Economic Aspects of Silver Alloy Brazing

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Johnson Matthey Metals Limited

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The majority of metal objects which play a part in our everyday lives are usually assemblies of two or more parts held together by one of the joining processes available to the engineer. He can employ any one of a multitude of mechanical fastening methods, adhesive bonding, welding, soldering and, of course, brazing. This survey is concerned with some of the economic aspects affecting just one part of the brazing technology: that of silver alloy brazing.

Although the brazing process has been known to man for some 2,800 years it has been reported that silver alloy brazing was first used in the industrial sense during 1865 to effect a repair in the transatlantic telegraph cable: the repair being carried out on board ship in the Atlantic. If true, this would tend to indicate that the development of silver-containing brazing alloys for industrial applications pre-date this by at least several years. It is known with certainty that during the last few years of the nineteenth century alloys from the silver-copper-zinc system were first used for the brazing of brass blades used in the construction of steam-driven turbines.

No further developments seem to have occurred until the early 1930's when workers in America added cadmium to the silver-copper-zinc alloy system and deliberately produced the first silver brazing alloys having solidus temperatures around 610ºC. (It has been said that the work of some German metallurgists pre-date the American development by some fifteen years or so, but the author has been unable to find any documentary evidence to support this claim.) From this it seems clear that the industrial use of silver-containing brazing alloys is a relatively new development; but a development, nevertheless which has allowed high speed, economic, mass production brazing techniques to become part of modern industry.

Mechanization

The traditional heating method employed for brazing is the hand torch. Despite an increasing tendency to mechanize brazing processes, probably a greater volume of work is still carried out by the older method than any other. Hand torches are most efficiently employed for low volume production, for short runs of changing work, for brazing a number of widely separated joints on massive assemblies, and for site brazing. The method has the advantage that it is flexible, and the capital investment in equipment and its maintenance is low when compared with that of other heating methods. The apparatus is also simple, and its operation is easily understood. A further advantage is that if interruptions in the production flow leave the equipment idle, even for extended periods, little cost is incurred since the only cost during this idle time is that of the small amount of floor space which it occupies.

Table 1

Effect of Operator Fatigue on Brazing Speed.

(a) Test conducted at 11.00 a.m. (Output about 220 joints an hour.)

Weight of alloy per joint g	Time per joint seconds*
1.54	16.0
1.62	17.0
1.58	16.0
1.53	16.5
1.64	15.8
1.60	16.2
1.61	17.1
1.57	16.8
Average 1.586	16.423

(b) Test conducted at 4.00 p.m. (Output about 181 joints an hour.)

Weight of alloy per joint g	Time per joint seconds*
1.55	20.2
1.59	19.7
1.58	19.2
1.62	19.9
1.63	20.0
1.59	21.1
1.54	19.8
1.60	18.8
Average 1.587	19.827

*This does not include assembly time, this being done elsewhere.

Off-setting these advantages, however, is the fact that the cost of a joint produced with a hand torch includes a high labour content. Moreover, it is necessary to employ a skilled man, who will command a relatively high wage rate. Additionally, the output of finished joints an hour is usually low, and joint reproducibility cannot be guaranteed with this source of heat.

For instance, some time ago it was decided to carry out a series of tests to determine the degree of accuracy that a highly skilled operator could achieve when hand torch brazing a simple tube-to-fitting joint (Fig. 1). It was decided to determine accurately the amount of alloy used for each joint, the time taken to produce each joint, and to project this time to determine the hourly output of finished work. Additionally, the test was carried out twice on the same day to determine what part, if any, operator fatigue played in the overall process. The results of these tests are set out in Table 1. It is interesting to note that although the average amount of alloy used for each joint remained virtually constant, the time taken to produce the joint increased as the operator became more fatigued. Under the test set conditions the following data was obtained.

(i) A minimum alloy usage of 1.54 g per assembly.
(ii) A maximum alloy usage of 1.64 g per assembly.

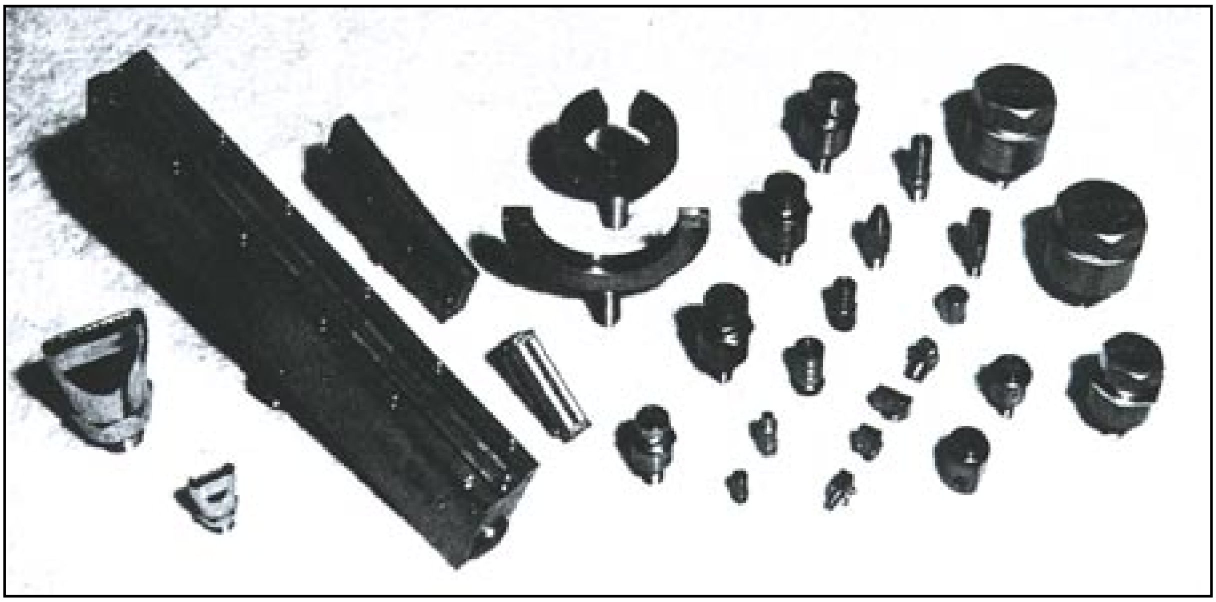
Thus assuming that 1.54 g is the minimum quantity of alloy necessary to produce a satisfactory joint, then the amount used under the test conditions varied by a maximum of 6.5 per cent.

Further, so far as the time factor is involved, by using similar criteria as a basis for the evaluation, one has a maximum variation of 13.4 per cent from the norm of 15.8 s. With such wide variations inherent in the process, it is clear that no precise costing of this particular job is possible except by using the maximum values of alloy usage and time taken to complete the work as the basic parameters. Under these conditions, the resultant piece-part cost is high when compared to the cost of producing the identical part by a mechanized flame brazing technique, as the tables presented later in this article will show.

Fig. 1 Simple tube-to-fitting joint used for the costing exercise

With such marked variations being commonplace with hand torch brazing processes, it is not surprising that production engineers have been forced to examine methods of mechanizing the brazing process so as to eliminate as many of these variables as possible. The process of mechanizing brazing applications is, in fact, a trend which has grown over the past decade. This has been brought about by a substantial increase in the level of brazing activity, which has resulted in an increasing use of the process for medium- and large-scale production runs, where the need is to speed up the

Fig. 2 Typical examples of the wide variety of high intensity burners which can be used for fixed torch heating



manufacture of standard parts and to minimize the use of skilled operators and costly inspection procedures. The application of fixed torches to such production processes affords the first step in mechanization.

With hand torches, the skill of the operator is relied upon to develop the necessary heat pattern, but with fixed torches the heat pattern is predetermined. Burners of special design (Fig. 2) allow rapid localized heating and, in consequence, provide far higher production rates than those attainable with hand torches. Moreover, since the heat patterns are predetermined, only semi-skilled labour need be employed; an immediate, and direct, saving in production costs. Additionally, variations in the amount of alloy used to produce each joint can be eliminated by the use of brazing alloy preforms. This feature, coupled with the fact that by using suitable timing devices in association with solenoid valves it is possible to construct machines which will braze a whole series of components at a predetermined rate, means that the time variation, present with hand torch brazing, can be eliminated.

Rotating tables (both continuously rotating and indexing types) and conveyor belt systems are frequently introduced into fixed torch arrangements. Almost invariably in such instances, the torches can be situated on either side of the work-track. This configuration makes it possible for the operator to produce consistent results continuously.

In addition to fixed torch heating, other methods such as induction heating, resistance heating and controlled atmosphere furnace brazing can play a valuable part when mechanized brazing is being considered. However, since the vast majority of automatically silver alloy brazed joints are produced with fixed torch arrangements this is not the place to consider the other heating methods available in any great detail.

Induction Heating

As far as mechanized induction brazing is concerned, it can really only be considered feasible if the components to be joined are of simple section and, ideally, made of ferrous materials. The induction brazing of ferrous metals to copper, brass, and other copper-base alloys can be difficult to accomplish and, even if success is achieved, it is almost always true that flame heating could work more quickly, utilizing equipment which is far cheaper to install and operate than the necessary induction equipment.

Resistance Heating

Resistance heating can be an efficient way of producing a brazed joint. This is especially so when the brazing of copper to copper using direct resistance heating and a preform made from an alloy from the silver-copper-phosphorus system (e.g. Sil-fos) is being considered. As is well known, alloys from this system require no additional flux when used for brazing copper to copper even when brazing is carried out in air. However, the process is not widely used and in consequence mechanized resistance brazing installations are few and far between.

Protective Atmosphere Furnace Brazing

Protective atmosphere furnace brazing, on the other hand, is widely practised. In many instances, however, this particular process is employed when it is required to join ferrous components and, in such applications, copper is frequently the preferred filler metal. Naturally, there are also examples where such furnaces are employed for the fluxless brazing of components using silver brazing alloys, typified by the silver-copper eutectic alloy, or the 60% silver-30% copper-10% tin material, but set against the background of conventional fixed torch and hand torch brazing, such installations account for probably less than 5% of the whole. Thus, for the purposes of this survey it is proposed to consider only the economics of flame heating brazing methods.

Costing

Earlier in this article an example of the inherent variability of the hand torch brazing process was shown. At that point it was mentioned that later the hand torch brazing job used for the example would be compared with the same components produced by a mechanized flame brazing process. Having now covered the basic differences between hand torch and fixed torch heating, this can now be done. The details of this costing exercise are set out below:

A. *Hand Torch Heating*: Tube-to-fitting joint (Fig. 1) (Oxy-acetylene):

1. Total output per year: 3,600,000
2. Hourly output per man: 180
3. Hours worked per year: 2,000
4. Numbers of men employed:
   Skilled men: 10
   Semi-skilled men: 5
5. Hourly wage rate:
   (i) Skilled men: £0.60 per hour
   (ii) Semi-skilled men: £0.45 per hour
   ∴ Annual wage cost of a skilled man
   = £0.60 x 2,000
   = £1,200

Thus total wage costs for ten skilled men
= £1,200 x 10
= £12,000

Similarly, annual wage cost of a semi-skilled man
= £0.45 x 2,000
= £900
∴ Total wage costs for five semi-skilled men
= £900 x 5
= £4,500

Thus, total wage costs for the operation
= £12,000 + £4,500
= £16,500 per annum. . . . . .A

6. Factory operating costs
   These include:
   - (i) Rates, lighting, heating
   - (ii) Social security benefits for employees
   - (iii) Pension fund contributions paid by the employer
   - (iv) Other miscellaneous items.

   In practice, these four items amounted to 125 per cent of the labour cost in wages of the men employed
   ∴ Operating costs
   = £16,500 x 125 per cent
   = £20,625. . . . . .B

7. Brazing material costs
   - (i) Alloy costs
   - (ii) Flux costs

   (i) *Alloy costs*
   Each joint needs 1.64 g
   ∴ 3,600,000 joints need:
   3,600,000 x 1.64 g
   = 5,904 kg
   But, 1 kg of the alloy used costs £15.15 (Table 4).
   ∴ Total alloy cost
   = 5,904 x £15.15
   = £89,445.6. C

   (ii) *Flux costs*
   Flux purchases by company in a year was 3,125 kg
   Flux price £0.9 per kg
   ∴ Flux cost
   = 3,125 x £0.9
   = £2,812.5. . . . . D

8. Equipment amortization
   The company concerned wished to amortize their equipment over a three-year period.
   ∴ Amortization rate = $33\frac{1}{3}$ per cent of equipment cost per year
   = $33\frac{1}{3}$ per cent x £250
   = £83.3 per annum. . . . . .E

9. Total cost of manufacture by hand torch brazing. The total cost of manufacture of the parts is arrived at by adding the final figures shown under headings 5, 6, 7 and 8.

∴ Total costs = A+B+C+D+E
= £16,500 + £20,625 + £89,445.6 + £2,812.5 + £88.3
= £129,466.4

$$\therefore \text{Cost per item} = \frac{£129{,}466}{3{,}600{,}000} = 3.596\text{p}$$

B. *Fixed Torch Heating*. In this instance, two continuously rotating table machines were employed, three operators being employed on each table. Using the identical costing parameters set out for hand torch heating, the costs derived in this case were as follows:

1. Operator wage costs . .	£5,400	
2. Overhead costs . .	£6,750	
		£12,150
3. Alloy cost	£82,890	
4. Flux cost	£2,812.5	
		£85,702.5
5. Equipment amortization	£1,000	
		£1,000
Total cost . .		£98,852.5

6. Number of units being brazed — 3,600,000

$$\therefore \text{Cost per item} = \frac{98{,}852.5 \text{ x } 100\text{p}}{3{,}600{,}000} \text{ each}$$
$$= 2.746\text{p each}$$

From the costing figures that have been produced it is clear that by mechanizing this particular brazing process, the company derived three major benefits:

1. Productivity has been greatly improved.
2. The cost of manufacturing the item has been reduced by approximately 24 per cent.
3. Even by maintaining the profit level constant, the manufacturer can reduce the price to the customer if he wishes so to do.

(It should be noted that no separate provision has been made in the above costing for fuel gas costs. Under normal circumstances such provision would be made, but in this particular instance the fuel gas costs, both for hand-torch and fixed torch brazing, were included under Item 6, “Factory operating costs”, by the company concerned.)

Recent Developments

When using automatic heating equipment, the usual procedure is for the operator to flux the components with an aqueous flux paste, assemble them, locate the alloy preform (either before or after final assembly), locate the assemblies in a jig and subsequently commence the heating cycle. As has been shown, the automation of the specific example used in this article has resulted in a substantial cost reduction of the finished parts. Where, then, can one look for further economies? The only area where further savings might be effected in current automated processes is in the fluxing and alloy preplacement process. If it were possible to locate brazing alloy and flux in the joint, at just the right point in precisely predetermined quantities, using automatic dispensing equipment two major advantages could be achieved.

1. The labour content of the brazing operation could be reduced still further.
2. In some circumstances, automatic loading of the parts into their jigs would be possible and a much higher level of output could be achieved.

American, British and West German industry has recently invested a considerable amount of time and money towards achieving these objectives. To some degree, these aims have been achieved by incorporating automatic fluxing and wire feeding devices on conventional automated heating devices. However, at best, this solution results in a marginal increase in productivity; and, even so, this solution can only be applied in certain instances. The major limitation of this solution to the problem is that not all fluxes are capable of being produced in a form suitable for automatic dispensing (i.e., in paste form). Clearly, further speeding up of the majority of brazing operations can only be achieved if:

1. All the fluxes likely to be used can be produced in paste form; and
2. The alloy and flux can be applied to the work-piece simultaneously.

From theoretical considerations, by using brazing alloy powder/flux paste mixtures, capable of being applied to the work with specially designed applicators, it should be possible to achieve a marked increase in the output rate of finished parts when compared to other brazing processes.

Clearly, there is no major problem in physically mixing brazing alloy powder with brazing fluxes to form an alloy paste. The difficulty lies in ensuring that once mixed, the brazing alloy powder remains in suspension in the paste. To achieve this is easier said than done, but after many years of research the problem has been solved. The next step has been to develop a range of automatic dispensers. Here again, the problems were many, and although there were many applicators available which would dispense glues, oils and resins satisfactorily, Brazepastes posed a difficult problem.

Most dispensers rely upon pressure, either hydraulic or pneumatic, to force the material from the orifice of the applicator. Brazepastes, being mixtures of relative dense powders in suspension in a fairly fluid medium, cannot tolerate high pressures. Under such conditions the brazing alloy powder separates from the flux to form a hard mass which rapidly clogs the outlet orifice of the applicator. It has, therefore, been necessary to develop a range of dispensers which are not subject to this difficulty. The results of this development (Figs. 6 and 7) fully overcome this problem.

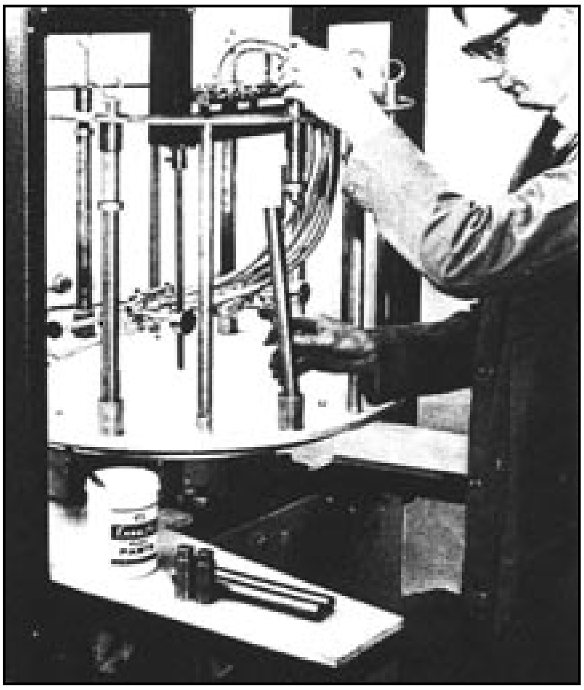
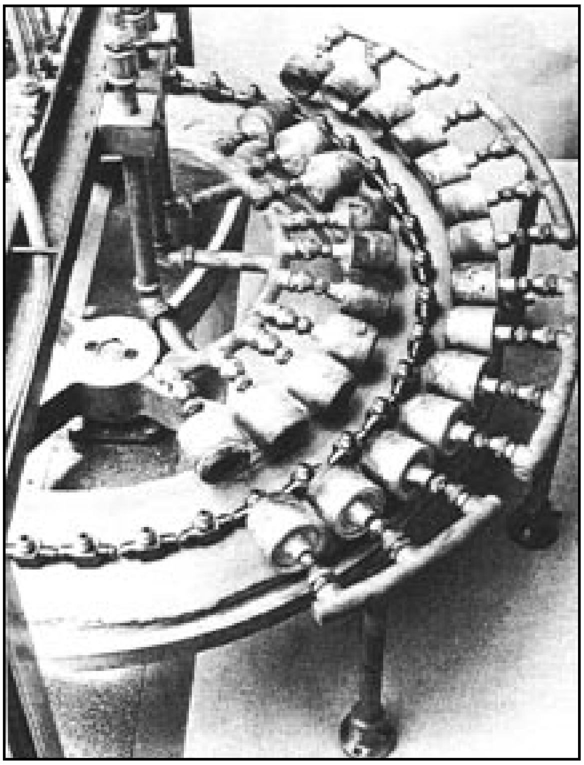


Fig. 3 Rotary indexing table machine which brazes two mild steel tubes together at a rate of 360 an hour (Courtesy: Solbraze Ltd.)

Fig. 4 Continuously rotating table machine used to braze hydraulic couplings at a rate governed by the speed at which they are loaded on to the machine (Courtesy: Solbraze Ltd.)



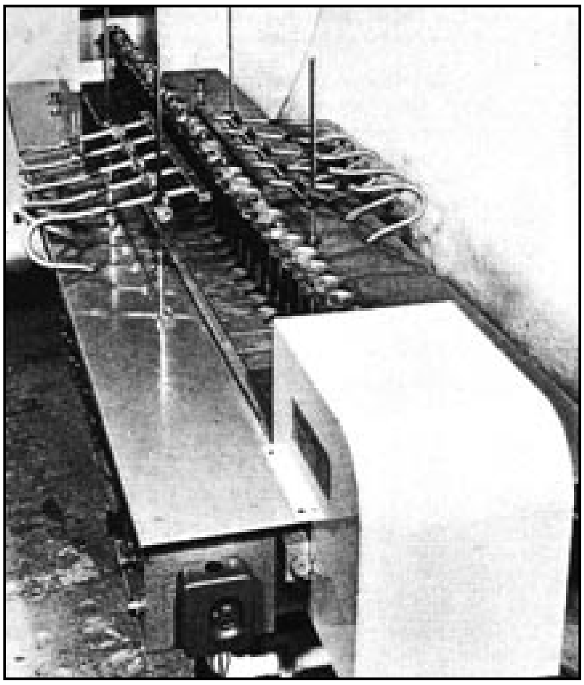


Fig. 5 Indexing conveyor machine used to braze hydraulic hose couplings. The machine indexes 10 times a minute (Courtesy: Solbraze Ltd.)

Thus, high rates of output are now being achieved both in America and the United Kingdom, by using JMM Brazepastes (which are available with flux, or without flux if protective atmosphere furnace or vacuum brazing is the selected heating method), in conjunction with special dispensers, and specialized heating equipment.

In use, the operator simply loads the components to be brazed into the jig (this is sometimes done automatically), the machine indexes automatically to the "pasting station", paste is applied, the machine then indexes through a series of heating and cooling stations, and, finally, the brazed component is automatically ejected or manually removed from the machine. From this sequence of events it can be seen that the output rate is controlled by the rate at which components can be loaded on to the machine, i.e., if loading takes 10 s, output is 360 an hour; if loading takes 6 s, output is 600 an hour.

One can now consider on a theoretical basis, the Brazepaste process applied to the tube-to-fitting joint used as the costing example in this survey. Table 2 shows that by using Brazepaste, further economies, amounting to approximately £5,650, could be realized in a full year. Clearly, with the introduction of the Brazepaste process it is now possible to proceed directly from hand torch brazing to this fully automated procedure, thus deriving the maximum possible production economy.

Table 2 Costing, Brazeplate Process

1. Total labour costs	£ 2,025
2. Material costs	£90,173
3. Equipment amortization	£ 1,000
∴ Total cost	£93,198
Total cost, Fixed torch heating	£98,852.5
∴ Additional saving	£5,654.5

Choice of Brazing Alloy

It is a widely held belief that the easiest way to effect a reduction in brazing costs is to change from a brazing alloy which has a relatively high silver content to one having a low silver content. It is interesting to ascertain whether this course of action is likely to result in a reduction in costs. For example, one may consider the case where an alloy comprising 42 per cent silver-copper-cadmium-zinc is intended to be replaced by one comprising either 23 or 30 per cent silver-copper-cadmium-zinc. Details of all three materials are given in Table 3.

In all instances, the alloy is intended to be used in the form of preformed rings, and the joint configuration to be brazed is that shown in Fig. 8, which, it will be noted, differs from Fig. 1 and, in consequence, the cost values now to be determined are not comparable with those shown earlier. From Table 3, the recommended

Fig. 6 American applicator, incorporating a single gun, developed for dispensing Brazepaste on to the workpieces situated on automatic brazing machines

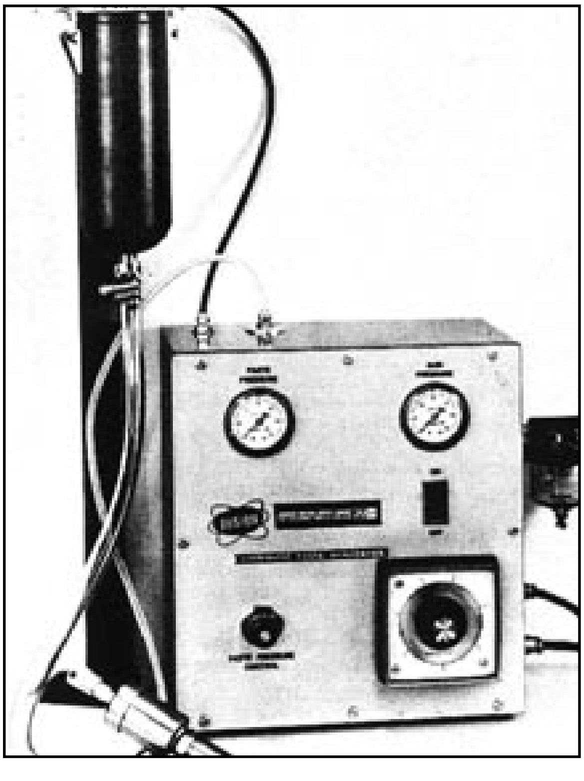


Table 3. Alloy Compositions and Joint Gaps

Alloy Composition	Melting Range °C	Recommended Joint Gap
42% Ag-Cu-Cd-Zn	608-617	0.1 mm
30% Ag-Cu-Cd-Zn	607-700	0.2 mm
23% Ag-Cu-Cd-Zn	616-735	0.2 mm

joint gap for the 42 per cent silver containing alloy is 0.1 mm. To calculate the wire diameter which will be suitable for this particular joint one can use the simple formula:

$$LG = \frac{\pi D^2}{4}$$

where L = length of joint
G = joint gap
D = wire diameter

However, in practice a 25 per cent excess of brazing material is recommended, so,

$$\frac{5\ LG}{4} = \frac{\pi D^2}{4}$$

which can be simplified to:

$$D = 1.27\sqrt{(LG)}$$

Substituting the known values in this equation we have

$$\begin{aligned} D &= 1.27\sqrt{(20 \times 0.1)}\ \text{mm} \\ &= 1.27\sqrt{2} \\ &= 1.27 \times 1.414 \\ &= 1.69578\ \text{mm} \\ &= 1.7\ \text{mm approximately.} \end{aligned}$$

Thus, in this particular example a brazing alloy wire ring is needed having an inside diameter of 25 mm made from 1.7 mm diameter wire. The cost for such a ring, made from the 42 per cent silver-containing alloy under consideration is 2.830p each.

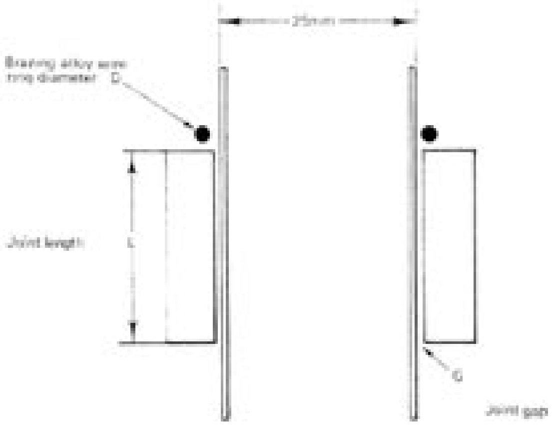


Fig. 8 Calculation of wire diameter D for a preform brazing alloy wire ring. D=1.27√(LG). G: See Table 3. L: 20 mm (see text)

In the second example, concerning the silver brazing alloy having only 30 per cent silver, one can see from Table 3 that the recommended joint gap is 0.2 mm. Substituting the known values in our equation:

$$D = 1.27\sqrt{(LG)}$$

One obtains

$$\begin{aligned} D &= 1.27\sqrt{(20 \times 0.2)}\ \text{mm} \\ &= 1.27\sqrt{4}\ \text{mm} \\ &= 1.27 \times 2\ \text{mm} \\ &= 2.54\ \text{mm} \end{aligned}$$

Thus, in this instance a brazing alloy wire ring is needed having an inside diameter of 25 mm made from 2.54 mm diameter wire. The cost of such a ring,

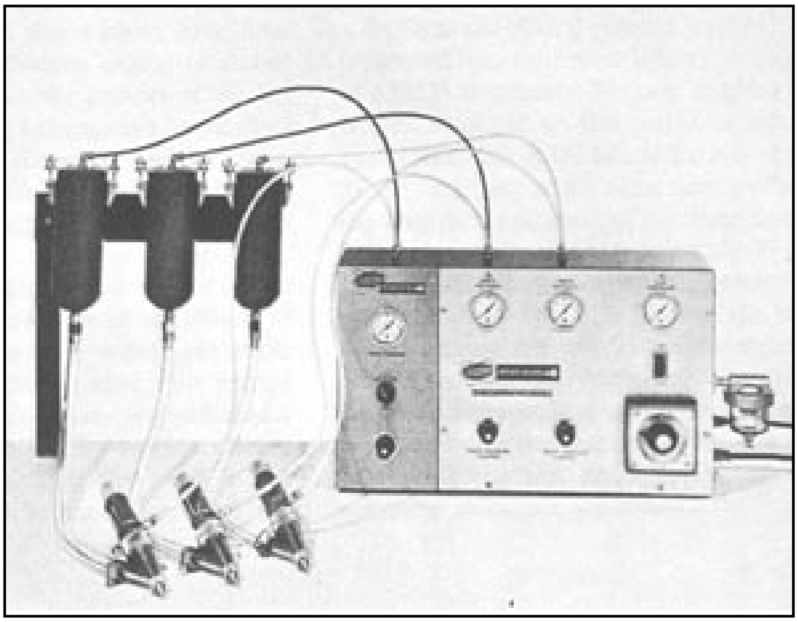


Fig. 7 Triple Brazepaste applicator intended to be used where paste application at widely separated positions on a single assembly is required. The duration of the Brazepaste application cycle is controlled by the single timer in the unit

Table 4 Cost of Materials

Alloy Composition	Wire Price per kg*	Percentage Change	Ring Size	Cost of Ring*	Percentage Change
A 42% Ag-Cu-Cd-Zn	£15.15	100.0	25 mm by 1.7 mm	2.830p	100.0
B 30% Ag-Cu-Cd-Zn	£11.40	74.9	25 mm by 2.54 mm	4.735p	167.3
C 23% Ag-Cu-Cd-Zn	£9.35	61.7	25 mm by 2.54 mm	3.755p	132.6

*This price will vary as the price of silver varies. Nevertheless the ratios of prices will remain in proportion to those shown unless there is a large change in the price of silver. Thus, these figures should not be considered to be absolute values.

made from the 30 per cent silver containing the alloy concerned is 4.735p each.

In the third case of the alloy containing only 23 per cent silver, again the recommended joint gap is 0.2 mm and accordingly the recommended wire diameter from which the ring should be made is 2.54 mm.

Thus, in this instance a brazing alloy wire ring will also be needed having an inside diameter of 25 mm made from 2.54 mm diameter wire. The cost of such a ring, made from the 23 per cent silver-containing alloy is 3.755p each.

Summarizing, it can be seen from Table 4 that although the price per kg of the various materials does, as would be expected, fall with a decrease in the silver content of the alloy, the cost of actually producing a joint does not. In fact, generally speaking, the reverse is true. With higher silver content alloys, the melting range is short and the liquidus temperatures are relatively low. This means, of course, that the heat input to the work, when compared to that necessary for the use of a 23 or 30 per cent silver containing alloy, is lower. It is not unusual in such instances, owing to the fact that a higher heat input rate is required, that production engineers should find it necessary to increase the number of torches used to heat the work when a change to a lower silver content alloy is made. On automated brazing equipment this may mean increasing the number of heating stations, with a corresponding reduction in the output of finished parts an hour.

Moreover, sometimes, the rejection rate of brazed assemblies also increases because of the effects of liquation, an alloy phenomenon which can occur when too slow a heating rate is used with brazing materials that have an extended solidus-liquidus range. Even if this problem can be avoided, there is little doubt that on account of the much higher brazing temperatures which have to be employed with these lower silver content alloys, the post-braze flux removal operations become more difficult. This inevitably leads to an increase, however small, in the cost of the finished product.

From this one can see that a cost-saving exercise, based solely on the intrinsic cost of the metals contained in the brazing alloy can in fact increase the cost of the finished product (Table 4).

It is interesting to note that motivation for such cost reductions almost always originates in the office of the brazing alloy buyer. Such a man usually has an understanding of the problems which might arise on the shop floor should he be swayed by the attraction of changing to a lower silver content alloy without paying sufficient attention to the change in other factors which will affect the performance of the alloy during the brazing operation. In consequence he is aware that it is the cost of the finished component which matters, and *not* the first cost of the alloy used to produce the component.

Conclusions

So far as the costing exercise is concerned we have progressed from hand torch brazing to the possible use of a JMM Brazepaste. We have reduced the number of men employed on this particular job from 15 to one (a reduction in the labour force of approximately 93 per cent) and at the same time we have reduced the manufacturing costs of the items from 3.596p to 2.714p (a reduction of approximately 25 per cent).

It has also been shown that one cannot simply consider the actual "per kilo" cost of the brazing alloy when carrying out cost reduction exercises. Such factors as joint gap variations, the possibility of requiring more heating stations, and the probability that post-braze cleaning operations will also become more difficult, and hence more expensive, must always be taken into account.

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