

Platinum Solder Core Wire: Development and Industrial Implications

R.J. Watt and A. Koursaris

Jewelry neck chain is joined by age-old techniques, the most popular being the rather involved solder powder method. The solder core method of chain manufacture is a simpler process and offers the possibility of higher productivity. Neat narrow joints are formed, and a color match between the solder and parent alloy may be approached. This is particularly important in the case of platinum alloys that have a high melting point, necessitating the use of solders with compositions substantially different from those of the parent alloy. The solder core method also lends itself to the possibility of higher levels of automation.

Keywords
bonding, jewelry chain, platinum, solder, solder core

1. Introduction

PLATINUM USAGE in the jewelry market has grown over the past few years, especially in the Pacific Rim. In 1993, Japan consumed 43.5 t of platinum for jewelry (Ref 1). Neck chain accounted for 19% of all platinum jewelry sales (Ref 2). As the demand for platinum neck chain increases, more efficient means of manufacturing will be required. The development of the solder core platinum wire was initiated with this in mind. This technique is already well developed for silver and gold alloys. The general practice is to use solder and parent material with similar precious metal contents. This prevents problems with color match and karatage.

In the past 10 years the demand for platinum used in jewelry has more than doubled (Ref 1), from 715,000 oz in 1983 to 1.61 million oz in 1993. Of the 1.61 million ounces used worldwide for jewelry in 1993, 1.35 million oz (84%) were consumed by Japan (Fig. 1).

The production of soldered joints in precious-metal neck chain has been achieved mostly by the solder powder method in the major manufacturing centers. In this method a length of chain is placed in a tumbler containing a mixture of flux, castor oil, and solder powder. This mixture is trapped between the butt joints of the links during tumbling. Excess solder on the surface of the links is removed by dipping in a bath of talcum powder. This prevents tarnishing of the surface and bonding of adjoining links to each other when the solder in the butt joints is melted. The chain is then heated in a furnace with a protective atmosphere, where the solder melts and fuses the link butt joints together. The removal of excess solder from the chain surface with talcum powder is never completely effective, and tarnishing may occur after brazing. Further finishing processes are thus required to restore the color.

With the solder core approach, a continuous strand of solder is incorporated into the center of the chain wire during fabrication. This wire is then formed into neck chain. Once formed, the solder core chain is also dipped in talcum powder to prevent excess solder from escaping from the core and bonding adjoining links to each other during brazing. The chain is then heated in a furnace with a protective atmosphere, where the solder melts and is drawn out by capillary forces acting within the joint, forming a bond. Tumblers are not required to trap solder powder in the link butt joints, as is the case with the solder powder method. It is believed that since very little solder to exposed to the chain surface, many of the link surface cleaning steps are unnecessary. As a result, there is potential for savings in production time and equipment outlay. A narrow gap in the link butt joint is also required for a strong capillary force to act and draw the solder out of the wire. Therefore, less solder is required to form a joint. The joint is less noticeable, which is advantageous, and thus precise color matching between the core and parent alloy may not be necessary. With the conventional chainmaking processes, color matching presents problems due to the wider gap in the link and the lower platinum content of the solder, which does not possess the gray luster of platinum.

2. Experimental Procedures

A number of methods can be used for the manufacture of solder core wire—for example, continuous casting and extrusion. In this study a fairly simple laboratory technique was applied. This involved the casting of a billet of platinum-copper alloy. The alloy, commonly used for platinum jewelry neck chain, contained 5 wt% Cu. The billet was cast using a small laboratory arc furnace. This billet was then roll forged into a bar 4.61 mm square and sectioned into 25 mm lengths. A hole was then drilled down the center of these bars and the hollows filled with solder wire with a melting point of 1020 °C. Figure 2 shows a schematic of the solder core billet. The volume ratio of the solder to the parent material was selected so that an overall fineness of 90 wt% Pt was achieved.

The billets were reduced to wire by cold rolling and drawing. Interstage annealing was required after reductions of about 30% to restore ductility. Wires were drawn down to diameters of 800, 500, and 300 μm for fabrication into neck chain. These wires were typically 2 to 3 m in length and were supplied to a jewelry manufacturer after annealing at 1000 °C for between 60 and 90 s. The wires were formed into different styles of neck chain. After cleaning and degreasing, the chains were dipped in

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talcum powder and then placed in a tube furnace, where they were heated in argon. The heating times varied between 3 and 15 min and were sufficiently long to melt the solder and form a joint in all cases. The brazing temperature was varied between 1020 and 1100 °C at 10 °C intervals. In some cases fluxes were used to assist the solder flow during brazing. This was done in order to test the effects of these two variables on joint quality.

After brazing, the joint quality was assessed by tensile testing, as shown in Fig. 3. Individual links were removed at random from a brazed chain and tested. The links were inserted through two U-shape wire loops of greater diameter than the platinum links. These wire loops were clamped in the jaws of the tensile test apparatus, and loading was applied to failure. Silver chain links produced commercially by the solder powder method were also tested in the same manner. The object of testing the silver links was to obtain data on the approximate strength requirements of common neck chains as well as on the variability in strength of links joined by the solder powder method. The silver links used in this test were made from wire with a diameter of 800 μm, as were the platinum links.

Brazed joints and solder core wire were examined with optical and scanning electron microscopes (SEM). Chemical analyses were carried out with an energy-dispersive spectroscopy (EDS) system coupled to the SEM. The composition of the brazed joints and surrounding areas was analyzed by EDS in order to determine the extent of diffusion that had taken place during brazing.

3. Results

The bimetal billets were fairly ductile and thus easily drawn down to wire. The appearance of a transverse section through one of the bimetal wires with a diameter of 800 μm is shown in Fig. 4. It can be seen that the solder is centrally located in the wire and that bonding between the solder core and the parent metal is also complete. No bonding problems were encountered with the platinum parent material and solder alloy used during these trials.

It should be stressed that annealing of the wire at regular intervals was an important step during wire drawing. If this procedure is not systematically carried out it is possible that fragmentation could result in the solder, which would produce

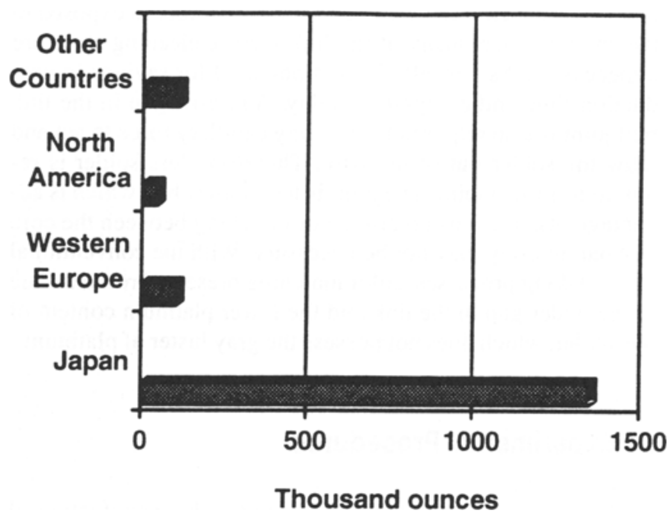

Fig. 1 Consumption of platinum in jewelry manufacture for 1993. Source: Ref 1

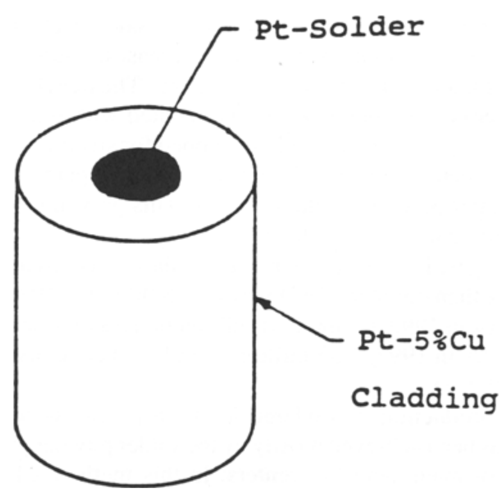

Fig. 2 Schematic of a bimetal billet

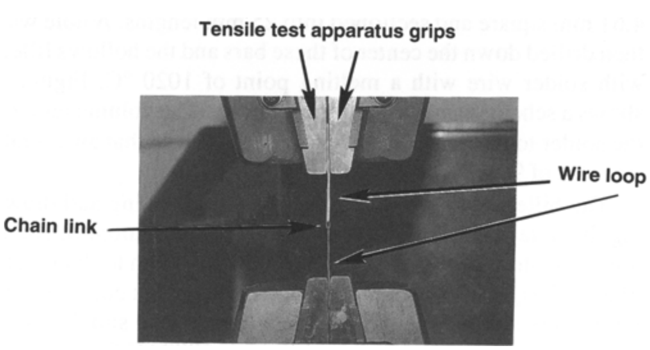

Fig. 3 Tensile test apparatus

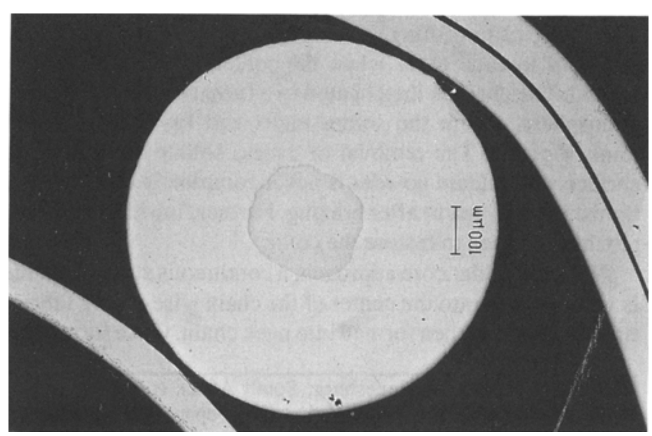

Fig. 4 Solder core wire, 0.8 mm diam

defective solder core wire and ultimately defective links. An example of this is shown in Fig. 5. Here fragmentation was encountered in initial trials conducted on a copper parent alloy and silver solder alloy. This type of defect was not encountered in the platinum bimetals, probably because sufficient interstage annealing was always conducted on the billet.

After drawing and full annealing, the wires were formed into neck chain. Some difficulties were encountered during chain manufacture. The machine operators, unfamiliar with platinum alloys and their higher hardness compared to silver and gold, had to experiment in order to establish acceptable machine settings. During this process a large quantity of the wire was used. Defects included burring, pinching shut of the solder core, and formation of oversize gaps between the butt joint faces of the links. Figure 6 shows a typical burr. It is suspected that these burrs at times prevented the formation of a joint, as

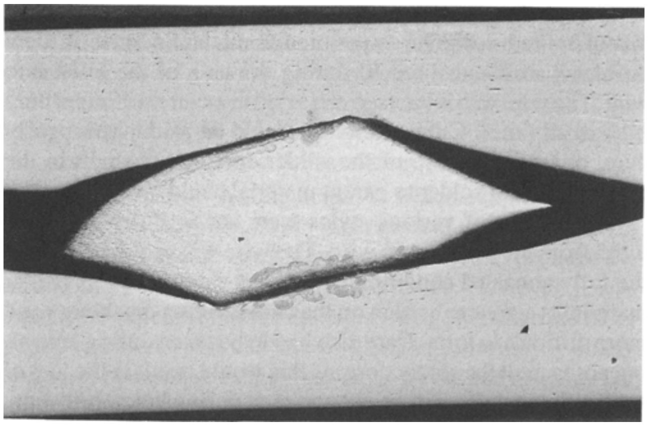

Fig. 5 Fragmented solder core. 35×

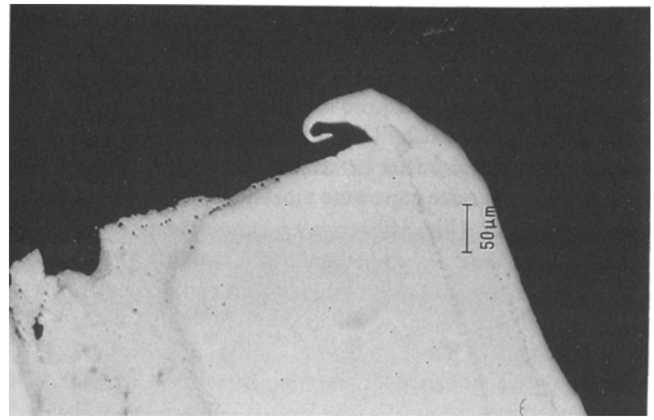

Fig. 6 Burr created during link manufacture

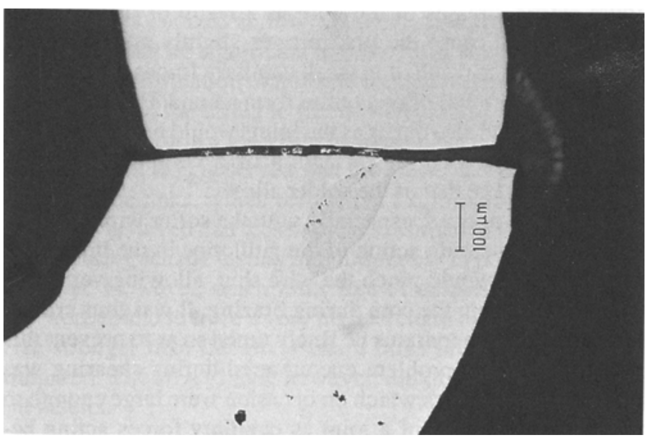

Fig. 7 Solder core that was partially closed during link formation

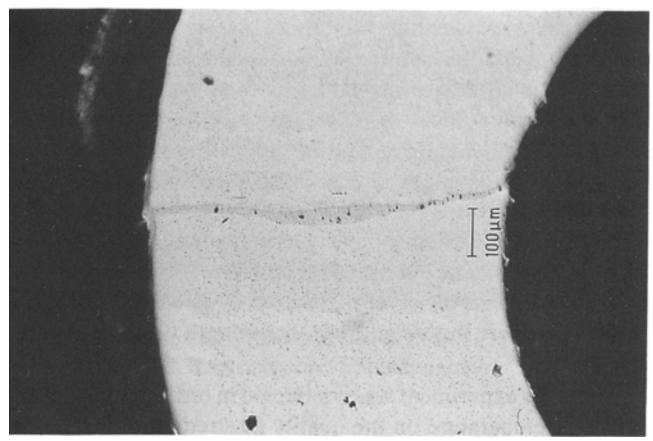

Fig. 8 High-quality joint made at 1030 °C

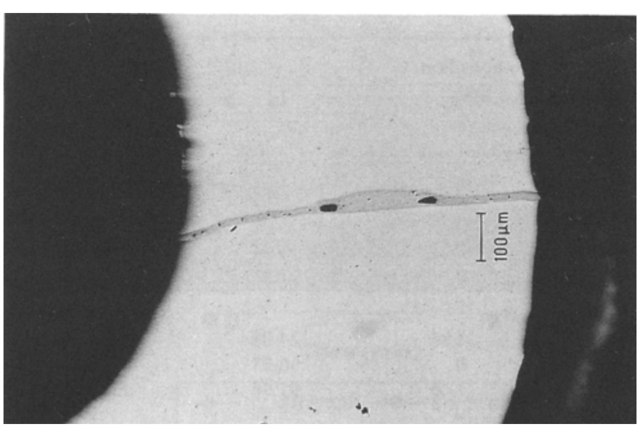

Fig. 9 Porosity in a link brazed at 1030 °C

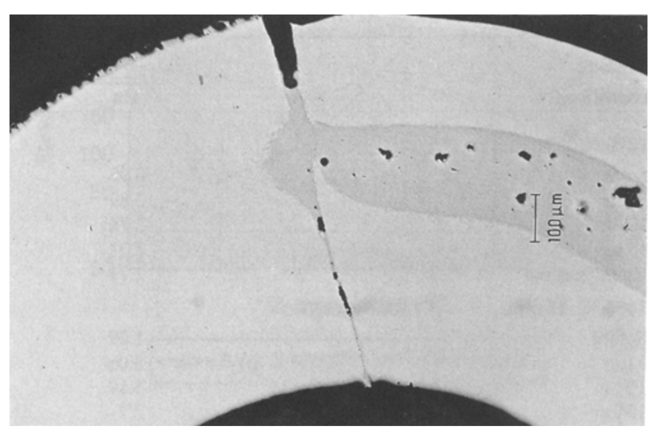

Fig. 10 Joint in solder core link made at 1060 °C

their presence would result in oversize gaps. Similar problems were encountered when large gaps were formed by the machinery. Pinched solder core was encountered infrequently, but when it occurred molten solder was unable to flow out of the core and into the joint to form a bond. An example of a partially shut solder core is shown in Fig. 7.

The last step in chain manufacture was brazing of the link butt joints. Problems encountered here were due to defective links produced during manufacture. Figure 8 shows an example of a high-quality joint, where the solder filled the entire joint area with no prominent defects. Brazing defects encountered were inadequate solder flow, inclusions, and porosity. Porosity (Fig. 9) was most probably caused by entrapped air or other gases generated by the flux. Inclusions may have been caused by entrapped flux or talcum powder. Weak capillary forces due to oversize gaps were most likely the cause of inadequate solder flow (Fig. 10).

Figure 11 shows the appearance of a joint made at 1070 °C for 15 min. This photomicrograph was taken in the SEM. The markings are the points at which the EDS analyses were conducted. The backscatter mode used for Fig. 11 shows very good bonding between the solder and the parent alloy. It also shows an abrupt compositional change between the solder and parent material, indicating that diffusion or alloying at the interface did not take place to any significant extent. Analyses by EDS were carried out in the solder and at various distances from the interface into the parent metal (Fig. 11). Table 1 shows the compositions obtained at these points. These results indicate that there was no significant penetration of the parent alloy by diffusion from the solder.

To ascertain the effects of time at a particular brazing temperature on the strength of the brazed joint, links were held at 1060 °C for periods between 3 and 15 min. The results are shown in Fig. 12. As can be seen, there appears to be no trend in the data with increasing time at temperature. For comparison, the results of tests on silver links are also included on the plot. These results are less erratic, but the strength values are generally lower.

A similar experiment was conducted in order to evaluate the effect of temperature on the quality or strength of the brazed joint. Links were placed in a furnace at temperatures ranging from 1030 to 1100 °C. All links were left in the furnace for exactly 15 min and tested as before. The results obtained (Fig. 13) exhibited the same lack of trend as previously. It should be stated that the number of links tested at each stage was small, and the results obtained should be viewed only as general trends rather than as statistical quantities.

4. Discussion

The platinum-copper solder core wire was successfully manufactured using the experimental method described. Few problems were encountered during drawing of the billet into wire. The wire was interstage annealed to ensure sufficient ductility at all times. Close attention should be paid to this procedure, or fragmentation of the solder core and changes in the original ratio of solder to parent material could result.

Chain links of various styles were successfully manufactured from the solder core wire. The wire was required to be in the fully annealed condition before link fabrication, as harder material is a greater burden on the chin forming machinery and more difficult to form. Care also had to be taken during annealing not to melt the solder core, as this would result in the loss of solder. Some defects were encountered during link fabrication. In some cases the gap between the butt joints of a number of links was found to be too large. This problem was probably due to insufficient annealing of the wire before link fabrication. Residual elastic stresses in the wire as a result of drawing and forming would cause the link to open slightly after forming. This wider space resulted in weak capillary forces and, as a result, little solder was drawn out to form a bond. Problems with aesthetics would also occur as the joints would be more noticeable, and in the case of formation of a complete joint, its strength would be that of the solder alloy.

It was also noticed, especially with the softer wires, that on occasion the shearing action of the guillotine in the link forming equipment would pinch the wire shut, allowing very little solder to exit from the core during brazing. It was thus critical that the shearing apparatus be finely tuned so as to prevent this problem. Another problem encountered during shearing was the formation of burrs,which on occasion were large enough to hinder the formation of a joint as capillary forces acting between the two faces of the butt joint would be insufficient to draw the solder out, due to the burr forcing the faces apart.

Table 1 EDS Results of Areas Shown in Fig. 11

Brazing conditions	Composition, %				
	Cu	Pd	Ag	Pt	Au
1070 °C, 15 min					
Solder	0.95	0.34	32.51	29.27	36.92
5 μm	2.89	0	0	96.51	0.65
10 μm	2.78	0	0	96.91	0.31
15 μm	2.72	0	0	96.64	0.63
Parent material	2.71	0	0	97.28	0
1080 °C, 15 min					
Solder	1.09	1.55	34.86	24.98	37.44
5 μm	3.06	0	0	96.51	0.41
10 μm	3.19	0.31	1.46	91.96	3.07
15 μm	2.7	0	0	96.48	0.81
Parent material	2.86	0	0	96.71	0.43

The distance between the parallel surfaces of the butt joint does affect the strength of the capillary forces and the height to which the solder will rise in the gap. This is shown by the Poiseiulle formula (Ref 3):

$$H = \frac{2\gamma_{L/V} \cos\theta}{\rho\, d\, g} \qquad \text{(Eq 1)}$$

where H is the vertical height to which the liquid will rise between two parallel plates, $\gamma_{L/V}$ is the free energy of the liquid in equilibrium with its vapor, ρ is the density of the liquid, d is the distance separating the parallel plates, and θ is the angle of contact. g is the gravitational constant where $g = 9.81$ m/s^2.

Equation 1 shows that the height to which a liquid rises in a capillary space increases as the separation of the surfaces is reduced. The automated machinery that was used to produce the chain could not automatically set this space. However, it was found from experimentation that the distance between the faces needed to be less than 50 μm, or a sound joint mostly likely would not be formed. In most cases, however, the distance fell well within this limit.

From the tensile test results it was clear that no correlation could be drawn between the effects of temperature and time on the strengths of the link joints. The EDS analyses performed on numerous links brazed at different temperatures and time periods showed that no significant diffusion had taken place. It appears that the formation of a sound butt joint depends strongly on the ability of the solder to fill the butt joint surface by capillary action and form a joint free from porosity or other defects. On occasion it was observed that the solder did not rise to the surface of the links, which resulted in the formation of a small notch. It is believed that these notches resulted in stress concentration during tensile testing and ultimately in poor and erratic strengths. However, when links free of defects were formed, they were found to have a very high strength and in most cases were stronger than the silver chain links to which they were compared. The silver links, however, did display more consistent results.

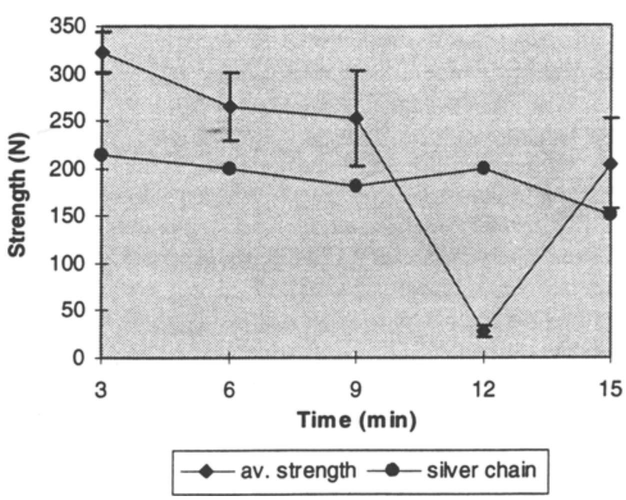

Fig. 12 Effect of brazing time at 1060 °C on link strength

One of the biggest benefits of the solder core approach is the possibility for increased automation of chain manufacture. In one continuous process, the solder core wire can be run through the chain fabrication machinery, passed through a talcum powder bath, and enter a tube furnace where the links can be brazed. Figure 14 is a schematic of how this system might look. This process route would reduce labor requirements and speed the manufacturing process.

5. Conclusions

Platinum solder core wire was produced using conventional wire fabrication techniques. The wire was found to form chain links without large modifications to chain fabrication equip-

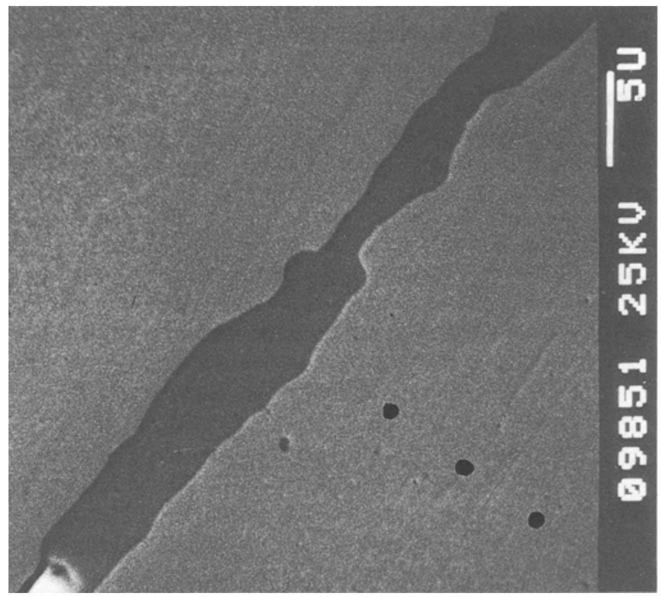

Fig. 11 Points at which EDS analyses were taken in a link brazed at 1070 °C. Backscattered SEM micrograph

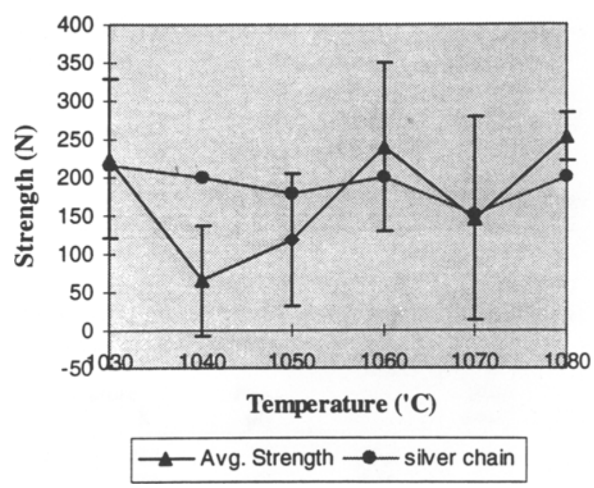

Fig. 13 Effect of brazing temperature on the strength of links brazed for 15 min

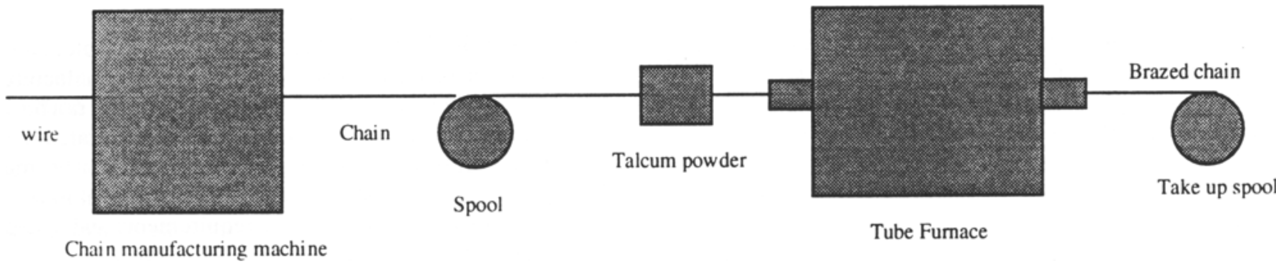

Fig. 14 Schematic of automated chain manufacturing equipment

ment. These links were successfully joined in a protective atmosphere of argon.

The joint strengths were largely independent of brazing temperature and time, and were influenced by the distance between the faces in a butt joint. This needed to be sufficiently small to allow capillary forces to draw the solder out of the wire core in order to wet the two surfaces and form a bond.

The solder core approach to the brazing of jewelry chain links lends itself to high production rates, owing to the possible elimination of certain process steps required by the more popular joining methods in use at present. Strong, neat joints can be formed that are also aesthetically pleasing.

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