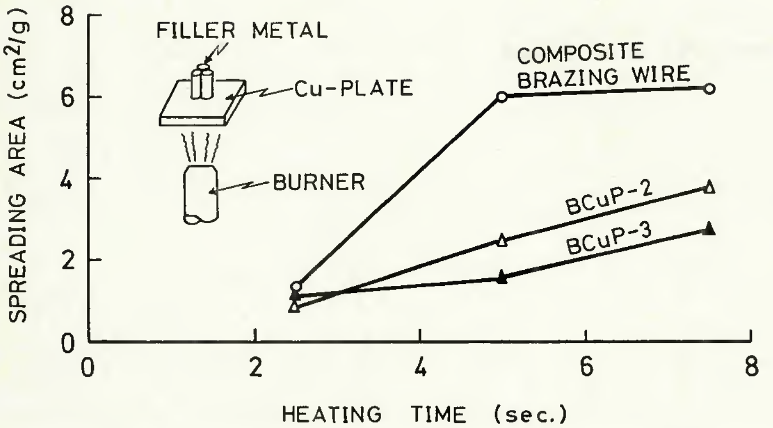


Fig. 10—Spreading area of various brazing filler metals as function of heating time. Flow of the filler metals started after heating for 2.5 s

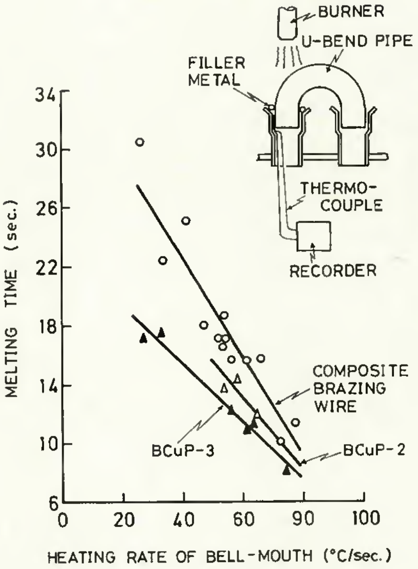


Fig. 11—Influence of heating rate on the time required for melting various brazing filler metals during torch brazing of pipe joints; the difference in melting times for the various filler metals decreases with increasing torch strength

Brazing Characteristics

In order to study the brazing characteristics of the composite brazing filler metal wires, the wetting properties and the required brazing times were investigated in detail.

Figure 9 shows various copper joints, which were torch brazed with the standard composite brazing filler metal wire. In all cases the excellent flow of the filler metal is recognized from the complete filling of the joint gap and the low contact angle between the filler metal and the copper base. The structure of the filler metal is homogeneous in that it shows no remnants of the sheath material. Thus the joints are similar to those brazed with a conventional filler metal.

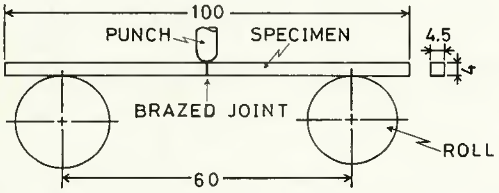
The wetting properties of various filler metals were measured in more detail by a simple spreading test indicated in Fig. 10. Using a burner of constant strength to heat the copper substrate, the filler metals melted after 2.5 s. The specific spreading areas obtained after further heating show superior flow characteristics of the standard composite brazing wire.

The brazing times for composite brazing wires in furnace brazing are influenced by the time dependency of the melting temperature shown in Fig. 6. However, in the case of torch brazing, which is by far the greatest application of the present filler metal, the stronger heating rate allows total brazing times similar to those obtained with a conventional BCuP-2 filler metal.

The melting rate of the standard composite brazing filler metal wire was obtained from the maximum velocity at which it could be fed into the flame of an acetylene torch of constant strength. Using a wire of 1.8 mm (0.071 in.) diameter, the melting rate was 144 mm/min (5.67 ipm). The corresponding values for the BCuP-2 wires of the same diameter were 138 mm/min (5.43 ipm) and for BCuP-3 wires 186 mm/min (7.32 ipm). These results indicate that with manual torch brazing the composite brazing filler metal wire will require brazing times similar to BCuP-2.

To study the brazing times under conditions resembling automatic torch brazing, copper pipe joints similar to those found in heat exchangers were brazed in an arrangement shown in Fig. 11. The strength of the torch was varied to allow various average heat up rates of the joint, and the time to completely melt the filler metal was measured.

Results showed a difference in melting times for the various filler metals according to their melting temperatures. This difference decreases with increasing heat-up rate, i.e., with the strength of the burner. However, because of the better flow characteristics of the standard composite brazing wire (Fig. 10) subsequent joint gap penetration proceeded more rapidly than in the case of the BCuP-2 filler metal. Therefore, the total brazing times necessary to ensure



FILLER METAL	NUMBER OF SAMPLES TESTED	NUMBER OF FRACTURED SPECIMENS
COMPOSITE BRAZING WIRE	10	0
BCuP-2	10	3
BCuP-3	10	0

Fig. 12—Results of bending tests on specimens which were brazed with various filler metals; punch radius is 6 mm (0.24 in.) and bending proceeded up to a bending angle of 170 deg

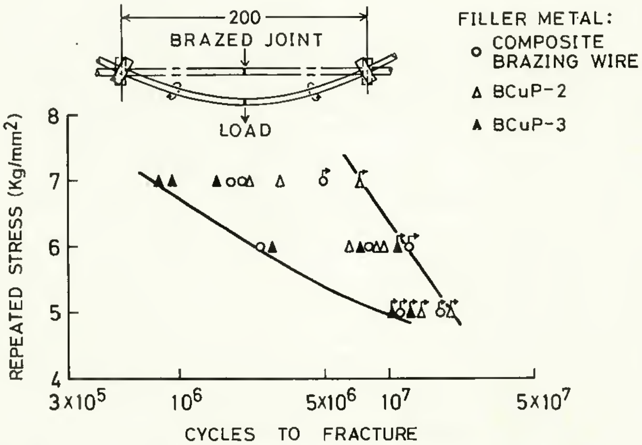


Fig. 13—Fatigue life of wire samples, which were brazed with various filler metals; points indicated by an arrow show fatigue lives higher than number of test cycles

complete filling of the joint gap were similar for both materials. Using a heat-up rate of 60 C/s, it amounted to about 19 s.

The above results indicate that, despite the different structure of the composite brazing material and despite its complicated melting process, the brazing characteristics are similar to those of the reference BCuP-2. Brazing can be carried out in conventional ways using usual operation procedures.

Joint Properties

Metallographic observation of joints brazed with the standard composite brazing wire showed a structure similar to that of conventional brazed joints—Fig. 8. To further investigate the quality of the joints, their mechanical properties were studied by bending and fatigue tests.

The bending tests were carried out with square copper wires, which had been butt brazed with the various filler metals. A three-point bending arrangement shown in Fig. 12 was employed. All samples brazed with the standard composite brazing wire, and the BCuP-3 brazing filler metal sustained the bending operation up to 170 deg bending without fracture. On the other hand, three samples brazed with the BCuP-2 brazing filler metal broke in the joint at bending angles between 65 and 110 deg, indicating the inferior ductility of this filler metal.

Figure 13 shows the results of the fatigue tests. For these experiments, brazed copper wire joints were prepared and elastically bent by applying a load to the joint as shown. Simultaneous rotation of the samples around their axis caused alternate tensile and compressive stresses, which are highest at the brazed joint. The number of cycles to fracture measured at three cyclic stress levels indicates that the fatigue lives of the samples brazed with the standard composite brazing filler metal wire are similar to those brazed with the conventional filler metals.

Handling of the Composite Brazing Wire

During brazing, the composite brazing filler metal wires can be handled in the same way as are conventional brazing filler metals since the sheath material provides sufficient stiffness to the wire. However, in contrast to the hard and brittle BCuP-2 filler metals, the composite brazing wire is easily bent into different shapes to provide brazing preforms for automated brazing. Samples having a diameter of 1.8 mm (0.071 in.) can be bent to a radius of less than 6 mm (0.24 in.) without fracture of the sheath tape.

Conclusion

A phosphorus-bearing brazing filler metal for copper has been developed; it consists of a powder core and an outer metallic sheath. During brazing, this composite brazing filler metal wire completely fuses into an homogeneous alloy and subsequently behaves in the same way as a conventional brazing filler metal of the BCuP-type.

A detailed investigation of the composite wire's melting and brazing characteristics confirmed that brazing can be carried out in conventional ways using normal brazing procedures. Easy fabrication and good formability will make the wire attractive for many applications. The basic concept of composite brazing wires outlined in this paper may in principle be extended to a variety of brazing and welding filler metals.