DOI: 10.1595/147106707X187173

# Strengthening of Platinum-5 wt.% Copper by Heat Treatment

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*Heat treatment of platinum-5 wt.% copper (Pt-5% Cu) below 500ºC is known to result in an ordering transformation which can significantly increase the hardness of the alloy. Microsample tensile testing of Pt-5% Cu shows that low-temperature heat treatment of previously cold-worked specimens results in an increase in yield strength and tensile strength, with a maximum in strength occurring after heat treatment at 300ºC; but ductility is unchanged.*

The mechanical properties of the widely used jewellery alloy Pt-5% Cu have been investigated by several researchers (see, for example, (1–3)) for the cast, cold worked and annealed conditions. It is however not widely known that platinum containing around 5 wt.% copper undergoes an ordering transformation after low-temperature heat treatment (4, 5). Recent work in the Centre for Materials Engineering (6) showed that the $Pt_7Cu$ ordered phase, which can form after heat treatment at temperatures as low as 200ºC, can improve the hardness of Pt-5% Cu. If the alloy is cold worked before heat treatment, the increase in hardness after heat treatment is significant. If the alloy is first quenched from high temperatures, an increase in hardness on heat treatment is measurable but not as great.

Given the widespread use of Pt-5% Cu in platinum jewellery, it is surprising that there is little information on this phenomenon in the technical literature. The hardness increase for this alloy has important implications for the manufacture of jewellery, since using low-temperature heat treatment as a final step in the manufacture of a jewellery piece can produce a better finish and improved scratch resistance. Conversely, hardness may be inadvertently increased by heating during manufacture, leading to difficulty in subsequent working of the piece. An understanding of the effect of heating on strength accordingly allows optimal planning of the manufacturing route.

The effect of the $Pt_7Cu$ ordering transformation on mechanical properties other than hardness has not previously been investigated. In this paper we investigate the effect on the strength and ductility of Pt-5% Cu of heat treatments which result in ordering. The tensile mechanical properties of platinum and its alloys have not been studied extensively, owing to the costs associated with tensile specimens of conventional (American Society for Testing and Materials (ASTM)) scale (7). These costs can be considerably reduced by microsample tensile testing, described previously in this Journal (3). Mechanical properties such as yield strength, tensile strength and ductility can be measured using specimens just 8 mm in length. In the present work the mechanical properties of Pt-5% Cu, before and after heat treatments which result in ordering, are fully characterised by microsample tensile testing and hardness testing.

## Experimental Procedure

Bars (50 g in mass) of Pt-5% Cu were cold rolled to reduce thickness by 50%, before homogenising at 1000ºC for 12 hours in an argon atmosphere. A fully recrystallised grain structure resulted after homogenising. Composition and homogeneity were assessed by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The thickness was then further reduced by 90%, and specimens were cut from the resulting sheet. The 8 mm long specimens for microsample tensile testing were cut with the long axis parallel to the rolling direction. Heat treatments were carried out at temperatures between 100°C and 1000°C for 3 hours, followed by furnace cooling.

After heat treatment all specimens were ground, then polished to a 1 μm surface finish. A Zwick microhardness tester with a standard Vickers indenter was used at 100 gf load to measure the hardness of the specimens for each condition. Metallography specimens were etched electrolytically in a solution of 25 g sodium chloride, 20 $cm^3$ hydrochloric acid 32% and 65 $cm^3$ distilled water; an alternating current was used at a potential of 10 V, for an etching time of 40 to 75 seconds, with a stainless steel anode and a graphite cathode used to complete the circuit. Tensile specimens were ground and polished to a 1 μm surface finish on both sides. Measured gauge widths were between 440 μm and 510 μm, and gauge thicknesses were between 125 μm and 350 μm. Tensile tests were carried out using a microsample tensile tester at a strain rate of $10^{-3}$ $s^{-1}$.

## Results

Figure 1 shows representative engineering stress/engineering strain curves for Pt-5% Cu in the cold worked condition and after heat treatment at several temperatures. Figure 2 is an extract from Figure 1, showing results for the cold worked condition and after heat treatment at

*Fig. 1 Stress-strain curves for Pt-5% Cu (cw = cold worked)*

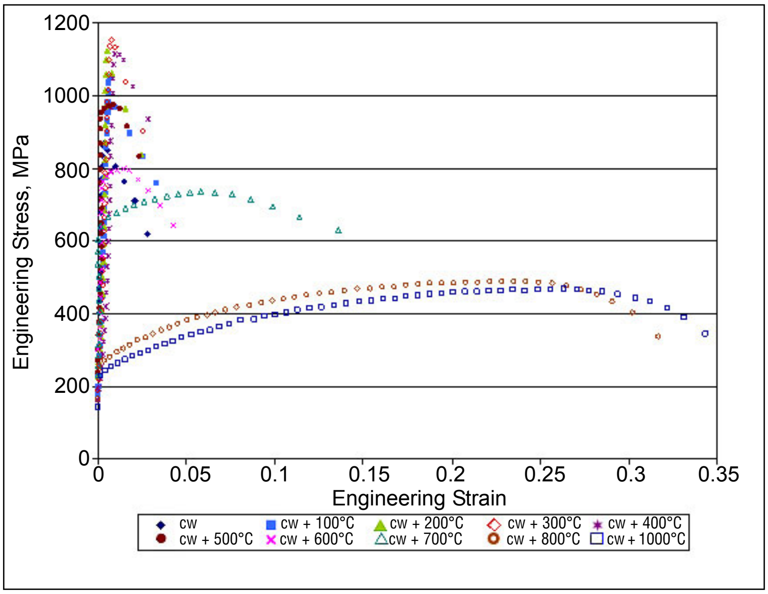
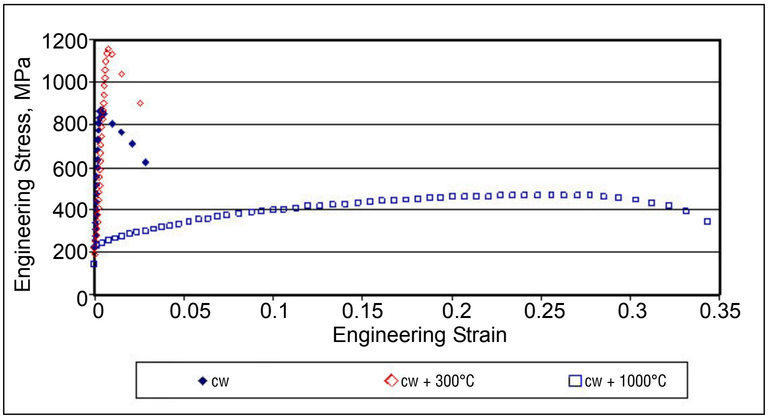



*Fig. 2 Extract from Figure 1: Stress-strain curves for Pt-5% Cu in the 90% cold worked condition and after heat treatment at 300°C (highest increase in strength) and 1000°C (cw = cold worked)*



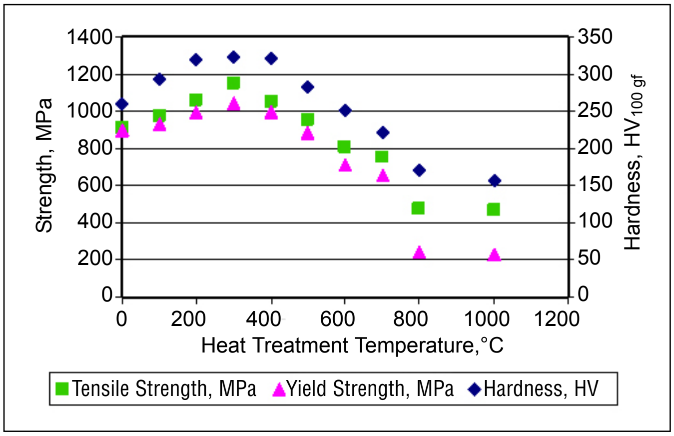



*Fig. 3 Mechanical properties of Pt-5% Cu vs. heat treatment temperature after heat treatment for 3 hours*

300°C (highest increase in strength) and 1000°C. Relative to the cold worked condition (90% reduction in rolling), yield strength and tensile strength are observed to increase after heat treatment at between 100°C and 500°C. Heat treatment at 600°C and above results in a decrease in strength and an increase in ductility.

Figure 3 shows the yield strength, tensile strength and hardness of Pt-5% Cu as a function of heat treatment temperature. Strength and hardness consistently increase after heat treatment between 100°C and 400°C, as seen in Figure 1. Heat treatment at 500°C results in little change in the properties relative to the cold worked condition; heat treatment at higher temperatures results in a decrease in strength and hardness. Measured values for hardness, yield strength, tensile strength and ductility (percentage elongation after fracture) are given in Table I.

Figure 4 shows the microstructure of the Pt-5% Cu alloy before and after heat treatment. After heat treatment at 300°C (the temperature which resulted in the greatest increase in strength), the heavily deformed and elongated grains from the cold working are unchanged. After heat treatment at 700°C, a recrystallised grain structure is observed, and after heat treatment at 1000°C grain growth has occurred.

## Discussion

Cold work followed by heat treatment below 500°C results in an increase in the yield strength, tensile strength and hardness of Pt-5% Cu. These results are consistent with a previous report (6) of an increase in the hardness of this alloy due to an ordering transformation. For this alloy the critical

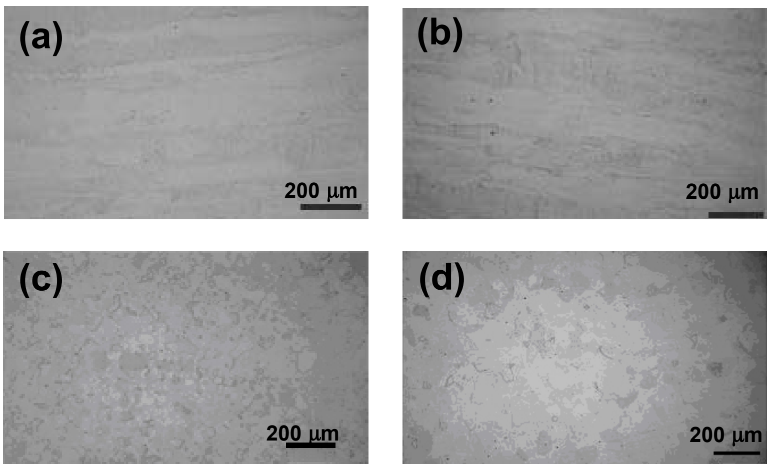



*Fig. 4 Micrograph of Pt-5% Cu: (a) 90% cold worked, then heat treated for 3 hours at: (b) 300°C; (c) 700°C; (d) 1000°C*

Table I

## Mechanical Properties of Pt-5% Cu Alloy in the Cold Worked Condition, and After Heat Treatment for Three Hours

| Heat treatment temperature, °C | Vickers hardness, HV | Yield strength, MPa | Ultimate tensile strength, MPa | Ductility, % |
|---|---|---|---|---|
| No heat treatment; 90% cold worked | 259 ± 11<br>*240* (3)<br>*241* (6) | 896 ± 40<br>*970* ± *100* (3) | 910 ± 53<br>*990* ± *90* (3) | 3 ± 1<br>*2* ± *1* (3) |
| 100 | 292 ± 9 | 932 ± 48 | 972 ± 56 | 3 ± 1 |
| 200 | 320 ± 9<br>*360* (6) | 994 ± 89 | 1056 ± 91 | 2 ± 1 |
| 300 | 322 ± 8 | 1048 ± 55 | 1153 ± 43 | 2 ± 1 |
| 400 | 320 ± 12 | 993 ± 60 | 1055 ± 61 | 2 ± 1 |
| 500 | 282 ± 11 | 887 ± 14 | 952 ± 18 | 3 ± 1 |
| 600 | 251 ± 16 | 711 ± 18 | 805 ± 18 | 4 ± 1 |
| 700 | 222 ±14 | 652 ± 13 | 749 ± 20 | 10 ± 3 |
| 800 | 172 ± 8<br>*150* (6) | 245 ± 40<br>*280* ± *30* (3) | 477 ± 24<br>*530* ± *40* (3) | 30 ± 7<br>*36* ± *9* (3) |
| 1000 | 158 ± 7 | 228 ± 31 | 469 ± 27 | 31 ± 8 |

*Values in italics are from References (3) and (6). Note that in Reference (3) heat treatment time is six hours*

ordering temperature, $T_c$, is around 500°C (4, 6), which means that a transformation to an ordered state can be expected to occur as a result of heat treatment below 500°C. This does not result in any change in grain structure relative to the cold worked state, as seen in Figure 4(b); the observed change in properties thus arises entirely from the ordering transformation.

Hardness is expected to be proportional to yield strength (8); this is observed in the results shown in Figure 3. Hardness measurements alone, however, do not provide a complete characterisation of mechanical properties, which requires tensile testing. It is of interest to note that, although heat treatment between 200°C and 400°C results in very similar hardness increases, there is a clear maximum in yield strength and tensile strength after heat treatment at 300°C.

Generally, ductility is expected to decrease as strength increases and *vice versa*: Figures 1 and 2 and Table I show that when strength decreases as a result of recovery and recrystallisation, ductility increases as expected. Heat treatment of cold worked Pt-5% Cu below 500°C, however, can result in a significant increase in strength relative to the cold worked value, but ductility remains unchanged. The ordering transformation which occurs below 500°C accordingly has an unexpected effect on tensile properties, in that an increase in strength is achieved without further loss of ductility.

Heat treatment at temperatures above $T_c$ does not result in an ordering transformation. In this alloy, heat treatment at temperatures above 500°C leads to recovery and recrystallisation, as shown in Figure 4(c), which results in a decrease in strength. Increasing heat treatment temperature above 700°C results in grain growth, and a consequent further decrease in strength and increase in ductility are observed.

## Conclusions

The hardness and strength of cold worked Pt-5% Cu can be significantly enhanced by heat treatment for three hours at temperatures between 200ºC and 400ºC, without reducing ductility. A short, low-temperature heat treatment can thus significantly enhance the mechanical properties of Pt-5% Cu jewellery items which have been produced by cold working.


## Acknowledgement

The financial support of the National Research Foundation and the Sainsbury Trust is gratefully acknowledged.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