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The 28th Santa Fe Symposium on Jewelry Manufacturing Technology

Better understanding of lost wax casting of platinum leading to improved casting alloys

Reviewed by Christopher W. Corti
COReGOLD Technology Consultancy, Reading, UK

Email: chris@corti.force9.co.uk

The 28th annual Santa Fe Symposium® was held from 18th–21st May 2014 in Albuquerque, New Mexico, USA, and attracted another large attendance of delegates from 15 countries worldwide, representing a good cross-section of those involved in jewellery manufacturing from mass manufacture to specialised craft operations. In general, many were finding the market is tougher now than a few years ago although there is a good optimistic outlook.

The programme of presentations was wide ranging from straight technical to other aspects of manufacturing – training, continuous improvement, market trend analysis, the new social ways of conducting business and product liability. On the technical side, platinum and silver featured strongly as did e-manufacturing. As noted in previous reports, the major sponsors of the conference were given the opportunity to have a display table in the lobby area and thus Johnson Matthey New York, Platinum Guild International and Palladium Alliance International had a strong presence and their technical brochures and publications were quickly collected by delegates.

As has become customary, the Symposium began with another in the series: 'Basic Metallurgy – Part IV: Deformation Processing, Joining and Corrosion' by Chris Corti (COReGOLD Technology Consultancy, UK) in which the difference between hot and cold working was discussed, along with a review of the various joining technologies used in jewellery manufacture – soldering, welding and diffusion bonding. Corrosion was discussed in terms of tarnishing of Ag and the carat golds and stress corrosion cracking, which can occur particularly in the low carat golds.

Platinum Casting

The investment (lost wax) casting of Pt jewellery is not an easy process and casting porosity is a feature that casters find difficult to avoid. In 2013, Teresa Fryé (TechForm Advanced Casting Technology, USA) gave an excellent presentation on the latest research she had conducted on the benefits of hot isostatic pressing (HIP) of 950 Pt castings to remove porosity and the improved properties that resulted, titled 'The Effect of Hot Isostatic Pressing of Platinum Alloy Casting on Mechanical Properties and Microstructures'. Unfortunately this presentation was not published in the 2013 Symposium Proceedings but has appeared in this year's 2014 Proceedings. This work has demonstrated that HIP of castings in four 950 Pt alloys results in the porosity, due to shrinkage on solidification, being substantially reduced, if not eliminated. This led to a marked increase in ductility without sacrificing tensile strength or hardness. For castings in the 950 platinum-ruthenium alloy, grain size was finer and more uniform and this alloy benefited the most from the HIP treatment since it tends to have larger amounts of porosity in the as-cast condition, **Figure 1**. In contrast, the 950 platinum-cobalt alloy, which tends to have the least porosity in the as-cast condition, showed the least benefit of HIP of all alloys tested. HIP is an additional process stage post casting

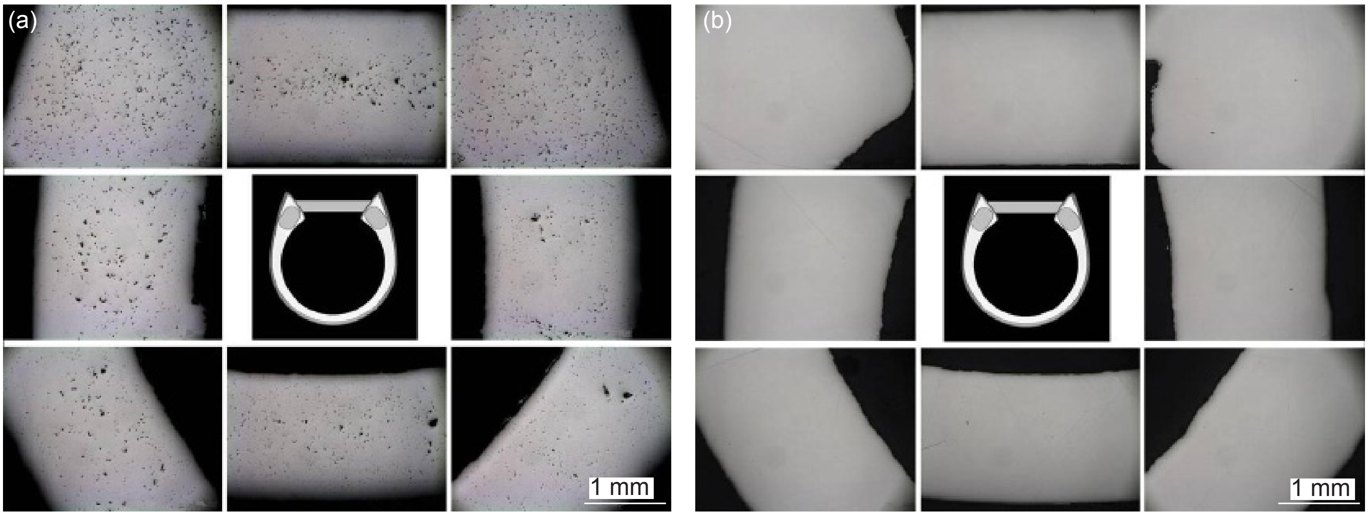

Fig. 1. Test cast ring in Pt-5Ru (centre) showing microsections of castings: (a) as-cast with double sprue, showing substantial shrinkage porosity; (b) after HIP showing removal of porosity (Courtesy of Teresa Fryé (TechForm Advanced Casting Technology, USA))

and adds to the costs but is finding increasing uptake by jewellery manufacturers since it better guarantees product quality.

This year, Ulrich Klotz (Research Institute for Precious Metals & Metals Chemistry (FEM), Germany) gave what for me was the highlight presentation of the Symposium. This was a late entry and consequently, for commercial reasons, cannot be published for a year (so should appear in the 2015 Proceedings.). His presentation, 'Platinum Investment Casting: Material Properties, Casting Simulation and Optimum Process Parameters' was a report on a collaborative European research project that has recently been concluded. A major feature was the use of computer modelling of the casting process, both by centrifugal casting and tilt casting and this has aided process optimisation. The effect of casting parameters on porosity is shown in **Figure 2**. In order to model the casting process, it is necessary to input various physical properties of the materials involved and Klotz reported on the work undertaken to obtain meaningful property data that were used in the simulations. Experimental casting trials were used to validate the modelling results. Both 950 Pt-Ru and 950 Pt-Co alloys, traditionally used in jewellery casting, were tested. Ru raises the melting point of Pt whilst Co lowers the melting point and has a narrower melting range. One feature of the project was some preliminary work to examine whether a tertiary alloy of Pt-Co-Ru would lead to improved castability; the early results suggest that it did and so opens an opportunity to develop improved Pt casting alloys.

Silver Alloys Containing Platinum Group Metals

There were two interesting presentations on Ag alloys for jewellery application, both of which involved platinum group metals (pgms) as alloying metals. In the first, Shankar Aithal (Stuller Inc, USA) reported on the 'Development of a Harder Sterling Silver Alloy'. The composition of this new alloy was not revealed except to say it contained five alloying metals including a reduced copper content, elements to confer tarnish resistance and that it is pgm-based. This suggests the main alloying metal is a pgm such as palladium or possibly Pt. Indeed, a 2013 US patent application by Stuller indicates that it is a Ag-Cu-Pd-Sn-Zn composition with 2.75% Pd (1). The new alloy is much harder than conventional sterling silver with an as-cast hardness of 90 HV–110 HV (compared to 65 HV) and can be age-hardened to 140 HV–170 HV, **Table I**. It also has a superior tarnish resistance. This looks to be a promising commercial alloy as conventional sterling silver (92.5% Ag–7.5% Cu) is considered soft for jewellery applications.

Many new sterling silver (92.5% Ag) alloys have appeared on the market in recent years, most claiming improved tarnish and/or firestain resistance. Grigory Raykhtsaum (LeachGarner, USA) reviewed these in

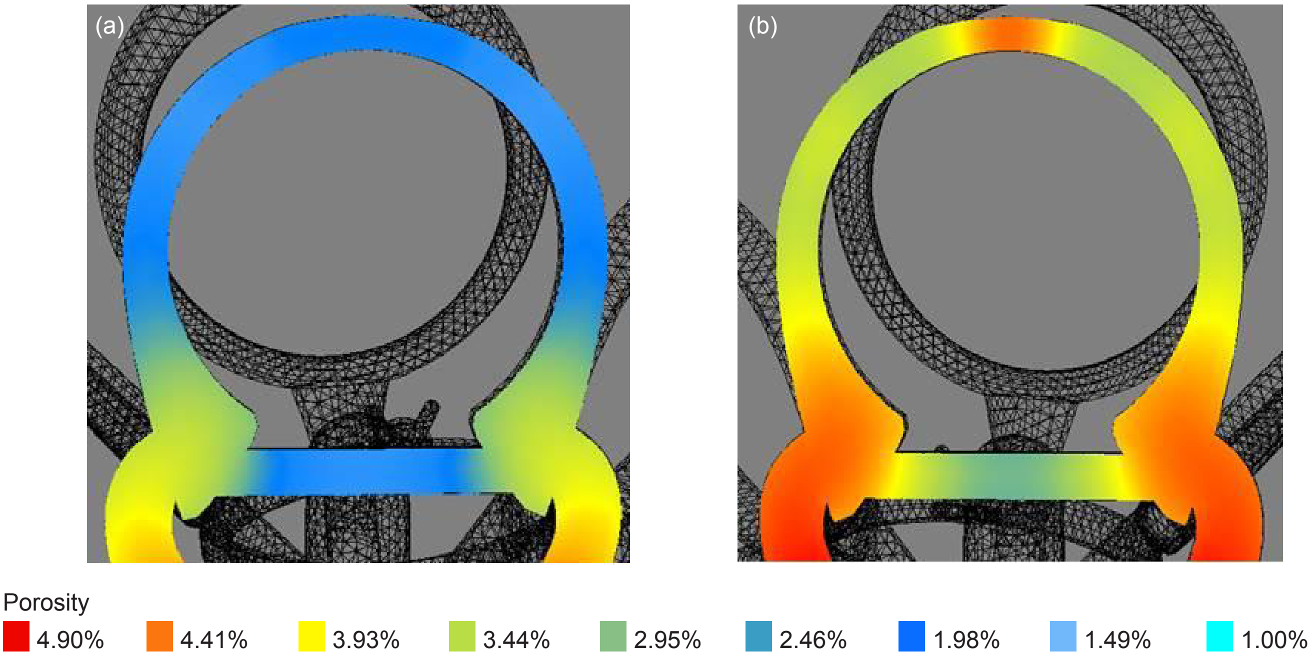

Fig. 2. Simulation of shrinkage porosity in casting of platinum. Flask temperature of 850ºC and melt temperature of: (a) 1850ºC; and (b) 1980ºC (Courtesy of Ulrich Klotz (FEM, Germany))

Table I Properties of SS941 Sterling Silver Containing Palladium[a]

Colour	a* = 0.05, b* = 4.68, L* = 95.08
Density, g cc^{-1}	10.40
Melting range, ºF	1680–1730
Melting range, ºC	916–943
Hardness (as-cast), HV	90–110
Hardness (annealed), HV	68–83
Hardness (age-hardened), HV	140–170
Hardness (60% cold work), HV	150
Ultimate tensile strength (UTS), psi	45,000
Yield strength, psi	20,000
Elongation (annealed), %	35
Elongation (age-hardened), %	30

[a]Courtesy of Shankar Aithal (Stuller Inc, USA)

an attempt to bring some order and structure to these developments in his presentation, 'Sterling Silver – U.S. Patent Review'. He reviewed the US patent literature from 1926 and identified 43 patents which he classified in terms of the objectives: tarnish resistance, improved strength or 'other'. He noted that there were two periods of strong patent activity: 1926–1940 and 1989–2012. In the latter period, he noted use of pgms (either Pd or Pt) as alloying metals in five out of 19 patents. In one, Pd is claimed to improve tarnish resistance and, in others, Pt is claimed to improve both tarnish resistance and strength.

Powder Metallurgy and Three-Dimensional Printing of Jewellery

Currently in the jewellery industry, rapid prototyping technology is used to produce plastic models direct from digital files by 3D printing, using photocurable polymers. These are, in turn, used as models to directly investment cast the final part in precious metals. The next step forward in the digital manufacturing age is the manufacture of jewellery using metal powders by 3D printing (several acronyms are in use, for example, direct metal laser sintering (DMLS), direct metal laser melting (DMLM) or selective laser melting (SLM)) direct from digital designs (computer files). This is an additive manufacturing process where a thin layer of metal powder is spread on a build platform and then selectively melted to build up the part layer by layer. It is a relatively new technology developed in the engineering sector and is now being adapted to jewellery and dental markets where items are smaller and require a superior surface finish. Several companies have developed suitable equipment for DMLS and some alloy companies are collaborating with them to develop the technology, using suitable precious metal powders for the process, including Au and Pt. Three presentations were focused on this new manufacturing route.

On the technology aspect, Damiano Zito (ProGold SpA, Italy) spoke on the 'Optimization of SLM Technology Main Parameters in the Production of Gold and Platinum Jewelry'. This presentation was a further development on a project reported at the 2013 Symposium, where surface quality equivalent to that produced by investment (lost wax) casting was the objective. Laser scanning parameters were shown to be important. This year's work focused on use of selected alloying elements to improve laser absorption by the powders, thus favouring melting, and to examine the structure and morphology of the support structures to optimise their density and maintain adequate thermal dissipation of the laser energy. Both an 18 carat red gold and a 950 fineness Pt alloy were used in the study as atomised powders of 0–53 microns size range. A lamellar design parallelepiped model was used to study the process parameters on a Realizer SLM^{TM} 50 machine. Two types of support structures with two spacing sizes were evaluated and applied to the model with three different slope angles with respect to the horizontal build platform. The study showed that Pt required less laser power than 18 carat gold to produce good uniform walls to the model, **Figure 3**. It was also shown that thin supports are more easily detached from the item and were advisable for high-slope walls, whereas more massive support structures are advisable for horizontal walls.

The addition of semiconductor elements such as germanium and silicon at low concentrations to increase electrical resistivity (i.e. lower thermal conductivity) was found to improve laser absorption of Au and led to a lower contact angle of the molten particle as well as reduced surface roughness. For Pt, which has a much lower thermal conductivity, such additions are not needed. As a consequence, laser power levels needed for melting Pt powders were much less than required for 18 carat gold. It was also found that the Pt alloy produced less porosity than the Au alloy. The work also showed that surface quality can be optimised and processing loss reduced by correct selection of supports.

The support structures used in 3D printing technologies are important and were the focus of a presentation by Frank Cooper (Jewellery Industry Innovation Centre (JIIC), Birmingham City University, UK) in his review, 'DMLM Supports: Are they the Jewelry Industry's New Sprue, Riser and Gate Feed?'. He explained the need for support structures and the complex role they play during 3D printing and the types of structures used. As he pointed out, they are sacrificial structures that need to be removed after completion of the build and so represent a waste of material and energy.

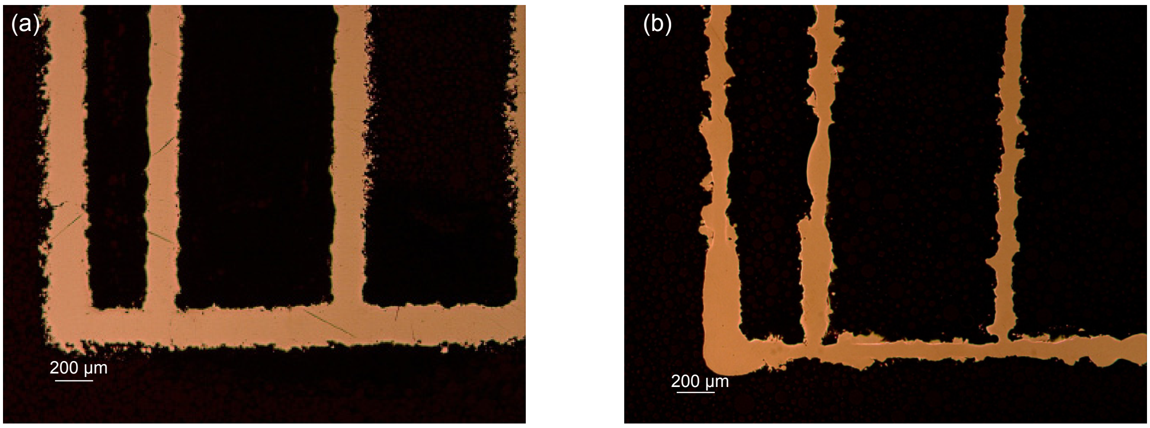

Fig. 3. Cross-section of walls of model part produced by selective laser melting (3D printing) using 62.5 W laser power and 0.33 m s^{-1} scanning speed in: (a) platinum and (b) 18 carat gold (Courtesy of Damiano Zito (ProGold SpA, Italy))

The software used to create the support structures was discussed. Cooper noted that all the jewellery DMLM technologies on the market are supplied with an integral support generation package as part of a full suite of software. He gave examples of their use and how the operator has to select the appropriate orientation and placement of supports for their piece from several options. Looking to future developments, Cooper suggested software would be developed that would automatically analyse a part and determine the optimum build orientation and support structure consistent with good surface finish quality. Such developments are already in train.

A more general look at the business model for the commercialisation of 3D printing of jewellery was presented by David Fletcher (Cooksongold, Heimerle + Meule Group, UK) titled, 'Use of eManufacturing Design Software and DMLS in the Jewelry Industry'. He noted that DMLS technology had now improved to the point where surface finish quality matched that achievable by investment casting. Also, that DMLS would not replace existing mature production processes such as lost wax casting as they are cost-effective for many types of design. He considered that e-manufacturing (DMLS) will focus on six areas: removal of tooling costs, light-weighting of products, customisation of design – individualised and incorporating security features, fast lead times (within hours from design to part), cost-effectiveness for designs that take advantage of the strengths of DMLS process and very high design flexibility. He then went on to discuss nine areas essential to its success, including the user interface, automated build structures and automated light-weighting, customisation and automated costing and quotation models.

Other Manufacturing Processes

Several presentations examined developments in traditional manufacturing and in new technologies. James Binnion (James Binnion Metal Arts, USA) discussed his use of 'DC Arc Melting for Jewelry Casting' and Sessin Durgham (Rio Grande Inc, USA) discussed the bench use of welding in his presentation, 'The Good Weld: Pulse Arc Welding for the Metal Artist, Jeweler and Manufacturer'. The fusing of Au to iron metal work was described by a goldsmith, Chris Nelson (Chris Nelson, Goldsmith, USA) in his presentation, 'Iron Mused/Gold Fused... "the New Iron Age"' and the use of an old technology was described by metalsmith Anthony Lent (Anthony Lent Studios, USA) in his presentation, 'The Drop Hammer and 19th-Century Die-Forming Processes for Contemporary Artisanal Manufacturing'. Researcher, Bruno Henriques (University of Minho, Portugal) described the 'Impact of Hot Pressing Processing Parameters in the Production of Powder Metallurgy Jewelry Parts' in which Ag and coloured Au were combined for decorative effect. The use of diffusion bonding of mixed metals was discussed by Chris Ploof (Chris Ploof Designs, USA) in his presentation, 'Mokume Gane Bonds: the Effect of Quenching on Bond Strengths'.

Another old technology was described by Jurgen Maerz (Jurgen Maerz, Jewelry Industry Consulting LLC, USA) in his presentation, 'Before Lost Wax casting: A Look at Traditional Jewelry Making in Germany Using Sand Casting' whilst Boonrat Lohwongwatana (Chulalongkorn University, Thailand) discussed new developments in thixocasting in his presentation, 'Semi-solid Casting of Silver and Titanium: From Theory to Practice'. Ag becomes more fluid in casting. In conventional lost wax/investment casting, rubber moulds are used to make replicas in wax of the master model. Ilaria Forno (Politecnico di Torino, Italy) described her research on silicone rubber for moulds to improve its thermal behaviour and hence model quality and mould life in her presentation, 'Deepening into Silicone: Is it a Rubber Wall?'. On the traditional craft jewellery front, silversmith Ann Cahoon (North Bennet Street School, USA) investigated several 'Bench Myths' with respect to sawing, filing and polishing to see if they withstood rational analysis.

The use of photocurable resins for producing jewellery models by rapid prototyping technology (aka stereolithography) has been mentioned earlier. However, Tsuneo Hagiwara (Digital Wax Systems (DWS) Srl, Italy) gave an interesting presentation on 'New Jewelry Products Produced in Photocurable Ceramic-filled Resins'. They can be made more attractive by adding colour and allow complex 3D shapes to be produced including 'gemstones'. They are hard and wear-resistant, take a good polish and are colour-fast.

Market, Training and Education

Three presentations were focused on education and training needs of the jewellery industry. Elizabeth

Brehmer (LeachGarner) spoke on 'Is the Jewelry Industry Addressing Training and Educational Needs?', whilst Lisa Johnson (Rio Grande Inc) spoke on 'Process Development for Continuous Improvement' which described her company's progress. Kageeporn (Kate) Wongpreedee (Srinakharinwirot University, Thailand) discussed jewellery education initiatives in Thailand in her presentation, 'Jewelry Education Evolution and the Promise of Future Jewelry Technologies'. She has been actively involved in new, innovative university courses to train future supervisors and managers and in research of new technologies to assist the Thai industry, such as lead-free nielloware, mokume gane and gem treatment by ion implantation.

On the marketing front, Juliet Hutton-Squire (Adorn Insight, UK) gave an insight into product development in her presentation, 'Using Essential Trend Analysis to Successfully Align Jewelry Production with Evolving Consumer Demand'. In contrast, Vashti Jattansingh (Raymond James Financial Inc, USA) gave an insightful look into 'Product Liability for the Jewelry Manufacturing Industry' and Anne Miller (IBM, USA) spoke about how the jewellery retail environment is changing in the new digital world and how to respond in her presentation, 'Social Business and Jewelry Manufacturing Adoption'.

Concluding Remarks

This was another excellent symposium in the annual series for those involved in jewellery manufacture, be it by machine in mass production or by handcraft in a workshop. All participants acknowledge that a good part of the value in attending is the opportunity for talking with the experts, networking with fellow professionals and for exchanging ideas and samples. The Santa Fe Symposium® proceedings book of the papers and the PowerPoint® presentations can be obtained from the organisers (2). The archive of presentations are being made available for download free, it is understood.

References

1 J. R. Butler, Stuller Inc, 'Sterling Silver Alloy and Articles Made From Same', *US Patent Appl.*, 2013/0,112,322

2 The Santa Fe Symposium: http://www.santafesymposium.org/ (Accessed on 13th August 2014)

The Reviewer

Christopher Corti holds a PhD in Metallurgy from the University of Surrey, UK, and has recently retired from the World Gold Council after thirteen years, the last five as a consultant. During this period, he served as Editor of *Gold Technology* magazine, *Gold Bulletin* journal and the *Goldsmith's Company Technical Bulletin*. He continues to consult in the field of jewellery technology and as a recipient of the Santa Fe Symposium® Research, Technology and Ambassador Awards, he is a frequent presenter at the Santa Fe Symposium. From 1978–1988 he was a Research Manager at the Johnson Matthey Technology Centre, Sonning Common, UK, and from 1988–1992 he was Technical Director at Johnson Matthey's Colour and Print Division.

