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The Hardening of Platinum Alloys for Potential Jewellery Application

By T. Biggs
Formerly Mintek, now 513 Atkins Place, Burlington, Ontario, L7T 2V2, Canada; E-mail: tarynbiggs@yahoo.ca

and S. S. Taylor and E. van der Lingen
Mintek, Private Bag X3015, Randburg, 2125, South Africa

Pure platinum is too soft to be used for jewellery and scratches easily. Alloying platinum increases its hardness significantly. However, platinum alloys used in jewellery do need to be easy to work and thus the alloy should be sufficiently soft, but not so soft that their wear resistance is low. A good compromise would be to work with a soft alloy during jewellery manufacture, then harden the alloy so the final finished properties were improved. In order to identify platinum alloys suitable for hardening, platinum with different alloying additions was studied. Platinum alloys with additions of less than 7 wt.% of Ag, Au, Cu, Co, Cr, Fe, Ga, Ge, In, Mg, Mn, Mo, Ni, Si, Sn, Ta, Ti, V, W or Zr were examined, and the merits of each system were assessed for commercial viability. The platinum-titanium system was deemed to show the most promise.

Pure platinum (Pt) is generally too soft (HV ~ 60) to be used for fabricating jewellery, so alloying additions are made to increase the hardness. Platinum jewellery alloys usually have platinum contents of 90 wt.% and higher. The most common alloys are hallmarked as 950 platinum (95 wt.%). Unlike carat gold (Au) jewellery alloys, where relatively large additions can be made (to alter the properties of the alloy such as its hardness or colour): for instance 18 ct gold contains 25 wt.% of alloying additions, the 950 platinum alloy hallmarking, only allows alloying additions of up to 5 wt.% (to alter properties, such as increase its hardness).

Several platinum jewellery alloys are available, and usage depends on national preference and hallmarking regulations. Typical alloying elements include copper (Cu), palladium (Pd), cobalt (Co), gallium (Ga) and indium (In). Cu is often added and creates a general-purpose alloy which casts well and is easy to work. Adding Co results in a very good casting alloy, while additions of Ga or In produce alloys with good springiness. Other popular alloying additions are iridium (Ir) and ruthenium (Ru). Pd can be added to platinum, but while this alloy has a good surface finish, softness limits its use. Examples of hardening platinum by alloying additions are shown in Figure 1 (1, 2).

There has been much work on hardening platinum by alloying and this is demonstrated in several patents. Citizen Watch Co. holds a patent for an alloy of 85–95 wt.% Pt, 1.5–6.5 wt.% Si with the balance being one or more of Pd, Cu, Ir, Rh, Au, Ag, Ni and Co (3). This company also patented a Pt-Fe-Cu-Pd alloy (85–90 wt.% Pt, 2.5–3.5 wt.% Fe, 7.5–12.5 wt.% Cu and 0–4 wt.% Pd) (4).

A patent on hard Pt alloys for jewellery application states the hard, high-purity Pt alloy contains 10–100 ppm Ce with a minimum Pt content of 99 wt.% (5). Another patent is concerned with maintaining the high purity of platinum while increasing its hardness by minor additions (0.01 to 1 wt.%) of titanium or a rare earth metal. No age hardening was reported (6).

Hard, but still workable, platinum alloys have been reported with good abrasion resistance. These were achieved by modifying a surface layer to induce hardening (7, 8). An intermetallic layer of platinum, containing especially aluminium and chromium, developed on the surface. One patent

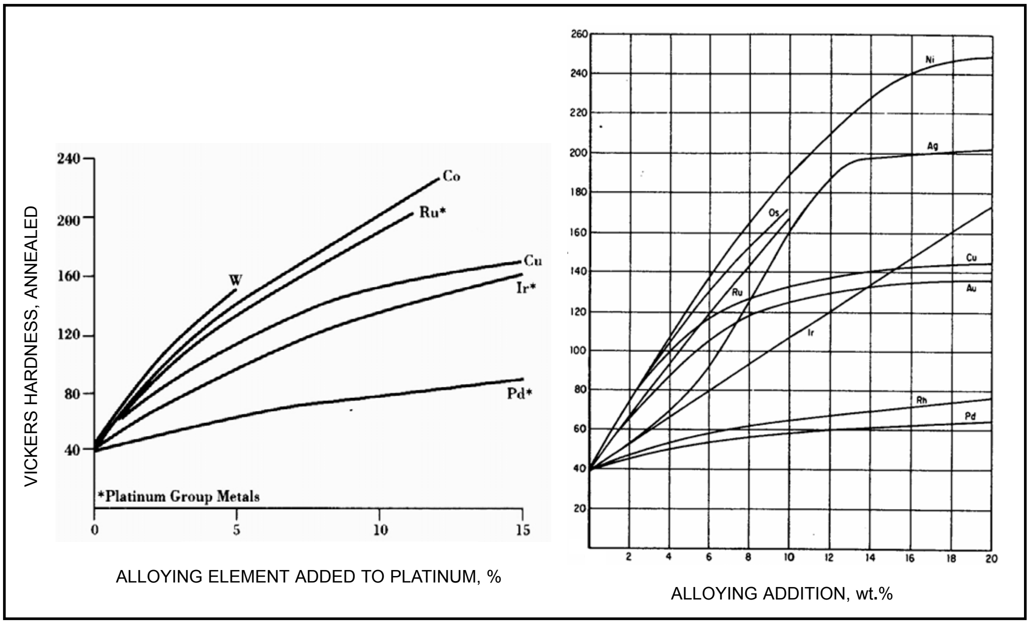

Fig. 1 The effects of alloying additions on the annealed hardness of various platinum alloys (1, 2)

claims a hard alloy that has a boron-containing surface layer (9).

However, these surface hardening techniques add to manufacturing costs; they produce no visible benefit to the consumer and are technically unsuitable for use by small jewellery manufacturers. Platinum jewellery alloys need to have good wear resistance and improved surface finish, and a very high final hardness can often impart these properties. Achieving a high hardness is desirable, but if the alloy is too hard it cannot be easily worked, so hardness and the degree of workability have to be balanced.

Casting is used in mass platinum jewellery production, but results in pieces having hardnesses similar to those of the annealed material (50 to 180 HV). During fabrication, an alloy will work harden due to cold working, and intermediate annealing is often required to soften it for further fabrication. It would thus be very helpful to have an alloy soft enough to work but which could then be hardened after fabrication or casting. Post-fabrication hardening can be achieved by an appropriate heat treatment. Heat treatment can result in:

- an increase in hardness
- a decrease in hardness, or
- no change in hardness.

The parameters of heat treatment – time and temperature – need to be controlled, as does the alloy chemistry. Heat treatment is used most often to anneal and soften the alloy. During deformation an alloy hardens, and subsequent annealing results in recovery (rearrangement of dislocations) and recrystallisation of new grains, producing a softer alloy. The higher the annealing temperature, the faster this occurs. Most cold-worked platinum alloys begin to stress relieve at 600ºC and they soften rapidly at 1000ºC, which may be regarded as the general annealing temperature for Pt alloys.

Age Hardening: Prior Work

Heat treatment can result in hardening (age hardening) if precipitation of another phase, or ordering, occurs at that temperature. The likelihood of one of these phenomena taking place can often be inferred from phase diagrams. Unfortunately, information on age hardening is limited due to a lack of research and development on platinum systems.

Age-hardenable platinum alloys currently in use by jewellers are from the Pt-Au system. A 95Pt-5Au alloy has an annealed Brinell hardness of 92 and an age-hardened hardness of 155, whereas a 90Pt-10Au alloy has an annealed Brinell hardness of 143 and an age-hardened hardness of 222 (10). The alloy with higher hardness will have better wear resistance.

Vines and Wise (10) investigated the effects of alloying additions on the age hardenability of platinum systems. They found that platinum alloys with low calcium additions can be age hardened. Small additions of calcium form insoluble low melting or brittle compounds with platinum.

Annealed platinum alloys containing 5–20% Cu displayed only slight hardening on ageing at 450 to 500°C for 30 minutes (10).

Pt-10% Ir alloys showed a slight increase in ultimate tensile strength after cold work and subsequent heat treatment. This was attributed to ordering, and occurred at around 780°C after periods of long heat treatment. Pt-Ir alloys with 10–40% Ir could be mildly hardened by heat treatment (550°C or 800°C) (10).

Pt-Fe alloys containing 10–70% Fe (maximum at 30% Fe) showed age hardening on slow cooling (10).

Finally, marked precipitation hardening was observed in the Pt-Ag system for 15–35% Ag. Relatively high Ag additions (> 5 wt.%) and long ageing times are required for hardening (10).

Recent work has focused on hard platinum alloys for ornamental purposes, with alloys containing < 95 wt.% Pt. An aged hardness of between 280 HV and 335 HV has been achieved with 85–90 wt.% Pt, 3.5–5.5 wt.% Fe and balance ≥ 5 wt.% Cu (11). Some alloys have been reported that can even be hardened by heat treating. Kretchmer holds patents relating to heat-treatable Pt-Ga-Pd alloys for jewellery, for example (12, 13).

Experimental Work

The ideal outcome would be a platinum alloy where, at high temperatures, the second element would be in solid solution with the platinum, but which, at low temperatures, would precipitate out (as a second phase). As hallmarking regulations were taken into account, only alloys containing at least 95 wt.% Pt were investigated. Alloying elements identified as having hardening potential, based on published phase diagram information, were selected for testing (14). If one element in a Group showed promise, all the elements in that Group were considered.

A preliminary study was conducted using 2 and 4 wt.% alloying additions. Selected alloys, with 3 wt.% alloying additions, were also made. Alloying elements were selected using criteria such as: cost, hazardous effects and availability, as well as phase diagram information and published data. For example, in the Pt-rich end of the platinum-titanium (Pt-Ti) phase diagram, an ordered $TiPt_8$ phase can form, which could result in hardening. As zirconium (Zr) and vanadium (V) are close to Ti in the Periodic Table and have similar phase relations, they were thought likely to have hardening potential.

As very little phase diagram information was available at the start of this study, the phase diagrams were only used as a guideline. A further study was then begun on systems that were identified as having potential. Alloying amounts in the order of 1–7 wt.% were added.

Alloy "buttons" were made by arc melting, on a water-cooled copper hearth, melting three times to ensure homogeneity. Heat treatments were conducted in a vacuum tube furnace and samples were subsequently quenched in water. Hardnesses were measured on a Vickers hardness tester with a 10 kg load.

Any precipitates that form during casting have the potential to increase the hardness of the as-cast alloy. So in order to start with minimum alloy hardness, the arc-melted alloys were given a 1000°C solutionising heat treatment for 20 minutes to redissolve any precipitates that had formed during casting. A temperature of 1000°C was selected, as this is the temperature commonly used to anneal platinum alloys after cold working. Subsequent heat treatments were given to induce hardening.

Ideally, phase diagrams should be used to select heat treatments but in most cases this information was unreliable or absent. As jewellers would use a hardening heat treatment process, temperatures in the region of 400–1000°C were selected for the heat treatments. Higher temperatures were considered to be impractical, and lower temperatures

Table I

Hardness (HV_{10}) of 98Pt-2X Alloys (wt.%): Hardening Potential of X after Ongoing Heat Treatments

Sample (alloyed composition, ~ wt.%)	HV*after HT# at 1000°C for 20 min and WQ^	HV after HT at 600°C for 20 min and WQ	HV after HT at 800°C for 10 min and WQ	HV after HT at 800°C for 30 min and WQ	HV after HT at 800°C for 10 min and WQ
98Pt-2Ni	102	100	102	102	102
98Pt-2Si	376	339	329	317	
98Pt-2Ti	**177**	**214**	**232**	**231**	**251**
98Pt-2V	159	157	148	150	148
98Pt-2Cr	113	112	111	104	-
98Pt-2Mn	102	102	101	104	-
98Pt-2Fe	114	102	100	102	-
98Pt-2Co	97	94	95	94	-
98Pt-2Mg	**140**	**154**	**147**	**139**	**-**
98Pt-2Cu	86	88	84	86	-
98Pt-2Ga	141	124	118	117	119
98Pt-2Ge	**265**	**305**	**233**	**230**	**222**
98Pt-2Zr	223	207	206	208	209
98Pt-2Mo	130	129	125	124	-
98Pt-2In	**118**	**133**	**135**	**135**	**135**
98Pt-2Sn	**123**	**131**	**138**	**139**	**136**
98Pt-2Ta	125	113	112	114	-
98Pt-2W	106	101	99	100	-
98Pt-2Ag	97	92	83	80	80
98Pt-2Au	86	73	71	71	72

**HV: Vickers hardness* #*HT: heat treatment* ^*WQ: water quench*

were expected to result in only slight changes and/or slow kinetics and thus long times for heat treatment. Times of between 30 minutes and 3 hours were considered suitable for heat treatments.

Results: Preliminary Study

Table I shows results from 98 wt.% Pt alloys. The alloys were subjected to an 'anneal' at 1000°C for 20 minutes, and successive heat treatments at 600°C for 20 minutes, 800°C for 10 minutes, 800°C for a further 30 minutes, and finally 800°C for 10 minutes. Hardness was measured after each heat treatment. Additions of 2 wt.% of Ti, Mg, Ge, In or Sn produced potential hardening effects, shown in blue in Table I.

A range of 96 wt.% Pt-4 wt.% X alloys was also investigated, see Table II. These 4 wt.% as-cast alloys were 'annealed' at 1000°C and then heat treated at 800°C for 10 minutes, 800°C for 10 min, 800°C for 10 min, 800°C for 30 min and then 800°C for 60 minutes. In contrast to the results from the 98 wt.% alloys, higher quantities of Ga and Zr improved the hardness by ageing (800°C), but no significant hardening was observed with 4 wt.% Ti and Ge. A slight increase in hardness occurred for 2 and 4 wt.% Sn.

Some 97 wt.% Pt alloys were also investigated, see Table III. These 3 wt.% as-cast alloys were 'annealed' at 1000°C and then heat treated at 800°C for 10 minutes, 800°C for 10 min, 800°C for 10 min, 800°C for 10 min and then 800°C for 60 minutes. This indicated that there is hardening potential for additions of 3 wt.% of Sn and Zr.

This preliminary study of 2, 3 and 4 wt.% additions suggested that hardening had resulted from heat treatments. The preliminary study also suggested that alloying additions of Ti, Zr, Sn, Ga, Ge, Mg and In to platinum resulted in increases in hardness after heat treatments at 800°C. These

Table II

Hardness (HV_{10}) of 96Pt-4X (wt.%): Hardening Potential of X after Ongoing Heat Treatments

Sample (alloyed composition, ~ wt.%)	HV after HT at 1000ºC for 20 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 30 min and WQ	HV after HT at 800ºC for 60 min and WQ
96Pt-4Ni	138	140	139	141	137	135
96Pt-4Ti	297	264	287			
96Pt-4V	205	195	195			
96Pt-4Cr	155	142	146	108	143	142
96Pt-4Mn	137	130	140	133	118	130
96Pt-4Fe	141	131	133	131	127	124
96Pt-4Co	135	122	123	141	137	123
96Pt-4Cu	119	113	112	112	112	117
96Pt-4Ga	**232**	**341**	**335**			
96Pt-4Ge	406	331	328			
96Pt-4Zr	**365**	**388**	**378**	**393**	**400**	**421**
96Pt-4Mo	185	167	167	165	164	164
96Pt-4Sn	**170**	**169**	**179**	**172**	**177**	**174**
96Pt-4Ta	165	159	157	154	161	158
96Pt-4W	149	144	123	138	138	138
96Pt-4Ag	84	73	71			
96Pt-4Au	100	94	87			

Table III

Hardness (HV_{10}) of 97Pt-3X (wt.%): Hardening Potential of X after Ongoing Heat Treatments

Sample (alloyed composition, ~ wt.%)	HV after HT at 1000ºC for 20 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 10 min and WQ	HV after HT at 800ºC for 60 min and WQ
97Pt-3Sn	**144**	**147**	**140**			**163**
97Pt-3Ni	138	130	124			123
97Pt-3Zr	**286**	**348**	**363**	**355**	**358**	
97Pt-3Cr	142		134			
97Pt-3Mn	108		102			
97Pt-3V	194	168	175	167	169	180

alloy systems were therefore selected for a further study. Although vanadium did not show a hardening effect in the preliminary study, it was included in a further study.

Results: Further Study

Platinum alloys in the region of 1–7 wt.% Ti, Zr, Sn, Ga, Ge, Mg, In and V were then investigated further. As-cast hardness and the hardness after heat treatment at 1000°C for 30 minutes were measured. Hardnesses after heat treatment at 800°C for 10 min, then that temperature for 10 min, 10 min, 30 min and then 60 min were recorded (15, 16).

Comments are made in subsequent paragraphs about the observed hardening in this further study, and pertinent observations are reported. Any phase diagrams (14) that exist are provided.

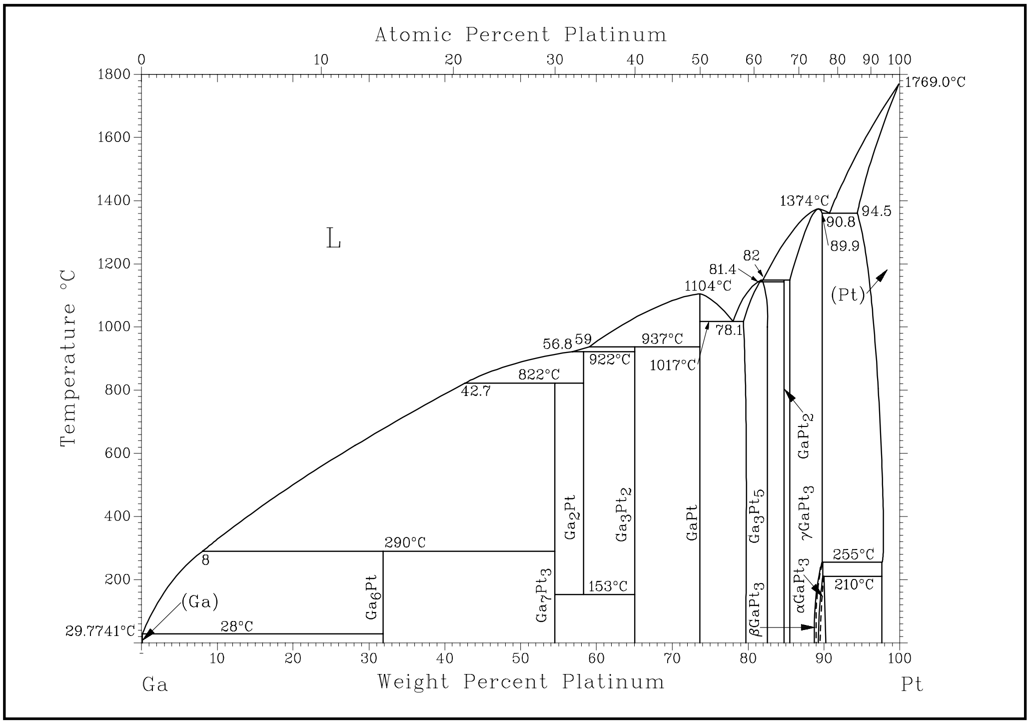

Fig. 2 Pt-Ga phase diagram (14); L is the liquid phase

Platinum-Gallium (Pt-Ga)

The addition of 1 to 6 wt.% Ga to Pt generally resulted in an increase in hardness, from around 80 to 225 HV after heat treatment at 1000ºC. After heat treatment at 800ºC hardening was observed in the region 3.8 to 6 wt.% Ga, and was particularly noticeable for additions of 4.4, 5.2, 6 and 6.1 wt.% Ga. The hardness values attained in this later study differ slightly from earlier values (Table II). This may be due to slight variations in composition. The hardening effect could also be very sensitive to changes in chemical composition. Increases in hardness values of ~ 100 HV, after heat treatment at 800ºC, were observed for additions of ~ 5 wt.%.

The Pt-Ga phase diagram (Figure 2) shows that alloys containing less than ~ 2.5 wt.% Ga are a Pt-rich solid solution. At 1000ºC a two-phase region exists for about 3.5 to 10 wt.% Ga alloys and at 800ºC a two-phase diagram exists in the region 3 to 10 wt.% Ga. During heat treatments at these temperatures a second phase may be precipitating out for samples containing 3.8 to 6.1 wt.% Ga.

Platinum-Germanium (Pt-Ge)

The addition of 1 to 5 wt.% Ge to Pt resulted in alloys with a range of hardness values, from 175 HV to 440 HV after heat treatment at 1000ºC. In some cases the heat treatment caused an increase in hardness of up to 125 HV above the base value. In these cases, subsequent heat treatments at 800ºC resulted in either very slight changes (increases or decreases) or a significant decrease in hardness. The highest observed increase in hardening was by around 40 HV, and subsequent heat treatments resulted in a decrease in hardness.

The phase diagram (Figure 3) shows that at less than 1 wt.% Ge, a Pt-rich solid solution exists. Above 951ºC, in the region of ~ 3 to 12.9 wt.% Ge, a phase field of [L + (Pt)] exists, with a two-phase region of (Pt) and Pt_3Ge below 951ºC in the region ~ 1 to ~ 9.5 wt.% Ge.

A heat treatment of samples containing more than 2.6 wt.% Ge at 1000ºC should thus result in some melting. Heat treatment at 800ºC of rapidly quenched samples could induce changes in hardness due to the precipitation of a second phase.

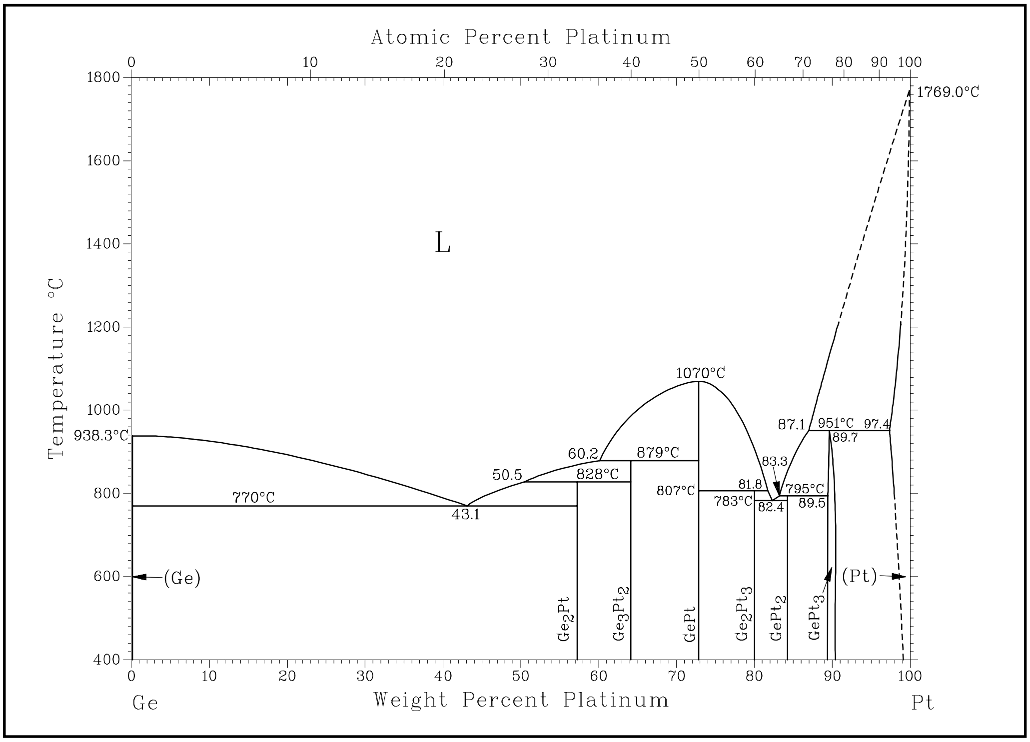

Fig. 3 Pt-Ge phase diagram (14)

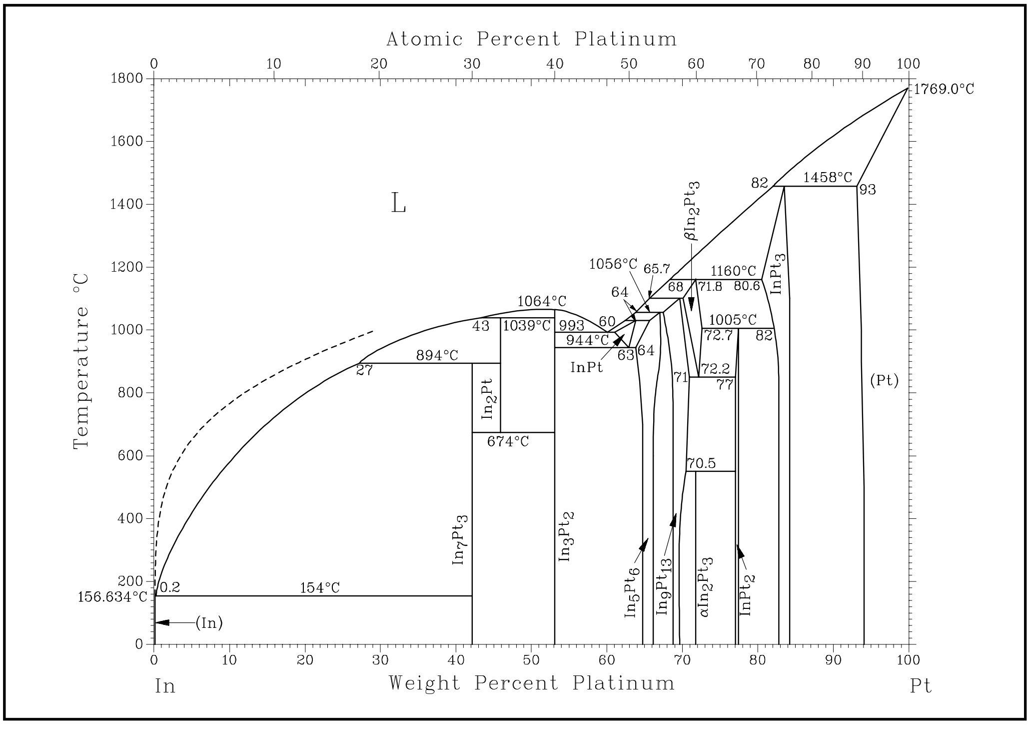

Fig. 4 Pt-In phase diagram (14)

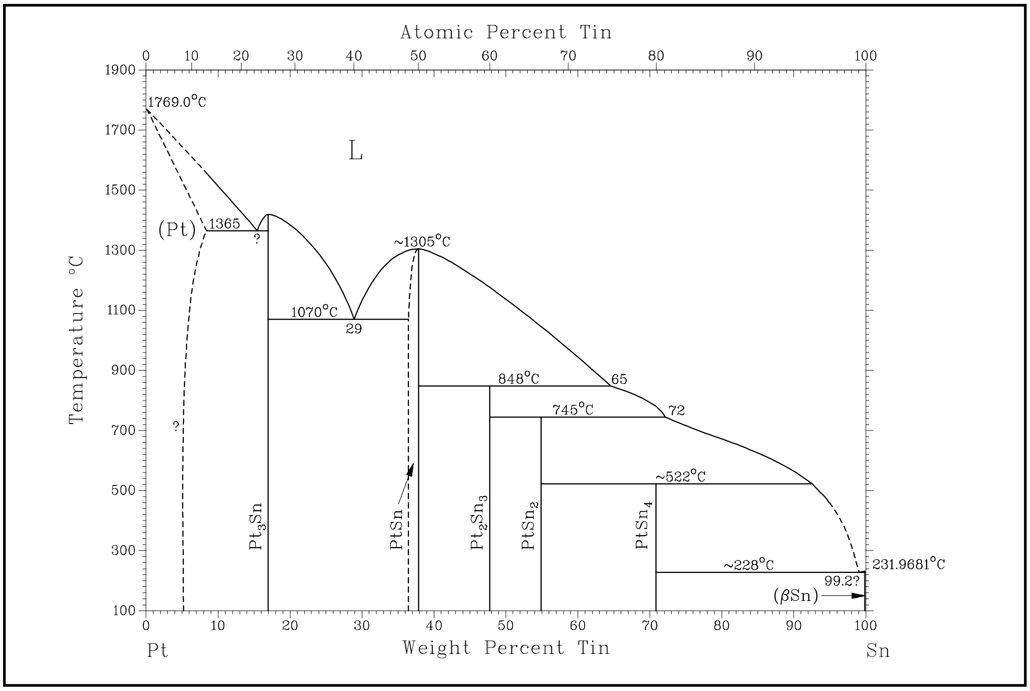

Fig. 5 Pt-Sn phase diagram (14)

The phase diagram has regions of uncertainty in the high platinum regions, particularly for the boundary of the Pt-rich solid solution.

Therefore this alloy system is not likely to be a good prospect for a commercial jewellery alloy as it is too sensitive to the specific heat treatment conditions.

Platinum-Indium (Pt-In)

The addition of 1 to 7 wt.% In to Pt resulted in alloys with a range of hardness values from around 110 to 180 HV, but up to around 270 HV after heat treatment at 1000°C. No significant changes in hardness were observed after the range of heat treatments at 800°C. One interesting result was an increase from ~ 200 to 275 HV in the 6.9 wt. % alloy after heat treatment at 1000°C, but this needs further investigation before it can be confirmed.

The Pt-In phase diagram (Figure 4) shows that a Pt-rich solid solution exists up to 6 wt.% In and for ~ 6 to ~ 15.9 wt.% In a two-phase region (Pt-rich solid solution and Pt_3In) exists. At 800°C and 1000°C the solid solution boundary is still close to 6 wt.% In and, if correct, cannot account for the observed changes in hardness. A possible explanation for the observed hardening may be ordering, but further studies would be needed to verify this.

Platinum-Tin (Pt-Sn)

The addition of 1 to 6 wt.% Sn to Pt resulted in a fairly linear increase in hardness with alloying addition, from around 110 HV to 215 HV, after heat treatment at 1000°C. Hardening was evident in alloys containing more than 3 wt.% Sn after heat treatment at 800°C. Hardening increases of between 20 HV and 40 HV were noted in alloys with additions of between 3.4 to 5.5 wt.% Sn.

The Pt-Sn phase diagram (Figure 5) suggests that a solid solution exists for alloys in the region 0 to 5 wt.% Sn. Thus, 3.4 wt.% Sn should be a Pt-rich solid solution. The 6 wt.% Sn alloy is a Pt-rich solid solution at 1000°C (on the boundary) and a two-phase mixture at room temperature. The Pt-Sn phase diagram is uncertain in the region 0 to 17 wt.% Sn. In the region 0 to 5 wt.% Sn, no conclusions were drawn about the cause of hardening. Ordering may explain the observed hardening, but further work would be needed to verify this.

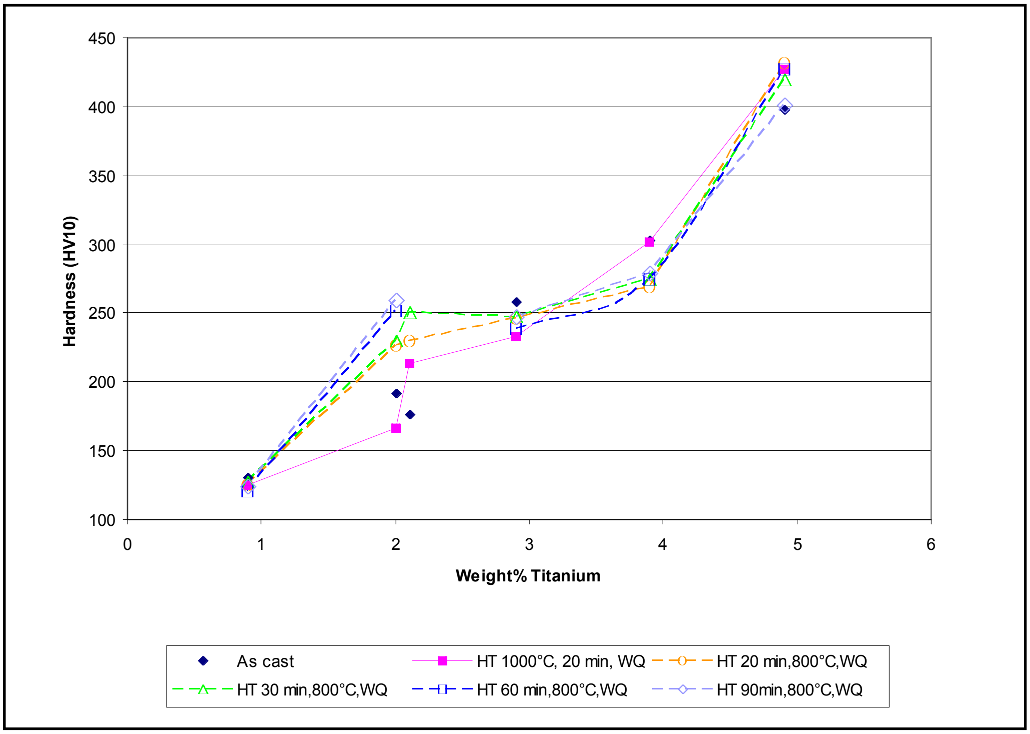

Fig. 6 Hardness values of Pt-Ti after different heat treatments (as cast, followed by heat treatments at 1000°C and then at 800°C for varying times)

Platinum-Magnesium (Pt-Mg)

A Pt-Mg phase diagram was not available during this study. Adding 1 to 5 wt.% Mg to Pt gave Pt-Mg alloys with a range of hardness values from around 100 to over 170 HV after heat treatment at 1000°C. Heat treatment often resulted in softening by 15 HV to 25 HV. No increase in hardening greater than 20 HV was observed on heat treatment at 800°C, so this system was not studied further.

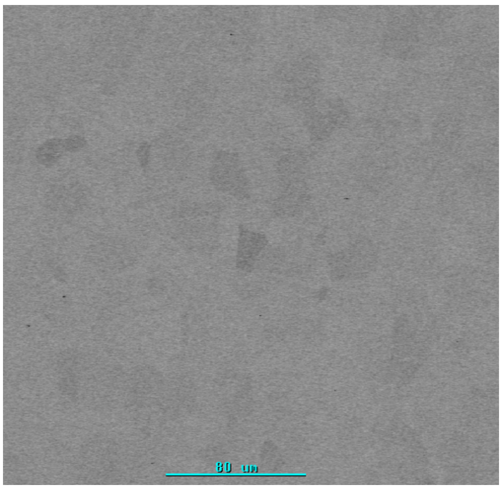

Fig. 7 A SEM backscattered image of a sample alloy of 98 wt.% Pt-2 wt.% Ti. The bar is 80 μm long

Platinum-Titanium (Pt-Ti)

The addition of 1 to 5 wt.% Ti to Pt resulted in a fairly linear increase in hardness with alloying addition: from around 125 HV to almost 430 HV, after heat treatment at 1000°C. Slight hardening (around 30 HV) was observed for the 5 wt.% alloy, although the 2 wt.% Ti alloy softened by about 30 HV, after heat treatment at 1000°C. Subsequent heat treatments on this alloy at 800°C led to a significant hardening of around 90 HV.

The 2 wt.% Ti alloy had a hardness of around 170 to 180 HV after heat treatment at 1000°C, a hardness of 260 HV after heat treatment at 800°C, and cold worked and heat-treated hardness values of around 400 HV to 430 HV (Figure 6). SEM

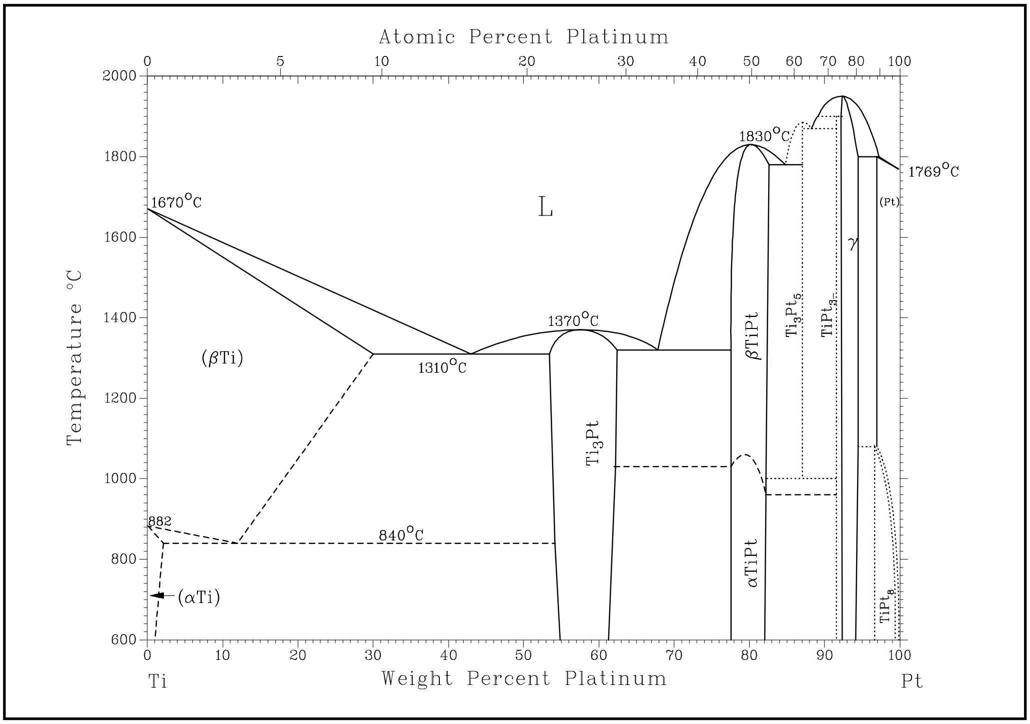

Fig. 8 Pt-Ti phase diagram (14)

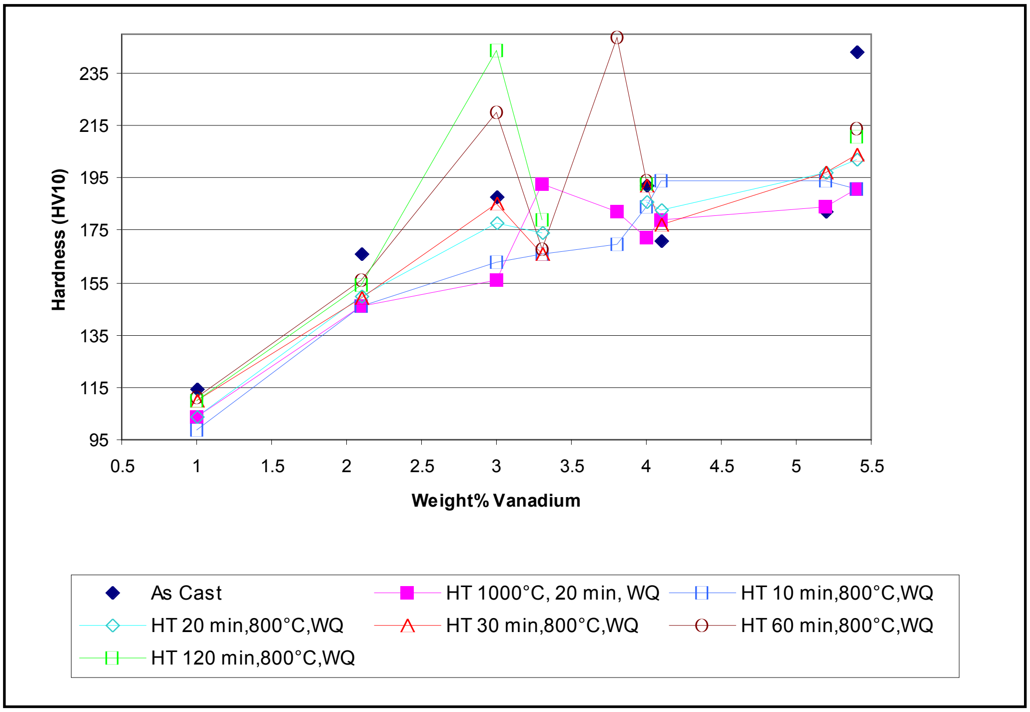

Fig. 9 Hardness values of Pt-V after different heat treatments (as cast, followed by heat treatments at 1000ºC and then at 800ºC for varying times)

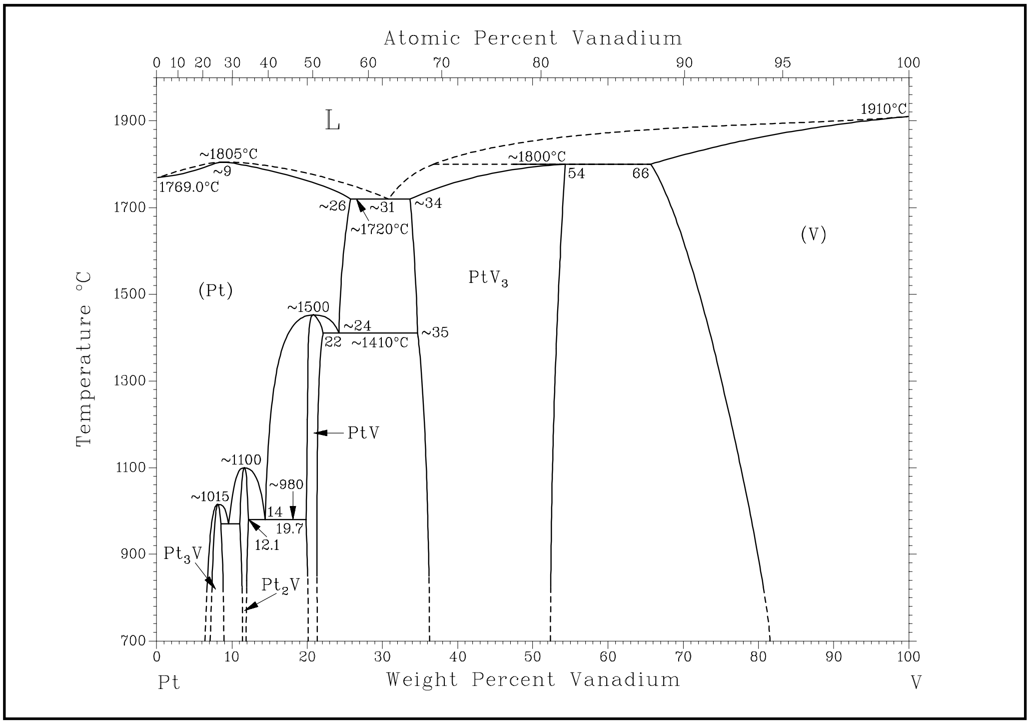

Fig. 10 Pt-V phase diagram (14)

examinations of the annealed and heat-treated microstructure showed no evidence of second phases (Figure 7).

The phase diagram for platinum-titanium has not yet been finalised in the regions of high platinum (Figure 8). It could be that hardening results from the formation of $Pt_{11}Ti$, but in this investigation there were no data to support or dispute this. This system has commercial potential and will be explored in a future paper in this Journal.

Platinum-Vanadium (Pt-V)

The addition of 1 to 6 wt.% V to Pt resulted in alloys showing a fairly linear increase in hardness, from ~ 100 HV to 193 HV, with alloying additions (Figure 9), after heat treatment at 1000°C.

After heat treatment at 800°C, hardening was not observed in alloys that contained additions of less than 2.9 wt.% V. Hardening was observed in alloys with additions of 3 to 5.4 wt.% V. At 3 and 3.8 wt.% V a significant increase in hardening of 50 HV to 100 HV was observed. A slight hardening effect was observed with ongoing heat treatments at 5.4 wt.%. However, the sensitivity is very high and the hardening range is narrow. In practice, this would be very hard to control and hence it would not result in a good commercial alloy. Ordered Pt-V phases have been reported elsewhere (17).

The Pt-V phase diagram is inconclusive below 800°C (Figure 10). It suggests that alloys containing up to ~ 6 wt.% V are Pt-rich solid solutions, which cannot explain the hardening. It may be that the boundaries of the Pt_3V phase are more Pt-rich than are shown in the phase diagram at lower temperatures or that there is another phase present.

Platinum-Zirconium (Pt-Zr)

The addition of 1 to 5 wt.% Zr to Pt resulted in a fairly linear increase in hardness, from around 140 HV to 410 HV, with alloying additions, after heat treatment at 1000°C.

A significant hardening effect resulting after heat treatment at 800°C was observed for 3 and 4 wt.% Zr additions, while a slight hardening was observed in the region of 4 to 4.7 wt.%. The reported phase diagram (Figure 11) shows that Zr

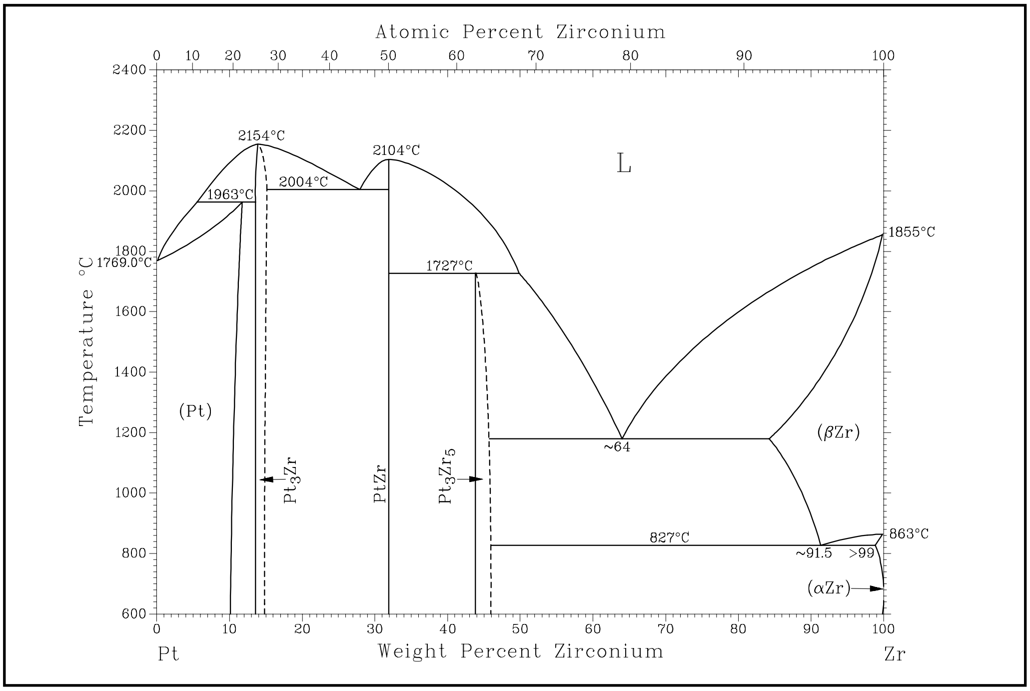

Fig. 11 Pt-Zr phase diagram (14)

was in solid solution throughout the temperature and composition ranges studied. The phase diagram cannot explain the observed hardening. The hardening effect could be of the order of 75 HV, which is very significant. Again, a possible explanation for the observed hardening could be due to ordering, but further studies would be needed to verify this.

Discussion

In this study annealed alloys were heat treated and investigated. The objective was to discover alloys that were soft enough to be worked by jewellers but which could be hardened subsequently to improve wear resistance.

Cold work results in hardening, and is determined by the production route. Heat treatment is

Table IV

Hardening Effects of Different Alloying Additions to Platinum

Addition	Amount, wt.%	Approximate increase in hardening, HV	Approximate initial hardness, HV	Is the alloy viable?	Comments/problems
Ga	5–6	100	175–225	No	Hallmarking, volatility
Ge	1–5	48–132[#]	165–351	No	Too much fluctuation
In	6.9	68[#]	205	No	Too much fluctuation
Mg	0.1–5			No	Nothing significant
Sn	5.5	40	215	No	Hallmarking
Ti	2	90	170–180	Yes	Good
V	3	50–100	160–180	Yes	Sensitive
Zr	3	70	280–300	No	Initial ductility

[#] *On heat treating the as-cast alloy at 1000ºC*

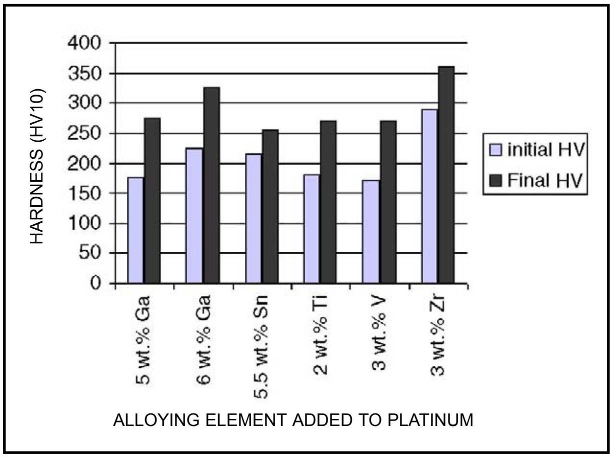

Fig. 12 The absolute initial and final hardnesses for a range of platinum alloys most improved by heat treatment

another hardening route, which can increase hardness if mechanisms such as ordering or precipitation hardening occur. This is very dependent on alloy chemistry and the phase relations in the system. Binary alloys with additions of Ga, Ge, Sn, Ti, V and Zr showed hardening as a consequence of heat treatment. Some of the more important hardening effects are summarised in Table IV and Figure 12. It was difficult to predict hardening behaviour from the phase diagrams because the phase diagram information was generally inadequate and incomplete, and more platinum phase diagram work needs to be undertaken.

Factors to be considered must include initial ductility – a most important factor as a jewellery alloy must be easily worked. While hardness is not a measure of ductility, it often gives an indication of this property. From experience, hardness values of around 300 HV or more were found to give formability problems.

The sensitivity of the alloy to compositional variation and heat treatment parameters must also be considered. If sensitivity to composition is too high then the hardening is not reproducible or repeatable as, realistically, the composition will vary. For heat treatment, a bench jeweller may only use a gas torch (compared to the laser welding equipment a manufacturer might have (18)) and this does not allow for accurate temperature control or controlled environments.

The final factor is the hallmarking regulations, and alloying additions of less than 5 wt.% are preferable to satisfy the requirements for popular hallmark 950. The platinum-titanium alloy was considered to be the most viable alloy system and was selected as a candidate for commercialisation.

Properties important for jewellery manufacture: workability, colour, tarnish resistance, wear resistance, castability and machinability, were all investigated (19–23). If alloys are cold worked prior to heat treatment, an even higher final Vickers hardness can be obtained. This was observed in the Pt-Ti system, and will be reported on later in this Journal. The effects of ternary additions on hardening were also studied, and will also be reported later.

Conclusions

This study suggests that the Pt-Ti system is the most viable one for commercialisation. The 2 wt.% titanium-platinum alloy has as cast and annealed Vickers hardness values that are low enough to allow the alloy to be easily formed or worked. Subsequent heat treatment can increase the hardness of the alloy by around 90 HV, to give high hardness and improved wear resistance to the finished material. This alloy is considered to have potential in jewellery fabrication.

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The Authors
Dr Taryn Biggs is formerly of Mintek, South Africa, where she was involved in numerous research projects in the platinum field. These ranged from investigating and developing jewellery alloys to failure analyses of platinum jewellery. She also worked on projects to develop industrial platinum alloys. She currently works at Dofasco, Canada, as a project manager in product development.

Stefanie Taylor works in the Physical Metallurgy Division at Mintek, South Africa. Her research interests include platinum alloys, particularly jewellery alloys, and also gold alloys for jewellery and industrial use. She has worked with processes ranging from casting to powder metallurgy and is currently looking at new processes and products for the South African jewellery industry.

Dr Elma van der Lingen heads the Precious Metals Group in the Physical Metallurgy Division at Mintek. She is involved in research on precious metals (platinum, ruthenium, iridium and gold) for jewellery, catalysis, nanotechnology, corrosion, fuel cell electrode development and biomedicine.