The 13th Santa Fe Symposium on Jewellery Manufacturing Technology

MARK GRIMWADE
Consultant, UK

The 13th Annual Santa Fe Symposium on Jewellery Manufacturing Technology was held at Albuquerque, New Mexico, USA on 16-19 May 1999. The attendees numbered 164 and these included 38 from countries outside the USA which is a measure of the increasing recognition being attached to the Symposium as an international forum for jewellery manufacturers.

The first morning was the orientation session consisting of an **Introduction to Metallurgy** by this author and a **Safety Review** with respect to the use of silica in investment powders, cyanides, cadmium, solvents and the repetitive strain injury known as carpal tunnel syndrome. This was presented by Dave Schneller, Co-Founder and Organiser of the Symposium.

Twenty four papers were presented during the remaining three and a half days and these covered a wide variety of subjects of interest to jewellery manufacturers and research investigators.

"Metallurgy of Microalloyed 24 Carat Gold"

Dr Christopher Corti, World Gold Council, London.

Dr Corti began by noting that in Western cultures, jewellery is purchased mainly for adornment whereas in the East it is bought primarily as a financial investment and this is reflected in the caratages of gold used. High carat golds are preferred in the East and low to medium carat golds in the West. However, the low strength and hardness of 24 carat gold means that such jewellery is prone to wear and scratching and design possibilities are severely limited. The development of a gold-1% titanium alloy (990 Gold) overcame many of these problems but has not been a commercial success. Recently, a number of 24 ct golds with finenesses of 99.5 – 99.9% hardened by microalloying additions have been developed and some have been marketed.

The basic mechanisms of hardening metals and alloys were reviewed and this led on to considerations of the theoretical basis for microalloying. The important factors which might contribute to strengthening by extremely small alloying additions are the atomic weight, density and atomic size difference of these elements compared to gold and the degree of solid solubility and likelihood of intermetallic compound formation and hence possibilities for precipitation hardening. Candidate elements include lithium, potassium, sodium, calcium, magnesium and beryllium and the rare earth metals. Phase equilibrium, atomic property and some previously published data were presented together with some information on patents for materials which have been developed and marketed. It is thought that there is scope for extending the principle of strengthening by microalloying to 21 and 22 carat golds. A version of this paper is being published in *Gold Bulletin*, **32** (2), 1999.

"Quality Assurance in Gold Jewelry Manufacturing: Implications of Alloy Properties"

G. Raykhtsaum and D.P. Agarwal, Leach and Garner Co., USA.

The implications for quality assurance of properties of jewellery alloys such as gold assay, overall composition, impurity levels, grain size, mechanical properties, melting temperature range and colour and how they may be affected by manufacturing processes were discussed. Gold assay has legal and financial implications. The legal aspects are obvious but it is essential to know accurately the gold content of scrap or initial grain and of the final product to avoid overcarating due say to zinc loss during casting. Energy dispersive X-ray analysis is considered to be a viable alternative to fire assaying as a quality assurance test. Atomic Absorption is probably the most suitable technique for measuring levels of minor impurities and additions.

Grain size measurement and control leading to small sizes minimizes the risk of the orange peel effect, reduces the possible deleterious effects of impurities and improves mechanical properties such as ductility, strength, workability and formability. The speaker recommended the use of a microhardness tester for evaluation of grain size and hardness. A tensile test is necessary when manufacturing wire and chain .

Colour is directly related to alloy composition although it is also effected by surface finish or any surface oxidation. Colour spectrophotometers are fairly expensive and it may be more practical to make a visual colour evaluation using reference samples. A colour kit manufactured by the Manufacturing Jewelers and Suppliers of America (MJSA) is useful in this respect (see *Gold Technology*, No.22, July 1997).

"The Effect of Silicon Content versus Quench Temperature on Low-Carat Casting Alloys"

Stewart Grice, Metallurgical Manager, Cookson Precious Metals Ltd., England.

The effects of silicon on the performance of gold casting alloys is well documented and the speaker drew attention to its beneficial influence as a deoxidiser and for increasing the fluidity of the melt as well as its use where intensive recycling of scrap occurs. There is a critical level of silicon content above which there is a catastrophic decrease in mechanical properties and this level is dependent on the (gold + silver) content of the alloy.

In this study, the effect of quench temperature for devesting castings of a standard 9 ct yellow gold with five levels of silicon (Si) ranging from 0 to 1% was investigated. Three standard trees were used to assess effects and these consisted of a selection of designs of castings, test pieces to determine mechanical and other properties, and a mesh design for measuring fluidity. Fluidity of the five alloys was assessed at a standard quench temperature of 450°C but other test pieces and castings were quenched at temperatures ranging from 400 to 600°C at 50° intervals. These temperatures were measured at the button. Superheat and flask temperatures were kept constant. Detailed information was given on melting ranges of the alloys, rates of cooling, surface finish of castings, failure rate versus silicon content, quench temperature and tree position; metallographic analysis which related failure incidence with the presence of low melting point phases; mechanical properties and grain size analysis.

The main conclusions were that susceptibility to failure increases with Si addition for a given quench temperature. The major mechanism of failure was not brittle intergranular fracture but hot tearing through low melting point Si-rich phases randomly dispersed throughout the alloy matrix. The use of alloys containing 0.5% Si or less was determined to be acceptable provided certain production parameters were adhered to. Quench temperature should be directly measured at the button and not as a function of time after casting. The cooling rate varied significantly with Si content. Suggestions for further work were given. It is planned to publish a version of this paper in *Gold Technology*.

"Don't Let Nickel Get Under Your Skin – The European Experience"

Roy Rushforth, Technical Director, Birmingham Assay Office, England.

This paper is an excellent review of the nickel allergy problem and the approach taken to the imminent legislation in Europe. It will be published in a future issue of *Gold Technology* and so is not reported here in detail. (Note: This paper has not been published in the 1999 Proceedings of the Symposium.)

"The Surface Enrichment of Carat Gold Alloys – Depletion Gilding"

Mark Grimwade, Consultant to the Worshipful Company of Goldsmiths, London and to the World Gold Council.

A version of this paper is published in this issue of *Gold Technology*, so is not reported here.

"Overview of Casting Technology"

Eddie Bell, Neutec/USA, The Bell Group, Co-Founder and Organiser of the Symposium.

In recent years, Eddie Bell has introduced new aspects into his overview of casting technology and this year followed the trend. The presentation was primarily concerned with the economics of casting and how they are affected by the phenomenon of 'KARAT CREEP'.

During the melting and casting process, there is a tendency for the melt to lose weight and this is often due to zinc losses arising from its high vapour pressure. This means that the caratage of the melt and subsequent castings will gradually increase as the gold content in relation to the total mass creeps upwards. The economics in terms of labour costs, gold cost and other factors such as flask size, the amount of investment used per flask, number of items per tree and the number of trees cast per day, were examined. It was concluded that process management and control has to account for the zinc losses and 'carat creep' in order to avoid excessive overcarating. It was suggested that this should be kept down to about 0.02%. (Note: This presentation is not included in the 1999 Proceedings.)

"Properties of Melt and Thermal Processes During Solidification in Jewelry Casting"

Dieter Ott, The Research Institute for Precious Metals (FEM), Germany.

Success in casting is dependent on many factors, such as size and shape of the castings, gating, pressure, properties of the alloys and investment, etc. Temperature and thermal processes dominate but there are strong interactions between all factors. Pressure and flow rate were discussed in last year's presentation by Dieter Ott and this year he turned his attention to aspects of the thermal processes.

The thermal and physical properties of the melt which influence metal flow and solidification are density, viscosity, surface tension, solidification temperature range, specific heat, thermal conductivity, and volume shrinkage during solidification. The important properties of the investment are gas permeability, specific heat, thermal conductivity and mechanical strength. It was stated that 'interface resistance' controls heat flow through the mould-metal interface and this will be determined by the properties of both melt and investment. Oxidation and metal/mould chemical reactions may have an influence. Generally, there is a lack of data on the thermal and physical properties of jewellery alloys but some values were tabulated which were either obtained at FEM or from published literature or were estimated. The techniques for obtaining the data were discussed.

A model for the casting process was proposed. It is very much simplified and only applicable to simple shapes such as rods, spheres, plates, etc. The aim was to demonstrate the influence of the various parameters on solidification time. The model was based on Chvorinov's Law and in its simplest form is written as:

$t_f = c.(V/A)^2$ ....eqn. 1

$t_f = C.(V/A)^2.1/(T_o - T_m)^2$.....eqn. 2

where

t_f is the freezing time

V/A is the volume to surface ratio for the casting

T_o is the 'solidification temperature' (a simplification in place of a range)

T_m is the mould (flask) temperature

c and C are constants which include thermal properties of the melt and investment.

The model was tested on spheres and rods using micro-thermocouple measurements and the measured values compared with calculated ones. Fairly good agreement was obtained for solidification time. The model was used to compute solidification times for a simple ring pattern and a rod-shaped spiral for standard 14 and 18 ct alloys.

"Metal Flow Optimizing – An Important Step to Successful Casting"

Klaus Wiesner, Product manager, C. Hafner Gmbh Gold & Silver Refining, Germany.

It is the speaker's contention that metal flow is an important parameter in casting. which is often overlooked when considering ways of reducing the failure rate. The behaviour of the molten metal as it enters the flask is almost always responsible for influencing the occurrence of porosity. In constructing the tree and sprueing and gating system the main requirements are a) continuous filling, b) turbulence free filling and c) filling with a good metal flow. The metal flow was examined at four points during the casting process as follows.

1) Flow from the crucible. Whether this is as a solid stream or as a spray is determined by the type of casting machine and the pressure acting on the melt.

2) In the button and central sprue. A smooth slick funnel is important as uneveness leads to unwanted turbulence. The thickness of the sprue should be such that a high casting speed is guaranteed without breakage of the investment. A tapered central sprue with a cone angle of 1-1.5° and a diameter of 18-20 mm is recommended.

3) In the casting (gating) system. Shape, gating (sprueing) methods, dimensions, angles to the central sprue, etc. were discussed with regard to turbulence, casting speed and pressure.

4) In the casting. Basic rules for castable designs were discussed and consideration given to obtaining the correct solidification sequence.

"Thermal and Microchemical Characterisation of Gypsum-Bonded Investment for Casting Jewellery Alloys"

Dr G. M. Ingo, Consiglio Nationale Richerche, Italy.

The thermal decomposition of calcium sulphate ($CaSO_4$) in gypsum-bonded investment has been studied using differential thermal analysis + thermogravimetry, X-ray photoelectron spectroscopy, and scanning + energy dispersive spectrometry. This is of importance because the thermal decomposition of gypsum can lead to the formation of sulphur dioxide and gas porosity in castings. Since zinc, copper and silver oxides may be present at the mould/metal interface in casting, this study included the effects of these oxides on the decomposition behaviour. The effects of three different atmospheres, namely, air, argon and argon + 5% hydrogen were also investigated.

It was shown that the decomposition temperature of the gypsum-bonded investment is lower than that of pure $CaSO_4$ and is very close to casting temperatures of typical jewellery alloys. In addition, it is further lowered in inert or reducing atmospheres and when copper oxide Cu_2O and ZnO are present.

"The Effect of Additives on the High Temperature Chemistry of Investment Materials"

Roland Loewen, Alchemy, USA. Paper presented by Jessica Bell.

The composition of typical gypsum-bonded investment powders was described and the chemical reactions between calcium sulphate and silica with and without the presence of carbon were discussed. Roland Loewen then discussed experiments where samples of powder were heated and the temperatures measured at which sulphur dioxide gas was emitted, this being a measure of the decomposition of gypsum. It is known that sulphur dioxide is a main cause of gas porosity in castings. Wax or sucrose additives were made to the samples to study the effect of carbon on the evolution temperatures. Additives were made to the investment + sucrose samples with the purpose of easing the removal of carbon and it was shown that 5% calcium nitrate raised the sulphur dioxide evolution temperature indicating a beneficial effect. However, the additive made the mould considerably stronger and more difficult to devest. Boric acid which is added as a protective agent when casting gemstones in place has a similar effect. Tests were devised to measure breaking strength and permeability of investments with additives. Cellulose and nylon flock were shown also to be effective carbon removers but these seemed to degrade surface smoothness.

Some interesting observations were also made on the use of microwave heating which was shown in laboratory experiments to be effective in removing free water and ejecting molten wax. Heating occurred from the centre of the mould outwards and this appeared to prevent the wax soaking into the investment. However, there is a technical difficulty in scaling up the equipment required for production processing.

"An Evaluation of the Permeability of a Jewelry Casting Investment"

J.C. McCloskey, D. Allen and A. Thibodeaux, Stuller Settings Inc., USA.

An experimental study to evaluate the permeability to air of gypsum-bonded silica investment moulds at temperatures typical of jewellery casting operations was described. Permeability was determined by measuring mould cavity pressures, temperatures and flow rate of air on flasks burnt out according to a standard burn-out cycle and placed in the vacuum chamber of a commercial vacuum assisted casting machine. Two wax patterns, namely, disc and cylindrical shapes, were used with various flask designs. Graphs of flow rate versus pressure drop across the mould wall gave linear plots and the permeability values were calculated from the slopes of these plots according to the equation

$$\text{Slope } m = \frac{\Delta Q}{\Delta P} = -\frac{K\,2\pi l}{\eta 2.3\log r_2/r_1}$$

where Q = rate of air flow

K = permeability

ΔP = pressure drop across porous mould

η = viscosity of air

l = length or thickness of test patterns

r_1, r_2 = outside and inside radii of the solid, respectively.

Results were presented for different flask temperatures and different types of flasks. It seems to this reviewer that this technique will be particularly useful in comparing permeabilities of different investments and relating the results to casting quality.

"Characterization and Correction of Casting Defects"

Timothy Donohue and Dr Helmut Frye, Techform Advanced Casting Technology, L.L.C., USA.

Seven categories of casting defects and described in detail together with their possible causes. These were metallic projections, cavities (porosity), discontinuities, defective surfaces, incomplete castings, incorrect dimensions or shape and inclusions. Proper identification of the defect is essential for correcting and controlling casting quality. The importance of having a controlled and comprehensive defect analysis programme was stressed. Once the defect has been classified, the possible causes can be examined and the appropriate corrective action taken.

"Quality Level Improvement in Investment Casting: Are Latest-Generation Casting Machines the Only Solution?"

Dr Valerio Faccenda, Consultant and P. Oriani, Pomellato SpA, Italy.

Dr Faccenda began by pointing out that even if fully automated, a melting/casting machine can only melt and cast but these are only the final steps of the process and it cannot correct any mistakes made in previous stages. Although he identified ten steps in the process, the main thrust of the presentation was on rubber mould preparation, burn-out, melting and casting. The importance of wax pattern quality and problems of undercuts were discussed. A technique for making a complex mould which avoids cutting with a scalpel was described.

The characteristics required for a burn-out furnace that will guarantee an accurately controlled burn-out cycle were examined. The construction of a suitable furnace utilising forced air circulation and avoidance of direct heating by radiation from the resistors was described. This ensures temperature homogenisation throughout the furnace and easier combustion of wax residues.

If the metallurgical properties of the alloys are not sufficiently known, there is a risk of producing defective castings. Examples of two recent problems were given. One concerned the use of silicon in 18 ct gold rings where anomalous grain growth and segregation to the grain boundaries led to a network of fine cracks and brittleness during resizing. The other related to the behaviour of different alloys with regard to gas porosity originating from decomposition of calcium sulphate.

Finally, provided that attention has been paid to quality control at all stages, the benefits of installing a fully automated static melting/casting machine with a pressure over vacuum system were described. Melting is achieved using low frequency induction heating. Optical pyrometry is used for measuring flask temperature and it is interfaced to a PC to record operating parameters. This enables the creation of a database that is continuously updated. Caratage uniformity is no longer a problem.

"P/M (Powder Metallurgy) and Potential Applications in Jewellery Manufacturing"

Dr Joseph Strauss, President, HJE Company Inc., USA.

The presentation began with an extensive overview of the principles and practice of powder metallurgy processing dealing with powder production methods, sintering, compaction, hot pressing, hot and cold isostatic pressing (HIP and CIP), metal injection moulding (MIM), powder rolling and spray forming. A great advantage of powder metallurgy is that it can be used for near-net or net shape processing and it can compete favourably on cost usually with the proviso that it requires many thousands of parts to make it economically feasible. This limits its application in jewellery and precious metal but it has been recently introduced for high volume processing of items currently cast and stamped in quantity. Examples were given where the press and sinter technique has been used to produce wedding bands and multilayered composites of different metals and alloys, thermal spraying of silver and its alloys which has a potential for sculptured pieces and precious metal clays which are commercially available and which are suited for one-off pieces. Finally, potential jewellery applications were considered. The two P/M manufacturing methods most suited to mass production are press and sinter and MIM and their competitiveness in relation to investment casting were discussed. A selection of prototype precious metal jewellery items were shown. It has been found that MIM parts can be finished to the same high standards as cast parts using newer techniques such as magnetically stirred needles and shot. (Note: This paper is published in the 1998 Proceedings but was presented at this year's Symposium).

"Oven Soldering – A Practical Approach"
Dana Castle and John Gavin, Findings Inc., USA.

This was a wide ranging presentation on all aspects of furnace soldering (brazing) for the jewellery industry. After dealing with the basic principles of furnace soldering, the speaker went on to discuss fixturing devices, belt furnaces, dissociated ammonia protective atmosphere, cleanliness, joint and fixture design, solder paste, process control, failure identification, testing and training programmes for employees.

"Surface Structuring by Electrochemical Techniques"
Dr Andreas Zielonka, Deputy Director, The Research Institute for Precious Metals (FEM), Germany.

Dr Zielonka noted that electrochemical processes are widely used to either promote uniform surface colour and brightness, or to deposit special coatings to improve strength and wear resistance, or even to produce jewellery items by electroforming. Another possibility for jewellery is to produce surface structures using photo resist films. This technology is used in other areas such as for printed circuit boards and micro-mechanical components.

The surface of the substrate to be structured is covered first with a resist and the various methods for doing this, in particular the LIGA technique, were discussed. Although exposure of resists through printed masks to give exposed and non-exposed areas is normally done using ultraviolet light, the use of strongly parallel X-Rays is recommended for special applications. Electrochemical deposition from a commercial fine gold electrolyte produces a structured gold surface. The surface structuring for decorative applications with a resolution of ~100μm is possible on complicated substrates and the structured parts can be soldered onto jewellery surfaces.

"The Use of Computers for Manufacturing Processes"
Ajit Menon, Landstrom's Original Black Hills Gold Creations, USA.

The paper described ways in which computers can be used to assist or monitor simple manufacturing processes. An obvious example is temperature monitoring particularly in flask burn-out cycles. Proportional Integral Derivative (PID) allows the computer either to control a proportional power supply to electrically heated furnace elements or to adjust the opening of gas valves to proportionally control the gas flame in the furnace. The main advantage of PID is that it prevents over– or under-shooting of furnace temperatures.

Other examples given in the paper include monitoring and maintaining bath parameters in electroplating processes, preparation of casting worksheets and CAD/CAM applications. The use of robots in jewellery manufacturing was also discussed.

"PC Update – Moving Towards the Millenium"
Richard Kaye, President, MPI Systems Inc., USA.

The problem of potential computer failures in the Year 2000 as it related to the jewellery industry was discussed and a detailed course of action for manufacturers to minimise these problems was described. Typical problems are likely to include internal systems which prevent or hinder normal operation of the business, suppliers who cannot process orders, infrastructure failures such as telecommunications and power failures, plant failures, customers who cannot place orders or process invoices, etc.

Electronic Commerce ("E-Commerce), defined as the sharing of business information, maintaining business relationships and transactions by means of telecommunication networks, was explained in three major areas of interest, namely, Internet transactions, Intranets and Extranets. Costs, risks and potential for competitive advantages were explored.

"Stone Casting Process with Invisible Setting"
Hubert Schuster, Jewelry Technology Institute, Italy.

The stone casting process with invisible setting was developed to meet the need to drastically reduce costs, compared with hand setting, using synthetic stones or cubic zirconia. These stones are eminently suitable for the process because their measurements are usually regular and they are already prepared for invisible setting. Diamonds, emeralds, rubies, sapphires, cubic zirconia, garnets and tourmalines have been used for this system and it is possible to cast in red, yellow and white golds and in silver.

The speaker described suitable stones and their preparation, the methods of supporting the stones, rubber moulds, injection waxes and how the stones are set in the wax. It is imperative to use a liquid additive or to use a special investment when casting with diamonds but this is not essential with other stones. Finally, recommendations were given on burn-out conditions and flask temperatures. After casting, flasks must be allowed to cool slowly to prevent thermal shock cracking of the stones.

"Observation Techniques for Gemstone Identification used in Jewelry Manufacture"

Arthur Skuratowicz, GJG, Anton Nash, LLC, USA.

This very interesting presentation dealt not only with the techniques for visually identifying gemstones and the distinctions between diamonds and their imitations but also with the various treatments that can be given to diamonds. These include fracture filling, laser drilling, colour enhancement, irradiation and surface coating. These treatments together with heating, diffusion + heat, and dyeing can be applied also to coloured stones such as rubies, sapphires and topaz. The lecture was amply illustrated with slides. (Note: This paper has not been published in the 1999 Proceedings.)

"Understanding Heat Treatable Platinum Alloys"

Greg Normandeau and David Ueno, Imperial Smelting & Refining Co. of Canada Ltd.

The physical and mechanical properties of a 95% platinum heat treatable alloy were given and comparisons made with other commercially available platinum alloys used in jewellery manufacture. Manufacturing processes including cold working, heat treatment, melting, investment casting and machining were discussed. Typical applications are findings, stampings, seamless bands and applications where spring properties are required.

"Platinum Alloy Applications for Jewellery"

Jurgen Maerz, Manager of Technical Education, Platinum Guild International, USA.

After defining the standards for platinum alloys allowed in the USA and the various European countries, the speaker discussed the platinum alloys that are commercially available for jewellery production The purpose of each type of alloy together with properties and applications were described. Jurgen Maerz also gave a short illustrated presentation on fabricating a platinum ring.

"A Study of Machining Parameters and Their Effect on the Surface Texture of Platinum Alloys for Jewelry Applications"

Dr Richard Lanam, Engelhard-CLAL and Constantino Volpe, Tiffany & Co., USA.

Factorial designed experiments were used to study the effect of the machining variables of feed speed, spindle speed, cutting depth and choice of lubricant on the surface texture of platinum alloys for jewellery applications. Three different cutting materials, namely, ceramic, cubic boron nitride and polycrystalline diamond were included in the investigation. Scanning electron microscopy was used to examine surface textures. The general conclusion was that cutting materials other than diamond can give acceptable results.

Every year, the **Santa Fe Symposium** give awards to those who they consider have made a contribution to the industry. This year, Research for Innovative Insight Awards were made to Dieter Ott, Richard Lanam and Constantino Volpe. Five Ambassador Awards were presented to John McCloskey, Jurgen Maerz, Valerio Faccenda, Anthony Eccles and Chuck Hunner. The Technology Award went to American Jewelry magazine and its editor Richard Youmans and the Industry Leader Awards were given to Helmut Frye and Timothy Donohue of Techform, Jeffrey Matthews and Andre Janiszewski.

The Proceedings of this 13th Symposium are published by Met-Chem Research Inc. (Edited by Dave Schneller), P.O. Box 680, Lafayette, Colorado 80026 and may be obtained from "The Santa Fe Symposium" at 7500 Bluewater Road NW, Albuquerque, New Mexico 87121 USA (Fax: +1 505 839 3248).