# Soldering Stainless Steel

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The purpose of this article is (1) to describe a technique for determination of the temperatures stainless steel wire is subjected to when soldered, (2) to report a temperature range for satisfactory soldering of such wires, and (3) to evaluate the influence of heating time during soldering.

## INTRODUCTION

In earlier work the effect of the heat of soldering on the mechanical properties of hard drawn stainless steel wire was reported.[1] It was found that the annealing range for this wire started at about 500°C and, since clinically satisfactory solders have a flow point of at least 600°C, the wire was softened as a result of the soldering. The degree and extent of softening depended on the operator's control of heat during soldering.

The literature relating to soldering temperatures for stainless steel is scant. Richman[2] demonstrated recrystallization in stainless steel as a result of using a high fusing silver solder, whereas no recrystallization occurred when a low fusing silver solder was employed. However, he did not estimate the temperatures involved. Skinner[3] gives a melting range of 607-688°C for low fusing silver solders but does not provide soldering temperatures. Vosmik and Taylor's work[4] in 1936 represents the only attempt to determine soldering temperatures for stainless steel. They soldered joints in a dark room and estimated the soldering temperature from the color of the wire.

This work was carried out at the Commonwealth Bureau of Dental Standards.

It has been shown that soldering temperatures can significantly affect the mechanical properties of hard drawn stainless steel wire.[1] Since so little appears to be known about the temperatures employed for soldering this material, work was undertaken to devise a technique for determining maximum temperatures during this process.

## DETERMINATION OF SOLDERING TEMPERATURE

Stainless steel and constantan (Ni 45%, Cu 55%) show different electrical potentials at elevated temperatures, an e.m.f. being generated when they are brought into contact. Since the e.m.f. varies with temperature, these materials can be used as a thermocouple. However, the electrical potentials of metals are increased by plastic deformation and, since hard drawn stainless steel wire has been severely cold worked, it has to be fully annealed before it can be used for temperature calibration and estimation. (The effect of cold work on the thermocouple used in this work was found to be quite considerable.)

It was found that stainless steel wire could be soldered to constantan wire with low fusing silver solders and fluoride fluxes. By measuring the e.m.f. generated when these two wires were soldered together it was anticipated that a good measure of soldering temperature should be provided.

*1. Calibration of Thermocouple*—Two 15 inch constantan-stainless steel thermocouples were constructed. A length of .020 inch diameter constantan wire and one of .022 inch diameter stain-



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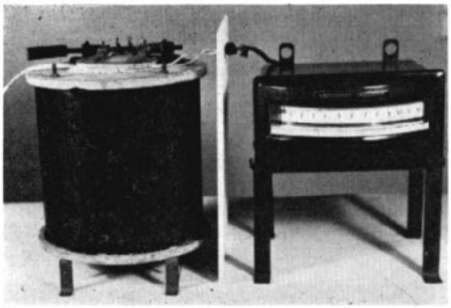

Fig. 1 Electric furnace and Cambridge Indicator used for standardization of constantan-stainless steel thermocouple. The thermocouple wires pass through small holes in a sheet of asbestos in order to baffle the cold junction from the heat of the furnace. A thermocouple for controlling furnace temperature leaves the furnace on the left.

less steel wire were welded at one end to form each thermocouple.

It was found during earlier work that the stainless steel wire completely recrystallized after a few minutes at 900°C so, after the thermocouples were insulated with beads, they were fully annealed by heating in a muffle furnace at 900°C for 30 minutes.

The thermocouples were calibrated by recording the e.m.f. generated at known temperatures over the soldering range, the e.m.f. being recorded on a Cambridge Indicator. The welded end of one thermocouple was inserted into a blind-ended stainless steel tube, the tube then being inserted into a crucible of molten pure metal contained in a cylindrical furnace (Fig. 1). As the furnace slowly cooled, the e.m.f. generated by the thermocouple was recorded as a scale indicator reading. This indicated reading dropped at a fairly regular rate until the molten metal started to solidify, when a significant arrest was noted. The steady reading at the arrest point corresponded to the freezing point of the metal and, therefore, to a known temperature.

In order to check the consistency of the two thermocouples, each was calibrated at the freezing point of pure zinc. It was found that there was a difference of less than 1°C between the two thermocouples. Because of the consistency shown by the two thermocouples, calibration was completed with only one of them. Indicator scale readings were recorded at the freezing points of pure zinc (419.5°C), antimony (630°C), aluminum (650°C), and silver copper eutectic (Ag 71.5%, Cu 28.5%; 779.4°C).

The results from the calibration are presented graphically in Figure 2, and from this graph scale indicator readings from the thermocouple can be converted to temperature in degrees centigrade.

2. *Materials*—Unitek No. 6 solder and Unitek flux were used for all joints. The 15 inch annealed constantan-stainless steel thermocouple which had been calibrated with the indicator was used. The weld bead was cut off, but the overall length was not reduced more than half an inch throughout the work.

Preliminary work disclosed that Unitek flux significantly affected the po-

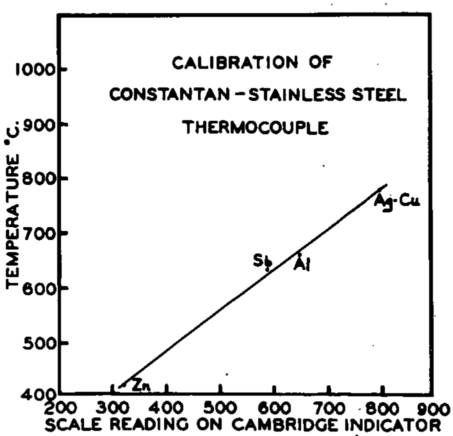


Fig. 2 Graph for conversion of scale readings from constantan-stainless steel thermocouple to degrees centigrade.

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tential of the thermocouple. When the two wires were held together and heated for soldering, indicated temperatures greater than 850°C were recorded before the solder had actually flowed. This same effect was noted using another fluoride flux, but if either flux was heated strongly for a few seconds it no longer affected the e.m.f. of the thermocouple.

In order to prevent any possibility of the flux affecting the potential of the thermocouple another soldering technique was tried. Here a welded thermocouple was connected to the indicator. Solder was flowed on to the end of a piece of stainless steel wire and, after refluxing, it was soldered to the fluxed weld bead of the thermocouple. This experiment showed that the flux had no effect on the potential of the thermocouple but, for some reason, the temperatures indicated during soldering were well below the melting point of the solder. Possibly the bulk of the weld bead allowed the heat to be conducted away too quickly. Because of this finding, the technique of soldering the two wires together was used throughout the experiments.

3. *Technique of Soldering*—The orthodontist, designated "C" in an earlier work[1], who showed the best control over heat during soldering, carried out this work.

Because of the necessity to burn the flux a little, it was not found possible to flow solder from one wire to the other. Consequently the soldering technique was modified slightly. The end of each wire was fluxed and, after being heated stronglv for a few seconds to eliminate the flux effect on the thermocouple. solder was flowed on to each wire. The solder-covered wires were then held together at 90° and heated with a fine-pointed gas-air flame until the solder flowed, the work then being withdrawn from the flame. The maximum reading on the indicator during soldering was recorded to the nearest 5°. The wires were cleaned between soldering by fluxing, heating, and flicking to remove old solder.

Even when soldering with this technique sometimes a very high reading was recorded from the indicator, showing an obvious flux effect. These readings were discarded; it is not felt that any significant flux effect is present in the soldering temperatures reported.

4. *Check on Calibration of Thermocouple*—As a check on the e.m.f. of the soldered thermocouple, at the conclusion of the soldering work the two ends were soldered together so that the wires were parallel and would fit back into the stainless steel tube used during calibration. The indicator reading for the soldered thermocouple was then determined at the freezing point of zinc (the maximum temperature required for this calibration being below the melting point of the solder). The reading at the zinc point was 324, only two higher than the 322 obtained earlier when the ends were welded. Since this represents less than 2° C, it provides good evidence for the reported soldering temperatures to be considered reliable.

5. *Results*—The results of the soldering work are presented in Table 1. Since the indicator was only read to the nearest 5 degrees, conversion to temperature was taken to the nearest 5 degrees centigrade.

## Effect of Heating Time During Soldering

The effect of the time of heating during soldering on the mechanical properties of hard drawn stainless steel wire is demonstrated in the following experiments.

Some lap joints were fabricated in

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TABLE 1

| Maximum Indicator Reading | Temperature °C |
|---|---|
| 670 | 680 |
| 680 | 685 |
| 685 | 690 |
| 680 | 685 |
| 660 | 670 |
| 660 | 670 |
| 680 | 685 |
| 660 | 670 |
| 680 | 685 |
| 655 | 670 |
| 665 | 675 |
| 680 | 685 |

Mean Soldering Temperature 680°C
Range 670 - 690°C

.022 inch diameter hard drawn stainless steel wire using Unitek No. 6 solder and Unitek flux. The soldering was done by the same orthodontist who soldered the thermocouple. Solder was flowed on to the fluxed end of one wire and, after refluxing, the joint was made by flowing the solder from the first wire on to the fluxed end of the second wire. Thus in the fabrication of these joints one wire was heated to soldering temperature twice, while the other wire was heated only once.

Three of these joints were mounted in acrylic resin, sectioned approximately halfway through, and then polished metallographically. Further details of technique appear in a previous publication.[5] Vickers microhardness determinations were then made at 0.5 mm intervals along the centre of each wire. The results of this investigation appear in Figure 3.

A study of Figure 3 shows that the degree of softening in each joint is not very different for the two wires, despite the fact that one wire was subjected to the soldering temperature for twice as long as the other wire. The softest wire in these three joints has not been reduced below about 480 VHN; this is approximately the same as the lowest level to which this orthodontist reduced an archwire when soldering a T joint,[1] the arch being heated for only half the time (one application of heat).

Thus it would appear that the time of heating is not a critical factor for softening of this wire in the temperature range this orthodontist employs when soldering.

## Discussion

From Table I it can be seen that maximum temperature reached during the soldering of joints was fairly uniform, varying only 20°C, from 670 to 690°C, the mean temperature being 680°C. Since the flow point of Unitek No. 6 solder is given as 648°C, it appears that soldering can be carried out approximately 30°C above the flow

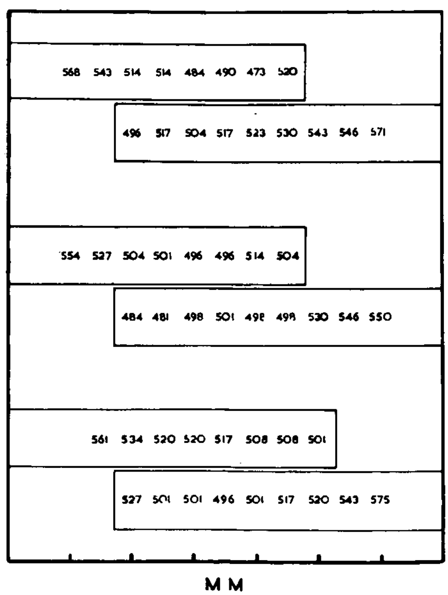


Fig. 3 Vickers hardness determinations on three soldered joints. Determinations were made at 0.5 mm intervals along the centre of each wire, and continued out of the softened area.

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point of the solder.

Vosmik and Taylor[4] investigated three different solders and estimated the soldering temperature to be about 60°C above the melting point of the respective solder. Since the lowest melting point was 685°C, the minimum soldering temperature was about 750°C. However, they did not differentiate between melting point and flow point for the solders investigated. In the case of Unitek No. 6 solder the melting point is given as 615°C, about 30°C below the flow point; it is probable that this work correlates closely with that of Vosmik and Taylor and the markedly lower soldering temperature is due to the availability of lower fusing silver solders.

While it is known that temperatures of about 680°C are well into the annealing range for stainless steel wire, and some softening is produced in consequence of soldering, the time of heating does not seem to markedly affect the degree of softening. Therefore, when excessive softening occurs in a stainless steel wire as a result of soldering, as has been demonstrated in earlier work, it would appear that higher temperatures are responsible rather than a longer heating time.

These findings indicate that if the desirable mechanical properties of hard drawn stainless steel wire are to be maintained, the temperatures employed during soldering should be kept to a minimum. They also indicate that the time taken to complete a soldered joint has relatively little effect on the degree of softening produced in the wire.

The practical significance of this work is that if soldering can be performed at a lower temperature by more gradual heating, and thus a longer heating time, far less softening will result than from a higher temperature and a shorter heating time. Also, since the flow point of the solder is the limiting factor as regards soldering temperature, we must be constantly on the alert for a solder with a lower flow point. It is significant that the lowest melting point of silver solders available to Vosmik and Taylor in 1936 was 685°C, whereas today several silver solders are available with a melting point about 610°C. Any further developments along these lines would materially assist the practice of clinical orthodontics.

## Summary

1. A technique was evolved for measuring the temperature stainless steel is subjected to when soldered. A thermocouple was constructed with constantan and stainless steel wire. The thermocouple was calibrated at temperatures over the soldering range so that when the two wires were subsequently soldered together, the e.m.f. generated by the dissimilar wires could be converted to temperature. It was found possible to solder the wires together consistently at 680°C ± 10°C. Since the flow point of the solder was 648°C, this meant that the soldering temperature was 20 to 40°C above the flow point of the solder.

2. Some hard drawn stainless steel wire was soldered to form lap joints. In each joint one wire had been subjected to soldering temperature twice, while the other wire had been heated only once. This meant that one wire had been heated for approximately twice the time of the other. These joints were investigated by the micro hardness testing method to determine the degree of softening produced by the heat of soldering. It was found that the time of heating during soldering had very little effect on the degree of softening.

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## Conclusions

1. It is possible to solder stainless steel at temperatures 20 to 40°C above the flow point of the solder; the soldering temperature need not exceed 690°C.
2. In the temperature range necessary for soldering stainless steel the time of heating is not a critical factor for softening of hard drawn wire.
3. In consequence of (2), soldering techniques for stainless steel should be directed towards limitation of temperature rather than limitation of heating time.
4. Research into solders which have a flow point lower than that of those currently available should prove profitable to the practice of orthodontics.

*145 Collins St.*

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