http://dx.doi.org/10.1595/147106713X668596

PGM HIGHLIGHTS

Platinum Alloys: A Selective Review of the Available Literature

Introduction

More than half of the platinum that is produced around the world each year currently finds use in automotive and other areas of industry as a catalyst and as a major constituent in various engineering alloys (**Figure 1**) (1). Platinum also has a place in jewellery manufacturing. The objective of this article is to review the existing phase diagrams and known properties of some platinum alloys that are used in industrial and jewellery applications, and also to present published data on some less used platinum alloys which nevertheless have interesting properties. The alloys covered are of platinum with palladium, iridium, rhodium, ruthenium, gold and nickel.

The data on mechanical properties of the platinum alloys presented in **Tables I–VII** are obtained from the monograph by R. F. Vines (2) published in 1941, still the most comprehensive source, from The PGM Database (3) hosted by Johnson Matthey, and from the internal database and website of Sigmund Cohn Corporation (4), a US pgm alloy fabricator. To keep the uniformity of units of measure all tensile strength (TS) data is presented in psi, and all the hardness data is presented in Vickers hardness (HV) (some of these values are converted from MPa and Brinell respectively). All alloy compositions are given in weight per cent (wt%) unless otherwise specified.

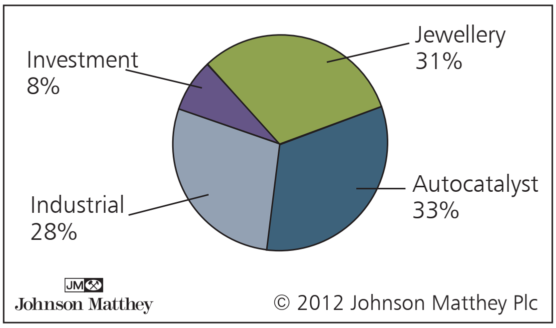

Fig. 1. Platinum demand by application. Industrial applications include chemical, electrical, glass, petroleum and other (1)

Platinum Alloys for Jewellery

Platinum alloys containing other platinum group metals (pgms), gold and some base metals present a variety of workable materials that demonstrate high strength, increased hardness and springiness. Many of these alloys are used for making jewellery (5), as they exhibit platinum's desirable white colour, and can be cast (6), extruded (7), rolled, drawn and formed (8).

A moderate brightness in combination with low red and yellow colour components make the colour of platinum a unique and attractive jewellery material that effectively accents the reflectivity of precious stones. **Table I** compares the colour of platinum with that of fine silver and typical 18 carat and 14 carat white golds using CIELAB colour coordinates, as measured by the author using a Macbeth Color-Eye® spectrophotometer model M2020PL. Platinum and its alloys show brightness L^* about 85, neutral a* and fairly low b* components. Silver shows a* and b* values similar to those of platinum but a much higher brightness L^*, about 95. The L^* and a* values of white golds are similar to those of platinum, however such alloys exhibit much higher yellow components b* of at least 9.0 and most of them require rhodium plating.

The Santa Fe Symposium presentation by Jurgen Maerz in 1999 provides a comprehensive review of common platinum jewellery alloys (5). The legal requirements of minimum platinum content narrow the alloy range and prohibit the utilisation of the enhanced mechanical properties of many alloys outside this range.

Table I
Colour of White Jewellery Alloys

Material	Brightness, *L**	Green-red, a*	Yellow-blue, b*
Platinum and pgm alloys	85	0	4.5
Fine silver	95	–0.5	4.2
18 carat white gold	84	0	9.5
14 carat white gold	84	–0.5	9.0

PGM Alloy Properties

One of the key factors affecting the properties of an alloy is the crystalline structure of the pure metals of which it is composed. The crystalline structures of the pgms are shown in **Figure 2**. Four elements, Pt, Pd, Ir and Rh, have a face-centred cubic (fcc) structure, where the atoms are positioned at each corner and in the centre of each face of the cube. In general, the fcc metals are soft in the annealed condition and are quite workable, similarly to gold, silver and copper. The structure of the other two pgms, Ru and Os, is the more complex hexagonal close-packed (hcp) structure, similar to that of zinc. Such a major difference in crystalline structure suggests the significant hardening effect of Ru and Os when alloyed with Pt. In fact, additions of Os to Pt make the resultant alloys extremely hard and practically unworkable.

It is not surprising that binary phase diagrams (9) of Pt-Pd, Pt-Ir and Pt-Rh (**Figures 3**, **4** and **5** respectively) show similarity, whereas the Pt-Ru (**Figure 6**) phase diagram has a different and more complex form. Pd, Ir and Rh show solubility in Pt for the entire compositional range at high temperatures and miscibility gaps are seen at lower temperatures. In contrast, Pt-Ru is a peritectic system. Ru has solubility in Pt within certain compositional ranges (10). The miscibility gap feature is a potential mechanism for age hardening of Pt-Pd-Ir-Rh alloys, although little published data is available, probably because of fairly slow ageing kinetics (11).

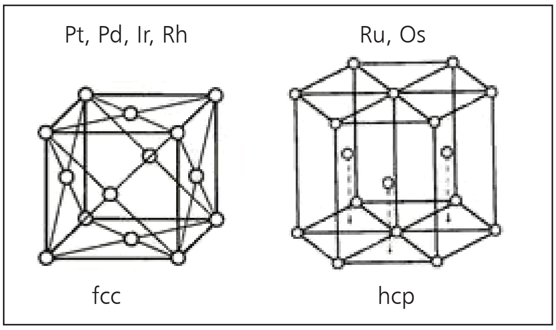

Fig. 2. Crystalline structures of the platinum group metals

Platinum-Palladium Alloys

Pt-Pd alloys are soft and workable. **Figure 7** shows that the hardness and tensile strength of Pt-Pd alloys reach their maximum values at about 40% Pd. The mechanical properties of pure Pt, Pd and some of their alloys are compared in **Table II**. Pt and Pd are very similar: both have low hardness and tensile strength in annealed and cold worked conditions. The additions of 10% and even 40% Pd to Pt increase the hardness and strength somewhat; however these values still remain fairly low. The use of Pt-Pd alloys is therefore quite limited. It is remarkable that when 6% Ru is alloyed with Pt in addition to 10% Pd, the resultant all pgm alloy shows significantly increased hardness and strength, and retains good ductility (25% elongation) and excellent resistance to corrosion.

Platinum-Iridium Alloys

Pt-Ir alloys are noticeably harder and stronger than Pt-Pd. Pure Ir is fairly hard. Additions of Ir to Pt result in a rapid rise in alloy hardness and strength as shown in **Figure 8**. Pt-Ir alloys with about 30% Ir and higher become extremely springy and practically unworkable – probably that is why the data in **Figure 8** is limited to 30% Ir.

The mechanical properties of pure Pt and Ir and some of their alloys are listed in **Table III**. Even though the hardness of the annealed Ir is about four or five times higher than that of Pt, Ir shows a tensile strength similar to that of Pt and a fairly good percentage elongation of 21%. Pt-5% Ir and Pt-10% Ir are common jewellery alloys. Pt-20% Ir alloy is much harder, stronger,

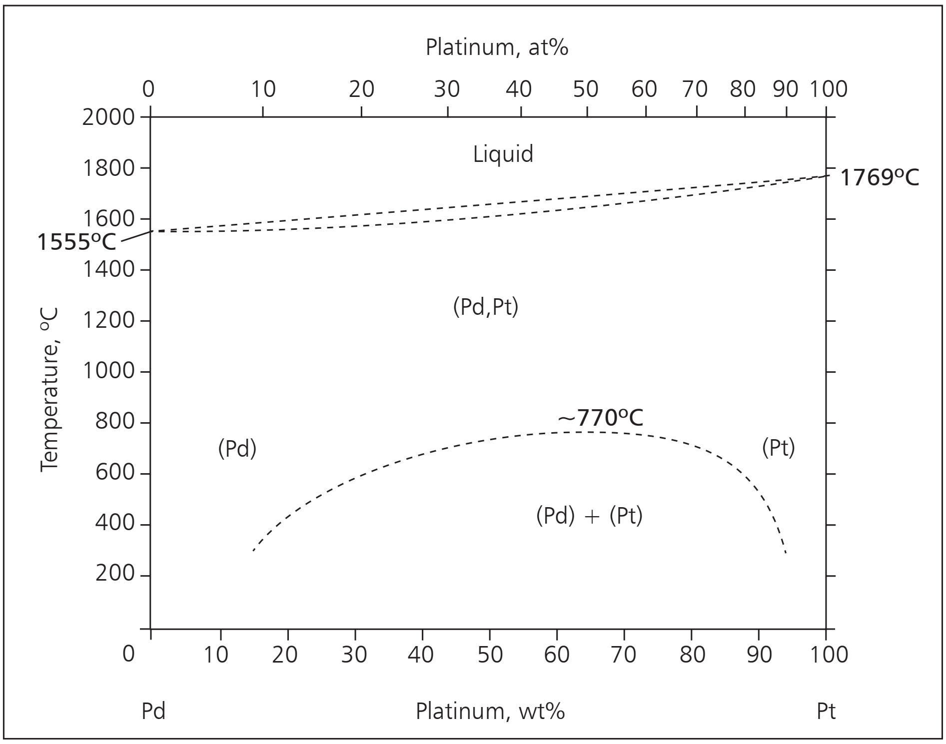

Fig. 3. Platinum-palladium phase diagram (9)

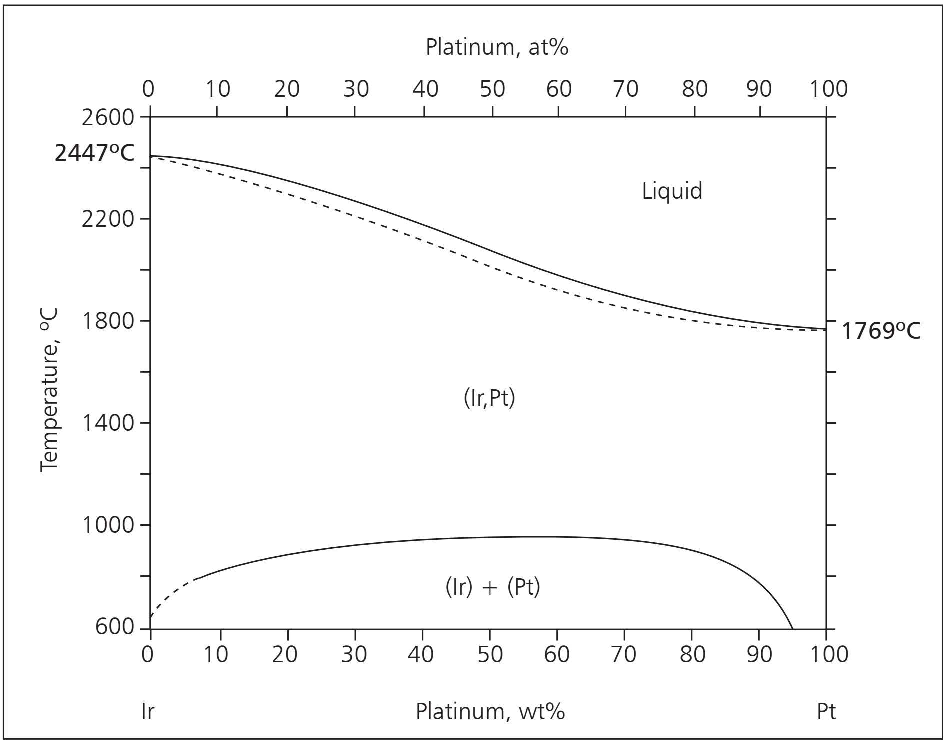

Fig. 4. Platinum-iridium phase diagram (9)

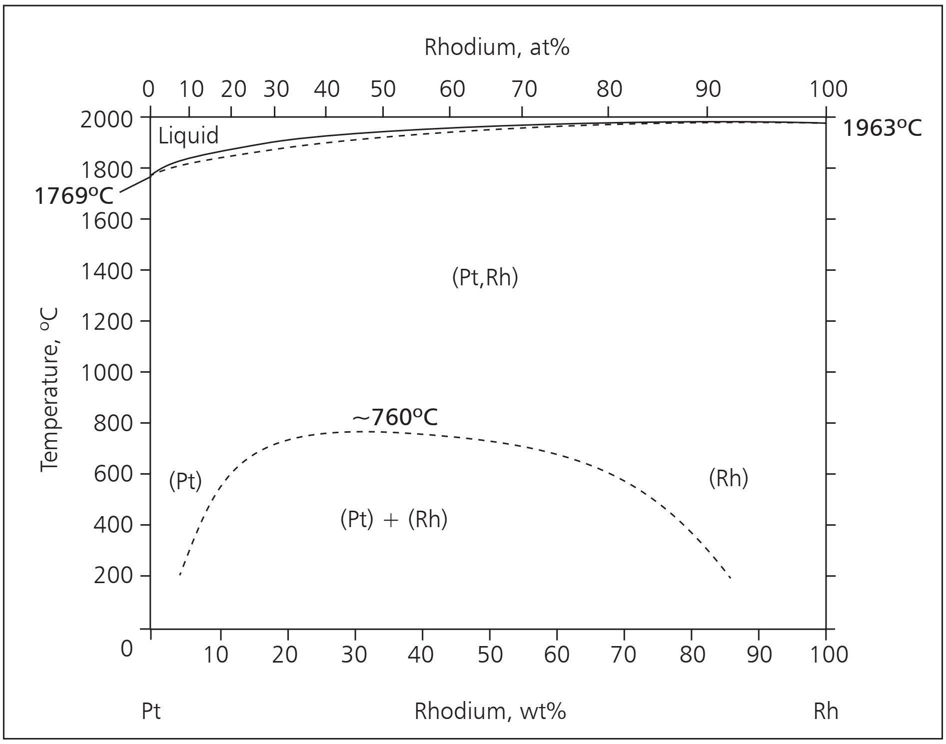

Fig. 5. Platinum-rhodium phase diagram (9)

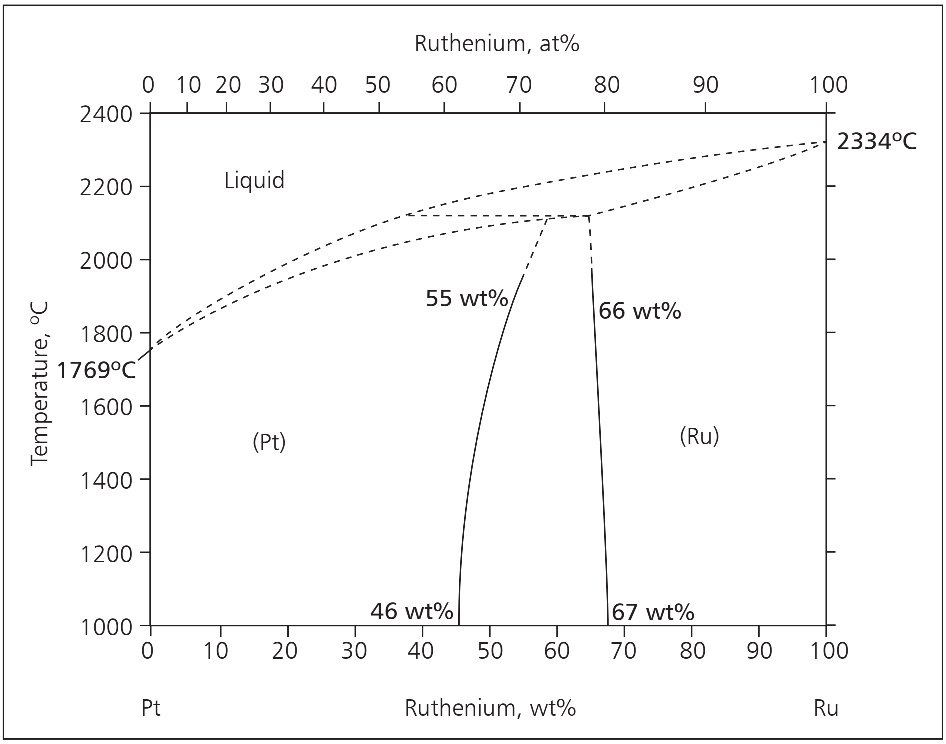

Fig. 6. Platinum-ruthenium phase diagram (9)

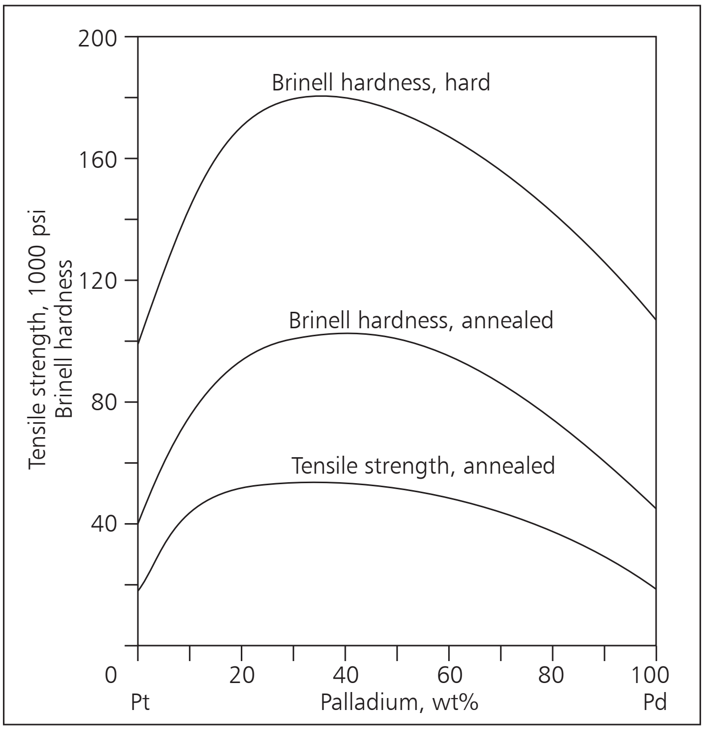

Fig. 7. Tensile strength and hardness of platinum-palladium alloys (2)

Table II

Mechanical Properties of Platinum, Palladium and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi
Pt	40	18,100	40	90	49,300
Pd	40	27,500	40	100	47,000
Pt-10% Pd	80	21,300	25	140	49,700
Pt-40% Pd	100	50,000	–	180	–
Pt-10% Pd-6% Ru	200	75,000	25	320	90,900

[a] *ann = annealed*

[b] *cw = cold worked*

and still maintains good ductility (20% annealed elongation). In the sheet form it can be rolled down to 0.0005″ (0.0127 mm) thickness. In the wire form it can be drawn to 0.001″ (0.0254 mm) diameter. This pgm alloy is used for precision machining of parts for implantable medical devices.

Pt-30% Ir alloy shows extreme hardness and strength. This alloy is not easily workable. Its main application is found in medical devices as a spring wire. The mechanical properties of Pt-20% Ir alloy can be enhanced by adding 10% Rh. The Pt-20% Ir-10% Rh alloy is less springy than Pt-30% Ir, shows good

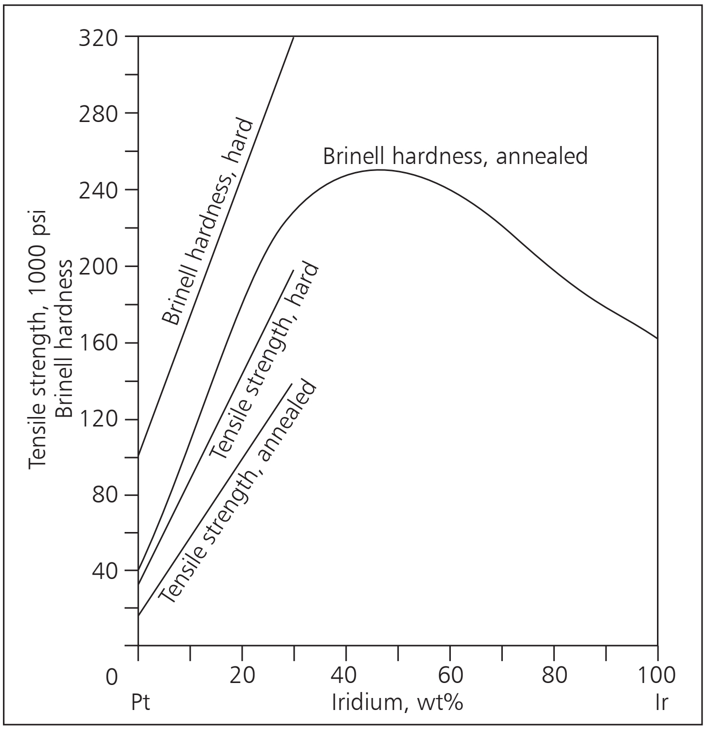

Fig. 8. Tensile strength and hardness of platinum-iridium alloys (2)

Table III

Mechanical Properties of Platinum, Iridium and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi
Pt	40	18,100	40	90	49,000
Ir	210	18,000	21	–	–
Pt-5% Ir	85	36,500	35	145	65,000
Pt-10% Ir	110	51,000	30	185	70,000
Pt-20% Ir	190	100,000	20	240	188,500
Pt-30% Ir	280	159,500	20	315	269,500
Pt-20% Ir-10% Rh	–	120,000	20	–	200,000

[a] *ann = annealed*

[b] *cw = cold worked*

workability, and retains good ductility (20% annealed elongation).

Platinum-Rhodium Alloys

Pt-Rh alloys are primarily used in thermocouples for operation at high temperatures (up to 1700ºC) in an oxidising or inert environment. Type S consists of Pt *versus* Pt-10% Rh, type R of Pt *versus* Pt-13% Rh and type B of Pt-6% Rh *versus* Pt-30% Rh. The standard wire sizes that are used to manufacture these thermocouples range between 0.001″ (0.0254 mm) and 0.032″ (0.813 mm). **Table IV** lists the mechanical properties of Pt, Rh and

Table IV

Mechanical Properties of Platinum, Rhodium and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi
Pt	40	18,100	40	90	49,000
Rh	100	81,000–125,000	9–33		215,000
Pt-10% Rh	90	45,000	35	150	90,000
Pt-20% Rh	115	68,000	33	200	133,500
Pt-30% Rh	130	71,000	30	235	152,000
Pt-40% Rh	145	83,500	30	290	178,000
Pt-15% Rh-5% Ru	–	95,000	18	–	200,000

[a] *ann = annealed*

[b] *cw = cold worked*

some of their alloys. Rh is very difficult to work and anneal. As a result, the published tensile properties of annealed Rh are inconsistent; its strength is reported between 81,000 psi and 125,000 psi, and the elongation between 9% and 33% (3). Pt-Rh alloys, however, are quite ductile, and show consistent and moderate rise in hardness and strength as the Rh content increases. The elongation stays practically constant at between 30% and 35% with Rh content up to at least 40 wt%. Pt-20% Rh alloy shows good hardness and strength, and excellent machining properties. It is used for precision part fabrication for the aerospace industry. Replacing some Rh with Ru, such as in Pt-15% Rh-5% Ru alloy, enhances the strength, but also results in the loss of some ductility from 33% to 18% elongation.

Platinum-Ruthenium Alloys

The hardening effect of Ru additions to Pt was first recognised by Adolph Cohn almost a century ago (12). Since then Ru-containing Pt alloys have become widely used in a variety of applications especially jewellery. **Table V** lists hardness, tensile strength and percentage elongation values for Pt, Ru, and two Pt alloys containing 5% and 10% Ru respectively. This data shows that alloying Ru with Pt yields much harder and stronger alloys without compromise in ductility.

Platinum-Gold Alloys

The addition of Au for hardening Pt was first suggested by Adolph Cohn in 1919 (13). The Pt-Au phase diagram in **Figure 9** shows a fairly broad liquidus–solidus melting range and a miscibility gap with the peak close to the solidus. A wide range of Pt-Au alloys undergo spinodal decomposition within the miscibility gap as shown in **Figure 10**. The tensile properties as a function of Au content are shown in **Figure 11**. Although both Pt and Au are very soft, Au acts as an extremely effective hardener for Pt (14). **Table VI** lists the mechanical properties of Pt, Au and Pt alloys with low Au content. The hardness and strength rise with the Au content; however the percentage elongation dramatically decreases. This limits the practical use of such alloys. The deterioration of elongation is attributed mainly to grain growth during solution annealing (15).

It is found that small Rh additions broaden the miscibility gap and displace it up towards the solidus line forming a peritectic-type system (15). Small Rh additions to Pt-Au alloys not only enhance the hardness and strength but also improve ductility by increasing the elongation as illustrated by the Pt-3.5% Au-1% Rh alloy. A similar effect of Rh additions is also observed at higher Au concentrations. Pt-Au alloys with small additions of Rh are hardenable (14–16).

Table V

Mechanical Properties of Platinum, Ruthenium and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi
Pt	40	18,100	40	90	49,000
Ru	250	65,200	3	–	–
Pt-5% Ru	130	65,000	30	200	115,000
Pt-10% Ru	185	123,000	30	220	150,000

[a] *ann = annealed*

[b] *cw = cold worked*

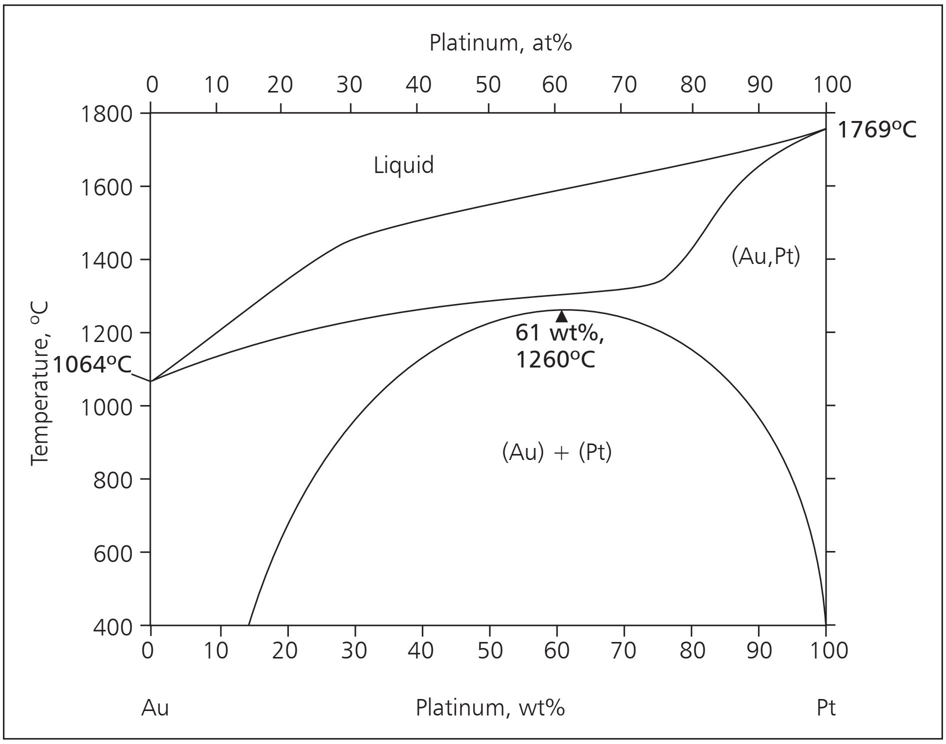

Fig. 9. Platinum-gold phase diagram (9)

Platinum-Base Metal Alloys

A fairly detailed review of Pt-base metal alloys was compiled by R. F. Vines (2). Pt-tungsten and Pt-cobalt alloys have been most studied; and these alloys are commonly used for industrial applications (16, 17). A variety of Pt-base metal alloys such as those containing copper, cobalt, nickel and gallium effectively respond to age hardening (18, 19). Ni, however, finds limited use as an alloying element with Pt even though it belongs to the same group in the Periodic Table. The Pt-Ni phase diagram in **Figure 12** shows the solubility of Ni in Pt for the entire compositional range.

Table VII lists the mechanical properties of pure Pt, Ni and their alloys. It is evident that the hardening effect of Ni on Pt is more pronounced than that of Ir: compare with **Table III**. The phase diagram also shows that alloys containing as little as 10% Ni undergo order-disorder transformation, a typical mechanism for age

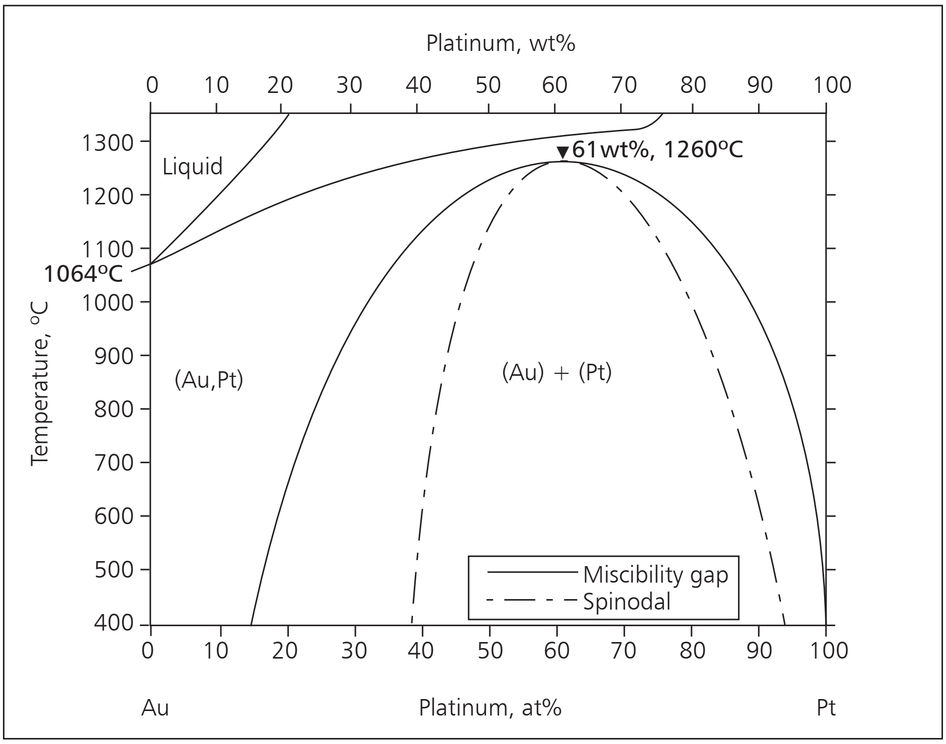

Fig. 10. Platinum-gold phase diagram (9) – spinodal curve

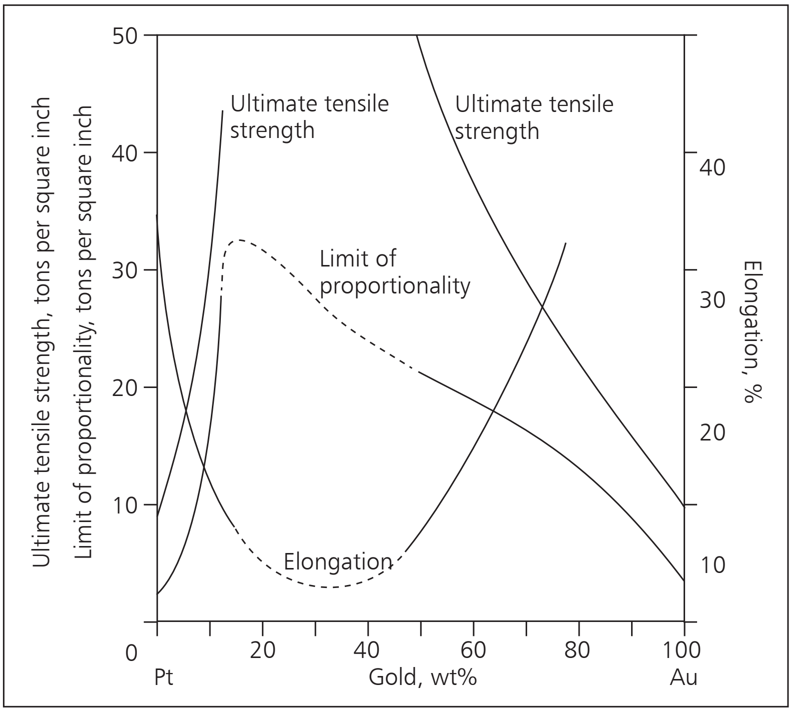

Fig. 11. Tensile properties of solution treated platinum-gold alloys (14)

Table VI

Mechanical Properties of Platinum, Gold and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi
Pt	40	18,100	40	90	49,000
Au	20	15,500	40	60	31,000
Pt-2.5% Au	70	31,000	26	138	49,000
Pt-5% Au	85	45,000	20	155	63,500
Pt-10% Au	130	77,500	12	–	91,500
Pt-3.5% Au-1% Rh	90	36,000	30	–	–

[a] *ann = annealed*

[b] *cw = cold worked*

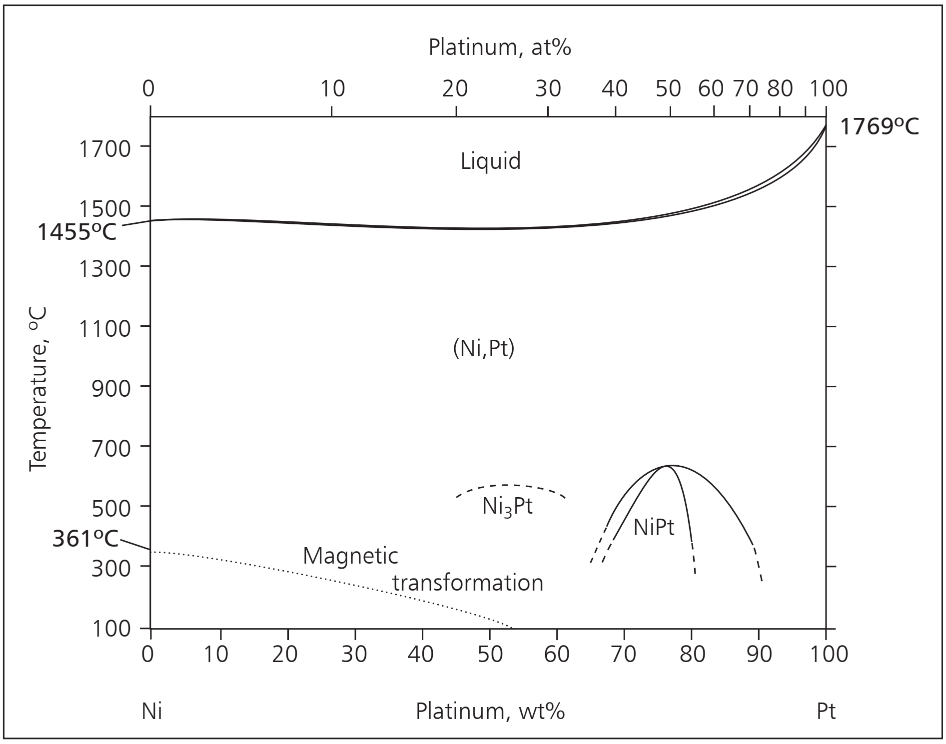

Fig. 12. Platinum-nickel phase diagram (9)

Table VII

Mechanical Properties of Platinum, Nickel and Their Alloys in the Annealed[a] and Cold Worked[b] Conditions and After Heat Treatment[c]

Metal or alloy	Vickers hardness, HV_{ann}	Tensile strength, TS_{ann}, psi	Percentage elongation, $\%E_{ann}$	Vickers hardness, HV_{cw}	Tensile strength, TS_{cw}, psi	Tensile strength, TS_{ht}, psi
Pt	40	18,100	40	90	49,000	–
Ni	85	45,000	45	220	90,000	–
Pt-5% Ni	130	66,500	26	–	100,000	–
Pt-10% Ni	220	118,000	28	380	230,000	300,000
Pt-20% Ni	280	132,000	–	–	250,000	–

[a] *ann = annealed*

[b] *cw = cold worked*

[c] *ht = heat treated*

hardening. For example, an ageing heat treatment increases the tensile strength of Pt-10% Ni alloy from 230,000 psi up to 300,000 psi (TS_{ht} in **Table VII**). The magnetic transformation curve in **Figure 12** indicates that Pt-Ni alloys with Ni content below 40% are practically non-magnetic. This is in contrast with Pt-Co alloys which show magnetism even at 5% Co.

Conclusions

Platinum alloys play a significant role in industry and in jewellery manufacture. It is apparent that there is a wealth of information available from a range of sources and suppliers, and some of it is more readily available than others. The present paper is an attempt to bring together, in convenient form, the basic data that exists in the literature for some of these alloys and to emphasise their interesting properties for industrial and jewellery applications.

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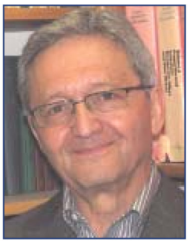

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