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Casting Platinum Jewellery Alloys

PART II: THE EFFECTS OF CASTING VARIABLES ON FILL AND POROSITY

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Comparisons are made between platinum-copper and platinum-ruthenium alloys used for jewellery to evaluate the effects of casting variables. The effects of flask temperatures, investments, and centrifugal speeds on microstructure, percentage fill, and porosity were examined over a range of temperatures. Optimum conditions and materials for successful casting of high quality platinum jewellery alloys, using a Hot Platinum induction melting and casting machine, are described. Suitable choice of investment materials and rotational speeds produced good grid fills with Pt-5%Cu and Pt-5%Ru alloys. Metal porosity was more difficult to control, due to the inherently chaotic nature of the casting process, but casting into a relatively cool mould minimised the probability of bad porosity for both alloys. Pt-5%Ru was found to be successful as a casting alloy when used with induction melting technology. It displayed superior uniformity, hardness and colour, compared with cast Pt-5%Cu alloy.

In Part I of this paper, published here in July, we compared two commercially available casting alloys: platinum-5% copper (Pt-5%Cu) and platinum-5% ruthenium (Pt-5%Ru) used by manufacturing platinum jewellers (1). Optimised performance was obtained for each alloy by changes in their working conditions.

Testing precious metal jewellery alloys to evaluate the effects of casting variables is infrequent – due to the cost of the metal involved – so it is difficult to find explicit guidelines on casting. This is particularly true with platinum alloys which generally require specialised investment materials and high temperatures (2, 3), although alloys with reduced melting temperatures have been available for some time (4). Testing the performance of a newly developed integrated induction melting and casting machine (Hot Platinum ICON3CS) provided an opportunity to study the effects of alloy composition on microstructure (1), and the effects of casting variables on fill and porosity. This paper reports the effects of varying flask temperature and centrifugal speed on the percentage fill of 10 × 10 grids and the porosity of 25 mm diameter rings, cast in two different platinum alloys using various investment materials.

In South Africa, the traditionally used alloy for casting platinum jewellery is Pt-5%Cu (melting range 1725–1745ºC) because of its relatively low melting temperature and high fluidity compared to other commonly used alloys such as Pt-5%Ru (3). The performances of Pt-5%Cu and Pt-5%Ru (melting range 1780–1795ºC) were compared. Pt-5%Ru is widely used for handworking, and the production of compatible cast components in the same alloy would be advantageous to match colour and hardness.

Our prior research showed that cast Pt-5%Ru is more homogeneous and has a finer grain structure than cast Pt-5%Cu (1). This current work shows that with the appropriate investment and rotational speeds good grid fill can be achieved with either alloy. Porosity is more difficult to control, because the casting process is inherently chaotic (5), but casting into a relatively cool mould minimises the probability of bad porosity for both alloys. With induction melting technology, Pt-5%Ru can be used successfully as a casting alloy, taking advantage of its superior uniformity, hardness and colour compared to cast Pt-5%Cu.

Casting Experiments

Casting tests were carried out in a Hot Platinum ICON3CS machine, which integrates induction melting and casting, see Figure 1. This machine routinely melts and casts up to 250 g of platinum alloy into a shallow cylindrical flask of radius 6 cm, which is rotated around a vertical axis. Rotational speeds from 350 to 1200 rpm are possible, generating accelerations equivalent to 8 to 97 G. It has a patented casting mechanism that ensures heat is applied to the metal throughout the melting and casting process, until the point at which the metal leaves the crucible.

The invested trees comprised a central sprue with the test pieces arranged tangentially. The test pieces on most trees were two simple rings 25 mm in diameter and two 10 × 10 grids, see Figure 2. These were combined for the sake of economy, but some tests were performed only with rings.

Testing was primarily concerned with assessing the performance of the machine, but provided the opportunity to study the percentage fill and porosity obtained when Pt-5%Cu and Pt-5%Ru were cast in different investments at different flask temperatures and centrifugal speeds. The investment materials used in the main test series were Bego's Wirovest, Ransom and Randolph's Astro-Vest, and Hoben's Platincast. Most tests were duplicated under nominally identical conditions. Additional industrial trials on casting Pt-5%Ru were performed with Romanoff's "J" Formula. The investment, burn-out, and devestment schedules are listed in Table I; test schedules and summarised experimental results are in Table II.

Fig. 1 Irshad Khan using the Hot Platinum ICON3CS induction melting and casting machine. It can cast up to 250 g of platinum alloy in a single batch

Results

The results of metallographic study of rings from twenty-five of these tests were presented earlier in this E-journal (1). Here we compare the performance of the four different investment materials and examine the effects of varying casting parameters, such as metal temperature, flask temperature, and centrifugal speed.

Investments

The investment process, summarised in Table I, closely followed the recommendations of the respective manufacturers in terms of volume of fluid to mass of powder. The burn-out cycles, see Table I, were arrived at after some preliminary experimentation, and in some cases differ slightly, but not substantially, from the recommended. The most obvious differences in the behaviour of the four investments were in their burn-out time and in the surface finish of the castings.

Wirovest provided the shortest burn-out, but the resulting castings had distinctly rougher surfaces than with the other investments. This is consistent with previously published results of casting platinum alloys in a quick burn-out dental investment (2). On the other hand, Wirovest was a strong investment which could be used to cast heavy thick sections and could withstand high rotational speeds without cracking. We used this investment to cast thick tubular sections in Pt-5%Ru, up to 350 g in mass, for the new South

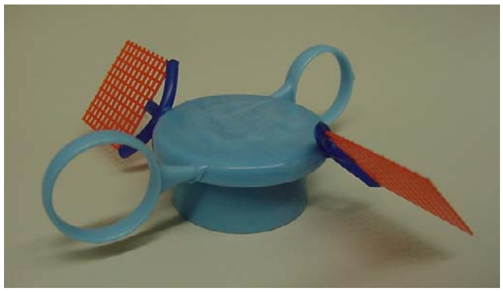

Fig. 2 A wax test model, 110 mm wide, with two rings and two 10 × 10 grids. Photograph by Chumani Mshumi

Table I

Schedule of Investment, Burn-out, and Devestment Conditions for Four Investment Materials

	Wirovest	Astro-Vest	Platincast	"J" Formula
INVESTMENT	36 ml Bego 'BegoSol' + water:powder (84 ml:800 g) mix, vacuum pour, vacuum bench set 2 h remove base	water:powder (218 ml:750 g) mix, vacuum pour, vacuum bench set 2 h remove base	water:powder (250 ml:750 g) mix, vacuum pour, vacuum bench set 2 h remove base	binder soln:powder (210 ml :700 g) mix, vacuum pour, vacuum bench set 2 h retain paper base
BURN-OUT	ramp 250ºC, 1 h hold 250ºC, 1 h ramp 570ºC, 1 h hold 570ºC, 1 h ramp 950ºC, 1 h hold 950ºC, 1h	ramp 30ºC, 0.5 h hold 30ºC, 2 h ramp 150ºC, 2 h hold 150ºC, 4 h ramp 870ºC, 6 h hold 870ºC, 3 h	ramp 30ºC, 0.5 h hold 30ºC, 3 h ramp 150ºC, 2 h hold 150ºC, 2 h ramp 450ºC, 2 h hold 450ºC, 2 h ramp 900ºC, 2 h hold 900ºC, 2 h	ramp 30ºC, 0.5 h hold 30ºC, 1 h ramp 90ºC, 1 h hold 90ºC, 1 h ramp 180ºC, 0.5 h hold 180ºC, 1 h ramp 870ºC, 2.5 h hold 870ºC, 1 h
DEVESTMENT	air cool manual clean	water quench manual clean	water quench manual clean	water quench clean with Romanoff "J" Break, platinum investment remover

African parliamentary mace. The investment manufacturer advised against water quenching. The consequent slow air cool made cleaning the hard investment from the castings difficult and it had to be removed mechanically by grinding. Wirovest is a dental investment which we would not recommend for general use by jewellers due to the rough surface finish, but it could be useful in specialist applications needing superior investment strength.

Astro-Vest and Platincast were largely similar in their working properties and burn-out times. The only noticeable differences were that Astro-Vest, which contains chopped glass fibre, had less tendency to crack during burn-out than Platincast, but Astro-Vest resulted in poor fill of most of the fine test grids (discussed in more detail below). Water quenching removed almost all the investment in both cases, except for a brittle glassy residue that formed in enclosed spaces in the castings with Platincast. This had to be removed mechanically. We would recommend either investment for general purpose jewellery production, with Astro-Vest having somewhat greater strength and Platincast aiding fill of thin sections.

The phosphate-based "J" Formula behaved very differently from the other investments. The investment slurry was thixotropic and the powder had to be added slowly to the liquid while stirring with a powerful mixer. The investment is designed not to set, but rather to congeal during the bench set, so instead of a rubber flask base a thick non-asbestos paper must be used and retained during burn-out. This leaves an ashy residue in the burn-out furnace, which could enter the casting mould. This investment was prone to cracking, with large-scale failure at high rotational speeds, and we failed to cast thick sections successfully with it. However, "J" Formula gave a very smooth surface finish and was indispensable for very fine castings, such as the 800 Pt-5%Ru beads, 2 mm diameter, cast for the new South African parliamentary mace. Cleaning up fine castings was simplified by the use of the proprietary "J" Break solution, a highly corrosive alkali requiring care in handling. Our experience

Table II

Schedule of Casting Tests for the Two 10 x 10 Grids; Results with Pt-5%Cu and Pt-5%Ru, in Pairs, Except Where Indicated (1)

Investment	Alloy	Melt, °C	Flask, °C	Speed, rpm	No.	Grid fill, %		Ring porosity
Wirovest	Pt-5%Cu	2050	940	600	2x	56 & 33	52 & 36	both bad
	Pt-5%Cu	2050	600	600	2x	11 & 1	5 & 1	both good
	Pt-5%Cu	2050	300	600	2x	0 & 0	7 & 0	both good
	Pt-5%Cu	2050	950	1200	2x	100 & 98	14 & 11	1 bad, 1 good
	Pt-5%Ru	1950	950	600	2x	rings only		both bad
Astro-Vest	Pt-5%Cu	1850	870	800	1x	93 & 88		bad
	Pt-5%Cu	1850	870	900	2x	77 & 42	24 & 3	both good
	Pt-5%Cu	1850	600	900	2x	99 & 88	17 & 8	both good
	Pt-5%Cu	1850	300	900	2x	28 & 14	23 & 8	both bad
	Pt-5%Cu	1850	870	1000	2x	41 & 27	53 & 31	1 bad, 1 good
	Pt-5%Cu	1850	870	1200	2x	77 & 69	29 & 24	both bad
	Pt-5%Ru	2050	870	800	1x	10 & 0		good
	Pt-5%Ru	2050	870	900	2x	85 & 56	91 & 44	both good
	Pt-5%Ru	2050	600	900	2x	19 & 0	68 & 50	both good
	Pt-5%Ru	2050	300	900	2x	26 & 18	58 & 52	both bad
	Pt-5%Ru	2050	870	1000	2x	36 & 26	0 & 59	1 good, 1 bad
	Pt-5%Ru	2050	870	1200	2x	94 & 91	86 & 68	1 good, 1 bad
Platincast	Pt-5%Cu	1850	900	600	2x	100 & 100	97 & 75	1 good, 1 bad
	Pt-5%Cu	1850	600	600	2x	65 & 73	6 & 0	both good
	Pt-5%Cu	1850	300	600	2x	96 & 95	72 & 46	1 good, 1 bad
	Pt-5%Cu	1850	900	800	6x	99.33 ± 0.88 *n* = 12		2 good, 4 bad
	Pt-5%Cu	1850	600	800	2x	89 & 73	100 & 93	both bad
	Pt-5%Cu	1850	300	800	2x	98 & 100	90 & 98	both bad
	Pt-5%Cu	1850	900	1000	2x	100 & 100	97 & 85	both good
	Pt-5%Ru	2050	900	600	2x	11 & 4	85 & 59	both bad
	Pt-5%Ru	2050	600	600	2x	2 & 0	58 & 42	both good
	Pt-5%Ru	2050	300	600	2x	1 & 0	98 & 34	1 good, 1 bad
	Pt-5%Ru	2050	900	800	6x	77.08 ± 28.00 *n* = 12		6 bad
	Pt-5%Ru	2050	600	800	2x	87 & 92	89 & 85	both bad
	Pt-5%Ru	2050	300	800	2x	94 & 92	75 & 41	both bad
	Pt-5%Ru	2050	900	1000	2x	100 & 100	100 & 98	both good
	Pt-5%Ru	1950	600	600	2x	rings only		both bad
	Pt-5%Ru	2000	900	1000	4x	rings only, with air bleeds		moderate to poor
	Pt-5%Ru	2050	900	1000	12x	rings only		moderate to poor

n is the number of measured grids used to calculate the mean and standard deviations quoted for the replicate tests

indicates that "J" Formula is best used only for filigree castings, and at the lowest functional rotational velocities: to avoid investment failure.

Fill Assessment

All the rings filled completely, even at the lowest combinations of flask temperature and centrifugal speed. Fill was also assessed in tests with the 10 × 10 grids by counting the number of squares completely surrounded by metal. For each test this provided a pair of values, expressed as percentages (Table II).

The overall performances of Astro-Vest and Platincast were compared by calculating the mean grid fill for the two different alloys (Table III). The casting conditions for the Pt-5%Cu and Pt-5%Ru

Table III

Mean Grid Fill in Percent, for Pt-5%Cu and Pt-5%Ru Cast in Astro-Vest and Platincast

	Astro-Vest	Platincast	Platincast, without 6 duplicate tests at 800 rpm
Pt-5%Cu	44.59 ± 30.76 n = 22	87.22 ± 24.23 n = 36	79.92 ± 27.92 n = 24
Pt-5%Ru	47.13 ± 31.58 n = 22	65.89 ± 36.16 n = 36	60.29 ± 38.94 n = 24

Casting conditions were broadly comparable for flask temperatures and centrifugal speeds. The difference in metal casting temperature of 200ºC was to accommodate the higher melting temperature and somewhat lower fluidity of Pt-5%Ru

alloys were comparable in terms of flask temperatures and centrifugal speeds. The difference in metal casting temperature was 200ºC to accommodate the higher melting temperature and lower fluidity of Pt-5%Ru. Previously published results indicated that a lower melting temperature of 1985ºC had failed to achieve good fill with Pt-5%Ru (1).

It was clear that overall Platincast produced significantly better fill than Astro-Vest, even when the 12-fold replicate tests in Platincast at a flask temperature of 900ºC and rotational speed of 800 rpm were omitted from the calculations. Presumably, Astro-Vest has a higher thermal conductivity than Platincast, but this was not measured. With Astro-Vest there was little difference in the mean percentage fill for Pt-5%Cu and Pt-5%Ru, and no discernable trend in fill relative to flask temperature or rotational speed over the ranges tested. With Platincast, Pt-5%Cu produced consistently better percentage fill than Pt-5%Ru. This was most apparent when comparing the 6-fold duplicate tests at the flask temperature of 900ºC and rotational speed of 800 rpm (Table II). The percentage fill for Pt-5%Cu was 99% with a standard deviation of only 1%, compared to 77% with a standard deviation of 28% for Pt-5%Ru.

For both alloys, a combination of high flask temperature and high rotational speed provided the best grid fill, with rotational speed having a greater influence than flask temperature (Figures 3–6). This trend was also evident in the more limited data for Wirovest. (The 14% and 11% fill values for Wirovest at 1200 rpm in Table II can be ignored because the centrifuge was stopped too soon and metal bled back into the sprue.)

Porosity

Porosity was assessed by visual inspection of polished metallographic sections of cast rings. The standard test samples had two rings (see Figure 2), only one of which was sectioned. A section was cut through the base of the feeder where it connected to the ring (sprue section) and a transverse section was cut through the outer shank of the ring (shank section). These were mounted in resin and ground and diamond polished. A sub-sample of these was etched electrolytically and studied metallographically (1). The rest were photographed and the porosity assessed qualitatively in terms of 'good', that is acceptable, with either no porosity visible, or small pores away from the margins; or 'bad', that is unacceptable, with large pores or finer porosity near the margins of the casting (Table II). Typical examples are shown in Figures 7 and 8. The melt temperatures were high in order to fill the grids cast with these rings.

We believe that most if not all of the porosity was gas porosity rather than shrinkage porosity, although with finer pores it is difficult to tell the difference. Inspection of the numerous photographs showed that porosity tended to be worse in the distal ring shank sections than in the sprue sections. This was surprising because the sprue sections had cooled more slowly than the distal shank sections, so were more coarse grained (1). Possibly, the proximity of the reservoir of molten metal in the thick feeder sprue had helped prevent the development of interdendritic shrinkage porosity in the slowly cooling sprue sections. It was also surprising that there was no obvious difference in the porosity of the two different alloys, given that generally the Pt-5%Cu had a coarser

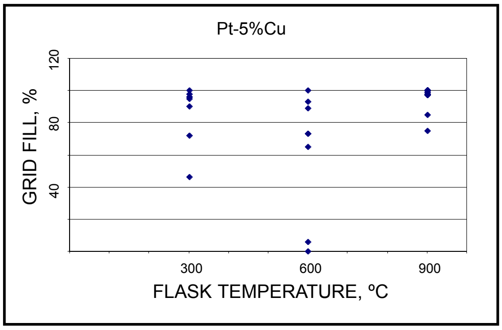

Fig. 3 Plot of percentage grid fill against flask temperature for Pt-5%Cu cast in Platincast investment. No discernable dependence can be seen

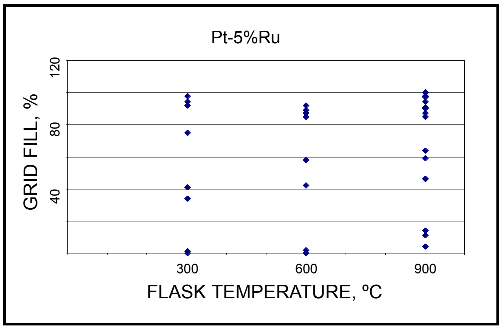

Fig. 5 Plot of percentage grid fill against flask temperature for Pt-5%Ru cast in Platincast investment. No discernable dependence can be seen

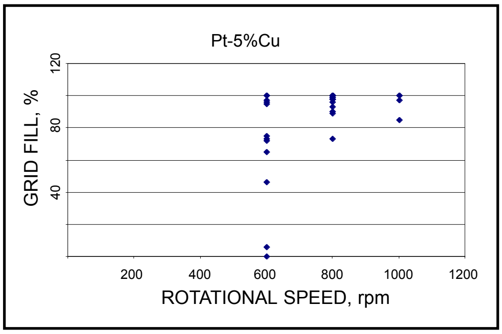

Fig. 4 Plot of percentage grid fill against rotational speed for Pt-5%Cu cast in Platincast investment. A trend of reduced scatter with improved grid fill at higher rotational speeds can be seen

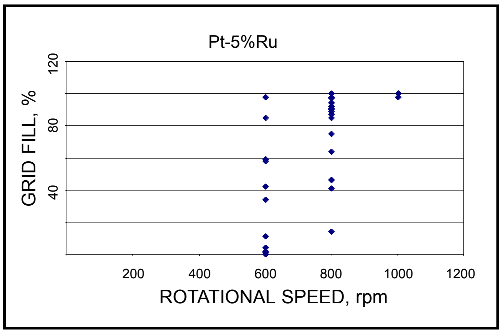

Fig. 6 Plot of percentage grid fill against rotational speed for Pt-5%Ru cast in Platincast investment. A trend of reduced scatter with improved grid fill at higher rotational speeds can be seen

grain size than the Pt-5%Ru under nominally comparable casting conditions (1). The lack of difference in porosity was evident by similarities in the ratios of good and bad porosity in both alloys in Astro-Vest and Platincast at comparable rotational speeds (Table II). Of the 58 comparable tests, Pt-5%Cu produced 13 good and 16 bad porosity results, while Pt-5%Ru produced 12 good and 17 bad. The almost identical ratios for this series of tests indicated that alloy composition had no discernable effect on porosity.

Nevertheless, a relationship was found between flask temperature and porosity. This is illustrated by a plot of the porosity index (the ratio of counts of bad to good porosity) for both alloys against flask temperature (Figure 9). There was a tendency to reduced porosity at flask temperatures between 600 and 800°C. Similar plots for the two alloys separately confirmed this trend for both alloys, with a minimum at ~ 600°C for Pt-5%Cu and at ~ 850°C for Pt-5%Ru. (The low numbers introduce more scatter, so only the combined ratios are illustrated.)

Cooling the flask to these temperatures before casting takes additional time, so we tried to reduce porosity at a flask temperature of 900°C (the burn-out maximum), casting Pt-5%Ru at 1000 rpm into a Platincast mould with only four rings, but with added air bleeds to allow compressed gases to escape. Four tests were conducted and the porosity was moderate to poor in all the rings assessed under these conditions (Table II). Another 12 tests under similar conditions but without the air bleeds confirmed that high rotational speed alone, aimed at driving entrained gas into the investment, did not produce pore-free castings.

On the basis of these observations we would recommend that in order to minimise the porosity, after burn-out the flasks should be cooled to at least 1300°C below the temperature of the molten

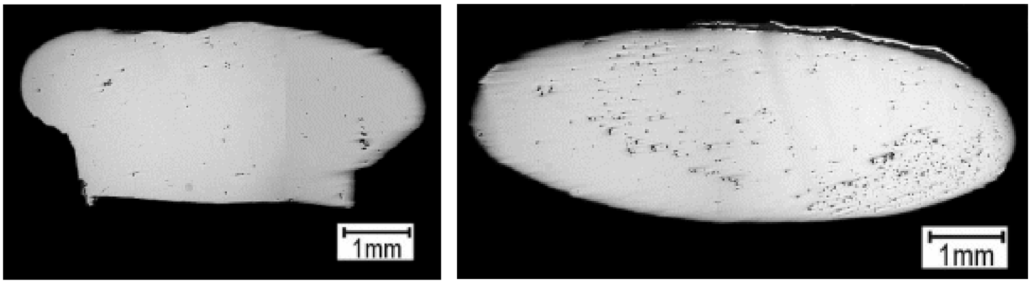

Fig. 7 An example of bad porosity: Pt-5%Ru, flask temperature 900°C, rotational speed 800 rpm, metal temperature 2050°C, sprue section on the left, ring shank section on the right

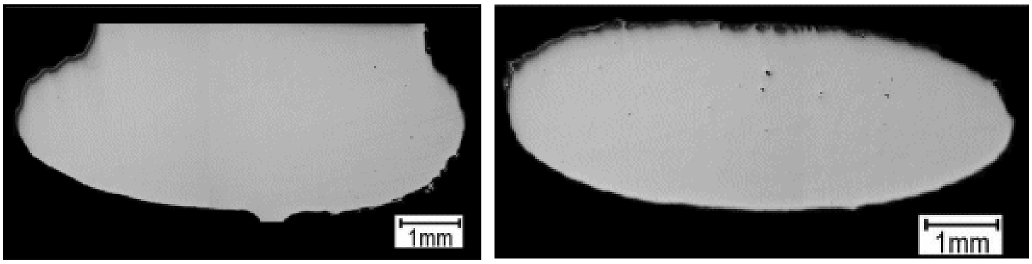

Fig. 8 An example of good porosity: Pt-5%Ru, flask temperature 900°C, rotational speed 1000 rpm, metal temperature 2050°C, sprue section on the left, ring shank section on the right

platinum alloy before casting. This accords with reports on a range of gold alloys, where lowered flask temperatures were beneficial in casting alloys had been heated significantly above their melting points (5).

No relationship between porosity and rotational speed was observed. Pairs of 'good' porosity values were obtained at speeds of 600, 900 and 1000 rpm (Table II), while a plot of bad/good porosity ratio against rotational speed showed no discernable trend (Figure 10).

Discussion

Jewellery casting depends on the flow of metal into a very convoluted mould at high speed to avoid premature freezing. This is an intrinsically chaotic process, and thus it is impossible to control all the variables in such a way as to produce consistently repeatable results. This is apparent, not only from the tests reported here but also from published results on other alloys (5). Nevertheless, results can be optimised by operating within ranges of casting parameters that minimise the statistical probability of undesirable outcomes, like porosity. There are not enough tests reported here for a rigorous statistical analysis, but some important and useful trends are apparent and are described below.

There were significant and systematic differences in grain size between the cast Pt-5%Cu and Pt-5%Ru alloys under nominally similar conditions, with the Pt-5%Cu casts having much coarser grains showing strong dendritic segregation (1). This reduced the hardness and chemical homogeneity of the Pt-5%Cu castings. Impractical, long annealing times would be necessary to homogenise such dendritic segregations, and this would result in grain growth and even larger grains, hence lower hardness, as further undesirable results. Therefore, the feasibility of using Pt-5%Ru for routine casting was explored, despite its higher melting point and lower fluidity than Pt-5%Cu.

The effects of casting variables on the percentage fill of fine grids and on ring porosity were examined. Higher rotational speeds promoted good fill, which was also affected by the choice of investment material. Consistent with other studies (2), porosity was always present, but there was a tendency for porosity to be reduced by casting into relatively cool flasks, at ~ 600 to 700°C. The choice of alloy appeared to have no effect on porosity, although Pt-5%Ru produced consistently finer grain size than Pt-5%Cu under nominally

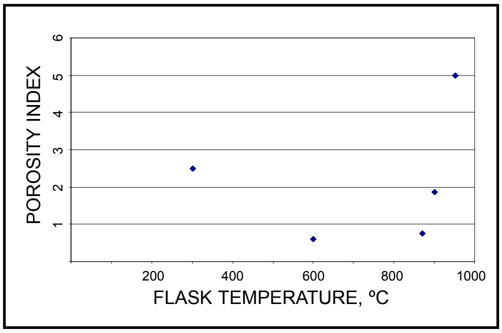

Fig. 9 Plot of porosity index (ratio of bad/good porosity) for all assessed tests with both alloys against flask temperature, showing the tendency for porosity to be at a minimum at flask temperatures between 600 and 800°C

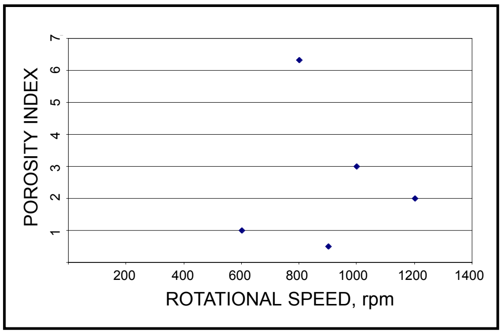

Fig. 10 Porosity index plot (ratio of bad/good porosity) for all assessed tests with both alloys against rotational speed, showing the lack of any systematic relationship between porosity and centrifugal speed

similar casting conditions. There was no discernable relationship between centrifuge rotational speed and porosity, and having air bleeds seemed not to affect porosity in any consistent way.

Induction melting technology was used to overcome the difficulty of melting Pt-5%Ru quickly and economically. The problem of the metal solidifying on the cold lip of the crucible was avoided by continuing to feed power to the tilting induction coil while pouring took place. The lower fluidity of Pt-5%Ru, giving poor fill in filigree sections, can be compensated for by using a suitably strong investment and by increasing the metal melt temperature and rotational speed. This enables the jeweller to take advantage of the finer grain structure, superior hardness, and whiter colour of cast Pt-5%Ru, making cast elements compatible in terms of colour and fusing temperature with hand-worked elements in the same metal.

For general purpose casting, Platincast and Astro-Vest were easiest to work with and both produced good results. Platincast facilitated fill of thin sections, but Astro-Vest had greater strength, which could make it the investment of choice for bulky castings. The Wirovest dental investment, with the advantages of high strength and a very short burn-out cycle, produced a rough surface. Wirovest could be useful for bulky castings, but requires more finishing than the other investments tested. From our experience, we would recommend "J" Formula only for filigree castings at the lowest functional rotational velocities, although the "J" Break platinum investment remover made cleaning convoluted shapes easy.

Overall, for general casting of jewellery shapes, we would recommend Platincast investment and Pt-5%Ru alloy, cast in a flask cooled to 650°C after burn-out, employing induction melting technology to cast at a metal temperature of 2000 to 2050°C. The centrifugal speed would depend on the configuration of the centrifuge, as well as the size and shape of the casting, but should generate accelerations between 35 and 70 G.

Conclusions

Precious metal casting takes place at high temperature and centrifugal forces, and is intrinsically chaotic. Consequently, porosity in platinum alloy castings cannot be avoided altogether, but the probability of unacceptable porosity can be minimised. Casting into flasks at least 1300°C cooler than the molten metal tends to reduce the occurrence of porosity. The behaviour of different commercial investments varies considerably and significantly in terms of strength and thermal conductivity. This means that the casting success rate can be increased by selecting the appropriate investment for particular tasks. High rotational speeds must be used in conjunction with a suitably strong investment material to obtain good fill in filigree sections. Induction melting and casting technology allows efficient melting of a higher melting temperature alloy, such as Pt-5%Ru, to take advantage of its superior colour, finer as-cast grain size, improved homogeneity, higher hardness and better polishing characteristics.

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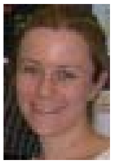

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