The 22nd international Santa Fe Symposium® was held in Albuquerque, New Mexico, from 18th–21st May 2008 (1), and attracted around 120 delegates from thirteen countries in all continents of the world. Once again, palladium jewellery manufacture featured strongly, with two presentations on investment (lost wax) casting studies that show how this new jewellery metal can be successfully cast. The importance of the platinum group metals (pgms) for jewellery was further supported by a presentation on the investment casting of platinum jewellery and one on the use of laser welding in platinum jewellery manufacture.

As noted at the 2007 Symposium (2), palladium is attracting considerable interest as a jewellery material in its own right. However, its success in the market depends on an ability to manufacture it cost-effectively by the conventional technologies. Investment (or lost wax) casting is the major manufacturing technology for precious metal jewellery and its application to palladium is seen as important. The relative lack of knowledge of the casting characteristics of 950 fineness palladium alloys, given that palladium is known to absorb hydrogen and oxygen, has been seen as a potential drawback. The current studies reported at the 2008 Symposium address that concern.

Casting of Palladium Alloys

The first presentation, ‘Investment Casting Behaviour of Pd-Based Alloys’, was given by Professor Paolo Battaini (8853 SpA, Italy), who has been involved in developing 950 palladium alloys (see (3)). Battaini notes that palladium-silver-based dental alloys with palladium contents between 40 and 60% have been developed since the 1970s and investment cast successfully. His presentation was concerned with reviewing the chemical and physical characteristics of such dental alloys, and investigating how the experience acquired in the dental field could be transferred to the jewellery industry. He reviewed the effect of alloying elements on the hardness of palladium, followed by a discussion of the hardness and melting range of some common dental alloys. He noted that the width of the melting range is larger (100 to 150ºC) than that of common 950 platinum jewellery alloys (15 to 30ºC), a factor which affects the solidification behaviour of these alloys. The cast microstructure of the dental alloys, he pointed out, is often complex and multiphase, frequently containing lamellar eutectic constituents, as shown in Figure 1. Apart from the primary palladium phase, the second phases are often intermetallics containing gallium. Segregation to grain boundaries or between dendrites is also common in high-palladium alloys. In contrast, 950 palladium jewellery alloys are expected to be single phase, as they are less highly alloyed.

Battaini noted that high oxygen uptake in dental alloys is often due to internal oxidation of base metals, and this could also occur in jewellery alloys...
if held in oxygen-containing atmospheres at high temperatures. Such internal oxidation would be detrimental to palladium jewellery, as it is with silver (where it gives rise to a dark coating known as ‘firestain’), in terms of polishing. High oxygen content also leads to gas porosity in both dental and jewellery alloys. Carbon absorption is another problem in dental alloys, and can also lead to gas porosity in castings, so palladium alloys are not melted in graphite crucibles. Palladium is well known for absorbing large quantities of hydrogen. Further, as with the other precious metals, silicon contamination causes embrittlement due to low melting point eutectic formation, usually located at grain boundaries and so, unless coated with zirconia, silica melting crucibles should be avoided, as should reducing conditions.

Palladium dental alloys are also susceptible to hot cracking due to the mismatch of expansion coefficients with the phosphate-bonded investment mould material. Such cracking has been observed in 950 palladium jewellery alloys after casting.

The above review led nicely into the next presentation, ‘Challenges for Palladium Casting Alloys’, presented by Jörg Fischer-Bühner (Legor Srl, Italy). This was a report on work conducted last year at the Research Institute for Precious Metals and Metals Chemistry (FEM), Germany, sponsored by Palladium Alliance International, to study the investment casting of 950 palladium jewellery alloys. This work, in which Johnson Matthey New York supplied the palladium alloys and industrial trials were carried out at TechForm and Au Enterprises, both in the U.S.A., is the first systematic investigation of the investment casting of 950 palladium alloys following the pioneering work by Teresa Fryé (TechForm Advanced Casting Technology Inc, U.S.A.) (see (2)).

The laboratory work was conducted by melting either under an argon cover on the crucible or under vacuum followed by backfilling with argon in the closed casting chamber of a centrifugal casting machine, using zirconia-coated silica crucibles. Melting time was controlled and casting carried out on a tree size between 90 and 180 g, using moulds made in either a two-part platinum investment powder with acid binder or a one-part platinum investment powder with a water binder. Flask (mould) temperatures were in the range 650 to 850°C. Two alloys were selected: 950 palladium-ruthenium-gallium and 950 palladium-silver-gallium-copper, for casting trials of a ball-on-ring test pattern, sprued either on the ball or on the shank opposite the ball.

The drying time of the flask before burnout influenced the incidence of porosity in the castings, with shorter times of 1.5 h yielding little porosity. For the one-part investment, optimising the powder:water ratio gave good castings, whereas excess water resulted in some porosity. It was concluded that 950 palladium alloys can be very reactive with the investment mould material, leading to gas porosity. They are especially sensitive to poor investment preparation and degradation of the investment powder over its shelf life. For the two-part investment, short but effective drying and binder removal are essential.

Using a flask temperature of 650°C, melting with just an argon cover on the crucible led to porosity in the casting, whereas use of a vacuum followed by back-filling the closed chamber with argon resulted in good castings. When the flask temperature was raised to 850°C, pore-free castings were obtained with just an argon cover on the crucible, where the feed sprue system allowed release of gas. The flask is full of air when just an argon cover on the crucible is used in melting, and this allows the melt to take up oxygen after pouring, so tailoring the feed sprue to allow gas release is important. In both gas atmosphere conditions, formation of inclusions within the alloy was observed and analysis showed these to be gallium oxide or silica.

The industrial trials at TechForm using their shell mould casting process resulted in castings with cracks and hot tears, typically at the junction of the feed sprue to the ring shank. Scanning electron microscope/energy dispersive X-ray (SEM/EDX) analysis of the fracture surfaces showed gallium enrichment and traces of silicon, leading to the conclusion that hot tears were due to low melting phases. The number of silica inclusion particles found in the castings increased with the amount of scrap used in the melt charge.
It was concluded that overheating of the melt and extended melting times should be avoided, as these allow the melt to take up silicon, phosphorus and oxygen. This leads to gas porosity and hot tears after the chamber is evacuated, creating reducing conditions, and back-filled with argon.

In subsequent work carried out by Fischer-Bühner and colleagues at Legor Group Srl, Italy, the development of palladium alloys containing gallium was studied. This showed alloys with gallium, silver and indium, with lower melting ranges (below 1500°C), to be preferable over other compositions. Systematic casting trials of such an alloy (known as 'Pd950G') were reported. Good castings could be obtained, with low levels of gas porosity and no cracks or hot tears, see Figure 2. By comparison, use of a 950 palladium-niobium-gallium alloy cast under similar conditions led to cracks, hot tears and significant gas porosity in the castings. This alloy had a higher melting range (above 1500°C), and it was concluded that this resulted in increased reactivity with the crucible and mould material. Casting trials on the Pd950G alloy conducted at jewellery manufacturers’ workshops showed that melting in air resulted in large amounts of gas porosity in the castings, but no cracks or hot tears. When an argon cover on the crucible was used, both gas and shrinkage porosity were observed, the latter due to non-optimisation of the feed sprue. The finished surface quality of the ring was satisfactory. Using the method of melting under a vacuum followed by back-filling with argon, good castings with low porosity and no cracks or hot tears were obtained. Trials in which Pd950G alloy scrap was recycled over several cycles showed little impairment of surface quality, no degradation of melt fluidity, a lack of cracks and hot tears and little increase of gas microporosity. From this study of their Pd950G alloy, it was concluded that it is possible to obtain good castings in 950 palladium alloys under typical industrial conditions, although strict process control is essential.

**Platinum**

Despite the quick advent of computer aided design/computer aided manufacturing (CAD/CAM) and rapid prototyping technologies in the jewellery industry, there has been a dearth of information on casting behaviour of the resulting patterns (or models) in the various plastic/polymer materials that result from the different technologies on offer. That was the subject addressed by Teresa Fryé (TechForm Advanced Casting Technology Inc, U.S.A.). This company specialises in shell-mould casting of platinum jewellery. In her presentation, ‘A Study of the Effect of CAD/CAM-Derived Materials in the Casting of Platinum Alloys’, Fryé observed that experience had shown all these plastic materials performed differently in the casting process. The study was undertaken to understand these differences. A number of plastic model materials were studied: two light-curing photopolymers, a thermoplastic produced by jetting, four grades of polymeric milling wax and one of a conventional hydrocarbon injection wax.

A test model was created, with a geometry designed to encourage failures typically seen in real
castings; it was based on a heavy torus shape with deep holes, sharp angles and deep recesses. The first set of tests were burnout experiments designed to assess the amount of residual ash after burnout under conditions of both restricted air and free flow of air. These showed that, surprisingly, there was little ash residue in any case, and that restricting air flow resulted in less ash for all materials; the lowest ash was found in one milling wax and the highest with one photopolymer. Thermal expansion was also measured, using a simple dilatometric technique. The milling waxes and the photopolymers showed substantial expansions (up to 200°C and 450°C, respectively), whereas the injection wax and thermoplastic had low expansions. These results have implications for the mould in the burnout cycle. The mould material expansion is complex and its compressive strength rises with temperature in the case of phosphate bonded materials.

Casting tests on platinum-10% iridium alloy were undertaken using the TechForm ceramic shell system with a phosphate-bonded platinum investment. These showed that injection wax, with low expansion and low melting temperature, performed well and produced good castings. In contrast, the milling waxes performed less well, with investment failure evident in the blind hole (Figure 3(a)) and the thin walled areas. The thermoplastic, with low expansion, gave good castings (Figure 3(b)), whereas the photopolymers produced mixed results. Some ceramic core relocation was also found with the milled waxes and one photopolymer. These results support the view that thermal expansion is at the root of the observed casting defects, whereas ash residue did not appear to be significant, contrary to perceived wisdom.

In his presentation, ‘Platinum and Lasers: The Natural Solution’, Jurgen Maerz (Platinum Guild International, U.S.A.) discussed the application of lasers to platinum jewellery manufacture and repair through several practical examples. All were concerned with laser welding, and the advantage for platinum of its low thermal conductivity, which means, for example, that gemstones are not damaged in the process. The examples presented demonstrated the versatility and design potential that laser welding confers, and serve as model case studies for those new to platinum.

Jewellery Properties and Manufacturing

The property of hardness and ‘The Role of Hardness in Jewellery Alloys’ were discussed by Chris Corti (COREGOLD, U.K.), in which he concluded that all precious metal jewellery should have a hardness value of at least 100 HV for satisfactory performance. Low hardness is a problem sometimes found with cast platinum jewellery due to poor alloy selection, for example; see (4). Some commercial palladium alloys also tend to have low hardness values in the as-cast or annealed condition, although this is being addressed by the alloy suppliers. The inconsistency of hardness data in the open literature was discussed in a subsequent

![Fig. 3 (a) Investment failure in a blind hole in platinum-10% iridium casting, cast from a model in milled wax produced on a CAM milling machine; (b) Good casting quality in a blind hole in platinum-10% iridium, cast from a model in thermoplastic material produced on a rapid prototyping machine (Courtesy of Teresa Fryè, TechForm Advanced Casting Technology Inc, U.S.A.)](image-url)
roundtable discussion at the 2008 Symposium. The need for an agreed standard testing procedure was identified, and it was noted that some alloys can show differing hardness values from cast surface to bulk alloy.

‘Designing for Rapid Manufacturing and Other Emerging Technologies’, was presented by Gay Penfold (Jewellery Industry Innovation Centre, Birmingham City University, U.K.). Her presentation was a stimulating look into the future in terms of the design potential afforded by CAD/rapid prototyping-based technologies. The ability to produce a range of related designs from one basic dynamic CAD program, each unique and different from the others, was astounding.

‘Basic Metallurgy of the Precious Metals – Part II’ by Chris Corti (COReGOLD, U.K.) was an update on Part I, presented at the 2007 Symposium (2). In Part II, he reviewed the development of microstructure through solidification and working. The importance of controlling grain size was central to this presentation. The problem of hard spots in carat golds, which lead to polishing problems, was analysed by Damiano Zito (ProGold Srl, Italy), in his presentation, ‘Hard Spots: A Trip through Ambiguity’. Many of these were found to be due to insoluble pgms that can occur in the fine gold bars used to make the alloys.

Andreas Zielonka (FEM, Germany), presented his research on ‘Incorporation of Gold Nanoparticles in Metal Matrix Systems’. This is achieved by a novel electroplating approach in which gold nanoparticles are dispersed during the electroplating of nickel. This approach to nanoparticulate metal matrix materials has considerable potential. The more conventional particulate approach to making jewellery was discussed by Joseph Strauss (HJE Company Inc, U.S.A.), who updated the Symposium on ‘Powder Metallurgy in Jewelry Manufacturing’. He reported on several instances of commercialisation of metal injection moulding (MIM) that are now emerging in Europe, the U.S.A. and the Far East, not only for jewellery but also for precious metal watch cases and medical components. On a more theoretical level, Boonrat Lohwongwatana (Chulalongkorn University, Thailand) spoke about thermodynamic modelling in alloy design in his talk ‘Alloys by Design’, an approach which can save considerable time and expense in alloy development.

On a more general theme, there were several presentations concerned with jewellery technology and practice: Klaus Wiesner (Wieland GmbH, Germany) discussed the practical aspects of ‘Wire and Bar Manufacturing’ for precious metal jewellery and Hubert Schuster (consultant, Italy) spoke about ‘Stone-in-Place Casting for High-End Jewelry’. The problem of defects in casting wax patterns was described by Patrick Sage (Neutec USA, U.S.A.), in his eye-opening presentation ‘Casting the Perfect Defect’. In particular, the malfunctioning of wax injectors was shown to contribute to the problem.

On the health and safety front, Samuel Davis (Stern-Leach, U.S.A.) spoke about ‘Methods for Reducing Ergonomic Risk’, describing several examples of improvements to working conditions implemented at his company. In a similar vein, Alexandre Auberson (Cartier, U.S.A.) discussed ‘Handling and Shipping at the Manufacture Stage’, in which he described how packaging of jewellery is a critical part of Cartier’s product offering in order to preserve the top quality finish and condition of the piece delivered to the retailer and customer.

A Lifetime Achievement Award was presented to John McCloskey, recently retired from Stuller Inc, U.S.A. John presented at the original Santa Fe Symposium, back in 1987, and has made many significant contributions over subsequent years to further our knowledge and understanding in jewellery manufacture, see also (3).

Concluding Remarks

Palladium as a jewellery metal was again the centre of attention at this Symposium. In particular, the good progress being made in understanding the technology of casting palladium jewellery will contribute strongly to its future success in this application sector. Furthermore, the technology for platinum continues to be developed and underpins its continued attraction in the marketplace. There is no doubt that the Santa Fe
Symposium is the important technology forum for the jewellery industry worldwide.

The Santa Fe Symposium proceedings are published as a book and as PowerPoint® presentations on CD-ROM. They can be obtained from the organisers (1). The 23rd Santa Fe Symposium® will be held in Albuquerque on 17th–20th May 2009 (1).

References
1 The Santa Fe Symposium: http://www.santafesymposium.org/

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Christopher Corti holds a Ph.D. in Metallurgy from the University of Surrey (U.K.) and is currently a consultant for the World Gold Council and the Worshipful Company of Goldsmiths in London. He served as Editor of Gold Technology magazine and currently edits Gold Bulletin journal and the Goldsmiths’ Company Technical Bulletin. A recipient of the Santa Fe Symposium® Research Award, Technology Award and Ambassador Award, he is a frequent presenter at the Symposium.