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Jewellery manufacturing technology has made substantial progress over the last 10 years of the JTF. In particular, we have seen large growth in the use of machine-based manufacturing and especially in digital technologies – CAD/CAM, rapid prototyping and manufacturing – allied to the use of conventional technologies such as lost wax/investment casting and powder metallurgy. There have also been developments in precious metal alloy technology so that alloys are better tailored to the needs of manufacturing processes as well as giving better performance in service when worn by the customer. Firestain- & tarnish-resistant silvers would be a good example here.

It is appropriate, therefore, to look into the future and explore where manufacturing technology is going over the next 10 years. There is no doubt that digital technologies will continue to have a growing impact but we can anticipate that the current limits of conventional technologies such as investment casting and powder production will be pushed to new boundaries as a consequence. This will place new demands on the machine technology. We can also expect old technologies to rise again with new developments. The motivation will continue to be increased efficiency in both use of materials and yields, leading to a reduction in costs, widening of design opportunities and the customising of design. In addition, the demand for ethical and sustainable jewellery will add to this pressure. Examples include use of biomimetics to produce stronger, more lightweight jewellery in innovative designs, enabled by rapid manufacturing technologies such as the new laser sintering/melting processes, and developments in the use of mixed colours, coatings and alloys to give new design effects and improved service performance.

The Next 10 Years:
Jewellery Manufacturing in 2024!

The Jewellery Technology Forum celebrates 10 years this year, having started in 2004. To have reached the milestone of 10 years strongly suggests that it meets an important need for the jewellery industry, not only here in Italy but across Europe and beyond. I congratulate the organizers for their courage in starting the JTF, for their undoubted success and wish them continued success over the next 10 years.

If we look back at the first JTF in 2004[1], there were 16 presentations from experts around the world, covering a range of materials – gold, platinum and silver - and manufacturing processes such as investment casting, hollow jewellery and laser welding of chain. They also embraced quality issues and health & safety as well as creative design, all topics that have regularly featured at most JTFs since. Today, it may seem surprising that computer-based technologies such as CAD/CAM and Rapid Prototyping did not feature at all in the original conference!

Clearly, jewellery manufacturing technology has made substantial progress over the last 10 years. In particular, we have seen large growth in the use of machine-based manufacturing and, especially, in digital technologies – CAD/CAM, rapid prototyping and manufacturing – allied to the use of conventional technologies such as investment (lost wax) casting and powder metallurgy. The benefits of computer-based modelling of the investment casting process have also been demonstrated. Alongside this, there have also been developments in precious metal alloy technology so that alloys are better tailored to the needs of manufacturing processes as well as giving better performance in service when worn by the customer. Firestain- & tarnish-resistant silvers would be a good example here. In all these areas, the JTF has been a leader in disseminating the latest advances in technology and Best Practice to our industry and giving us the confidence to update our manufacturing technology in order to improve quality and productivity, as well as innovating in design.

The 10th Anniversary of the JTF is a good time to reflect on the progress that has been achieved but it is also an opportunity to look to the future and consider where manufacturing technology is going over the next 10 years. What technologies will we be using in 2024? What follows in this presentation is a personal view.

PROGRESS OVER THE LAST 10 YEARS

It is always instructive to look back over history and see what progress has been made as it helps to shape how the future may develop. We should consider not only the technology – materials, machines and processes – but also other factors such as design trends and market forces which influence the technical needs and motivate new technology development.

Market and Design Trends

Probably the major influence has been that of the cost of manufacture of jewellery in the Western world, where labour costs are a significant proportion of manufacturing cost. This has led increasingly to the mass manufacture of low-moderate priced jewellery being shifted to the Eastern world, to countries such as China, Thailand and India, where labour costs are significantly lower. Quality of product has, perhaps, suffered initially, but that is no longer the case. We have also seen the market for jewellery growing substantially in these developing markets, especially in China, as the Eastern economies develop. These markets are increasingly attractive to Western manufacturers who succeed on innovative design leadership. Italy & Europe are seen as design leaders worldwide.

This trend has put increasing pressure on European manufacturers to lower their production costs through improved productivity and use of the latest machine technologies and best practice. Thus, a lean manufacturing, 'just-in-time' approach, coupled with maximizing throughput in value streams, as epitomized in the Theory of Constraints[2,3] , has been favoured , together with a Total Quality ethos. Coupled with this has been an emphasis on higher manufactured quality and innovative design as a way of maintaining and growing market share, i.e. moving to the higher added value market sector. As just noted, Europe is seen as a design leader.

I should also note here that manufacturing in the Far East has been changing from old craft-based workshops employing traditional goldsmiths to the adoption of modern machine-based technologies in large factories. Some of the most technologically advanced factories I have seen are in the Far East!

Another important market trend, particularly in Europe and other Western markets, has been the preference for white precious metal jewellery – silver, white gold, platinum and, more recently, palladium. Coupled with rising prices of precious metals, this has put pressure on improving both alloys and manufacturing processes with some emphasis also on lighter weight products to meet price limits. The growth in popularity of branded jewellery has also been a notable trend, with big brands emerging in the high-end, design-led sector, where high margins can be achieved at significant market volumes.

On the design side, I have mentioned that there is a continuing & growing demand for innovative design and there is also a trend for customized jewellery, each piece with a design unique to the customer. The new computer-based technologies have increasingly played a larger role in enabling such innovation in design and in getting new product to market faster. The recent JTF presentations by Beatriz Biagi[4] and others[5] have demonstrated this trend.

Lastly, I will mention the growing market interest by the consumer in jewellery that is produced from ethically sourced materials, that is 'safe' and made in a socially responsible manner – "green" jewellery. I will say more on this trend later but I note the problem of nickel skin allergy which particularly impacts white golds; this has had an effect on the market.

Jewellery Alloys and Coatings

Conventional jewellery alloys – carat golds, sterling silver and 950 platinum alloys – have been developed and used successfully for many years. However, some do have known deficiencies where improvements would be welcome. Prime among these are silver and the casting of platinum. I could also mention the desire for stronger high carat & 24 carat golds too.

Sterling silver, for example, dominates the silver jewellery market but this silver-copper alloy is relatively soft and suffers from firestain and poor tarnishing behaviour. We now have a better understanding of the causes of firestain and tarnishing and of ways to test alloys to assess their resistance[6,7]. Two approaches have been taken by our industry to address this problem: development of improved alloys and also protective coatings. We should note that tarnish-free alloys are not possible from thermodynamic considerations. We can only delay its onset.

There have been a number of new sterling silver alloys developed that have improved tarnish and firestain resistance and many of these are readily available in the market. These are generally based on small additions of germanium or silicon to the alloy, often with reductions in copper, that enable a thin transparent oxide film to form on the surface rather than the black silver/copper sulfides associated with tarnish. Such alloys have been described at JTF and the Santa Fe Symposia, for example[8]. Others in the market have small additions of gold or platinum group metals but are not as effective in conferring resistance. Attempts to strengthen sterling silvers have been successfully demonstrated[9] and some of the new tarnish-resistant silvers can also be age-hardened[8].

The other approach has been to develop thin coatings, some transparent, that give protection against tarnishing. For example, Isomäki has reported thin transparent aluminium oxide- based coatings on sterling silver deposited by Atomic Layer Deposition (ALD)[10]. These are pinhole free and show good resistance to tarnishing and wear. Actis Grande has demonstrated similar effects with Plasma-enhanced CVD silica-based coatings[11]. Legor have reported coloured resin-based coatings containing nanoscale ceramic particles that are applied by electrophoresis[12]. These show enhanced tarnish and wear resistance and can be obtained in a range of colours to give a decorative effect.

I mentioned 'green' jewellery in the previous section and, particularly, the nickel skin allergy problem and so-called 'safe' jewellery (i.e. non-allergenic). As we all know, the EU legislated against nickel in jewellery back in 2002. This applies particularly to white golds which have traditionally used nickel as an alloying metal to whiten the colour of gold[13]. This has resulted in Europe to the use of white golds with low nickel contents to meet the nickel release requirements. These are not usually of a good white colour[14] and require rhodium plating. The wide use of palladium as an effective substitute for nickel is limited in commercial alloys because of technical and economical factors. Much research has been undertaken to develop improved, nickel-compliant or nickel-free white golds, with very limited success [14,15]. Of importance today is that the EU regulations have been recently amended and the nickel release requirements are stricter.

Manufacturing Processes

There has been a continuous change in manufacturing technology over the last decade. As well as evolution of existing processes and machines, new technologies have appeared and made some inroads. I cannot describe them all but will focus on the major ones as I see it. With the downturn in the economy over the last few years, recent emphasis has been on thrifting of materials and improving machine and process performance to meet market needs.

a) Investment casting

If we look back over the last 10 years or so, the biggest manufacturing process that we use in our industry and which has received most attention is the investment casting process and the sub-processes within. At JTF, about 30% of presentations over the last 10 years have been on this subject, for example. So have we made significant progress during this time? The answer is 'Yes, we have' in some significant areas.

Firstly, the art of rubber mould cutting and the setting of gem stones in the rubber mould or in the waxes produced from them (for Stones-in-place casting) has reached new heights and the late Hubert Schuster was, perhaps, one of the World's best experts in this field. As regular attendees at JTF will know, he has shared his knowledge with us at JTF on several occasions[16] and the capability of our industry has been raised.

Important progress on the casting of platinum has also been reported[17] and, very recently, Fryé has shown how Hot Isostatic Pressing, performed after casting, can reduce defects and result in improved casting quality[18] with the additional benefit of improved mechanical properties. The advent of palladium as a jewellery metal in the last few years has required new research into the processing of it into jewellery; casting has been a particular concern and technical progress has been made[19].

We have also advanced our knowledge of the casting of silver[20]; these studies have resulted in practical guidelines to ensure more consistent, defect-free quality castings.

b) Computer modelling of casting

The use of computer modelling of the investment casting process in recent years[21] has taken us to another level of understanding of the process. Its ability to predict thermal characteristics dynamically has important benefits in predicting the likelihood of defects such as porosity and assisting in the optimisation of casting tree design and the casting parameters. Most work has been done on carat golds and silver but platinum has also benefited. We now understand the characteristics of the tilt casting process compared to centrifugal casting of platinum.

c) CAD/CAM and Rapid Prototyping (3D Printing)

The major progress over the last 10 years has been in the use of CAD/CAM and, particularly, Rapid Prototyping (3D printing) technologies. The use of such technologies has now become widespread in our industry. Progress in machine development and resins for models for jewellery application has been substantial. I will note here the advent of a Do-It-Yourself assembly kit of a RP machine that retails at US$3,000 in kit form[22]; this brings affordable 3D printing technology to the small craft jeweller/designer. Particular attention has been given to the direct investment casting of resins, both in terms of tailored investment powders and in terms of casting quality[23]. This approach is now considered as Rapid Manufacturing.

d) Powder metallurgy and Rapid Manufacturing

The use of powder metallurgy processing in the manufacture of precious metal jewellery intrinsically has many attractions, particularly economic, as there is very little waste material generated, a disadvantage of traditional processes such as stamping and investment casting. However, it has only found limited interest for the manufacture of plain wedding rings[24]. Some interest has been generated in Metal Injection Moulding (MIM) for more complex-shaped parts but it has not grown into a mainstream manufacturing process[25]. Strauss has put this down to several factors, including unavailability of precious metal alloy powders.

Nontheless, there has been a substantial breakthrough in the last 2-3 years in the development of Rapid Manufacturing processing of precious metal powders, using selective laser melting or sintering technology, to produce finished parts[26]. Excellent reviews[27] of this technology and its potential in the jewellery industry have been presented by Strauss in 2009 and Cooper in 2012

THE NEXT 10 YEARS: MANUFACTURING IN 2024!

This section is a personal view of the future of jewellery manufacturing technology. Will it be much different to what we have today? The answer is Yes and No! Undoubtedly, the best of what we use today, such as investment casting, will persist and continue to evolve but new developments will impact and change the manufacturing scene. Some will be taken up on a large scale and others will only find a niche in the widening spectrum of technologies used. We must recognise that much technology innovation is developed and exploited in other engineering industries and then is adapted later to meet the needs of our industry. That trend will continue into the next decade.

Market and Design Trends

I believe precious metal prices will remain relatively high because of the 'demand & supply' equation. Some forecasters predict increasing prices. We must recognise that, as gold is also a monetary asset, its price inversely reflects the value of the US dollar and that it serves as a buffer in difficult economic and political conditions. I do not see the world political situation becoming calm and peaceful in the near future. There will continue to be turmoil, both natural and man-made. We can also predict that the developing countries, such as the BRICS nations, will strengthen their economies and become stronger economic forces in competition to the USA and Europe. That will grow the market for jewellery and, perhaps, alter the economics of manufacturing in those countries, as standards of living rise.

In terms of design, for jewellery, fashion and luxury goods, Italy & Europe will continue to be the market leader, but overseas competition will strengthen too. Europe must strive even harder to maintain its dominant role. Technology will continue to play a role here as the advent of new technology can open up new design opportunities[28].

Thus, jewellery manufacture in Europe will continue to focus on high quality product and innovative design, with much of the lower end product continuing to be made in the Far East and also in other developing countries, such as those in Africa, Central and South America and Eastern Europe.

There will also be growing demand for green jewellery, and this will place a bigger emphasis on ethical sourcing of materials such as the precious metals and gems to avoid so-called 'conflict materials' that fund terrorism and damage the environment. Mining companies will focus more on socially responsible mining. Green jewellery, made from sustainable, accredited materials and by socially responsible manufacturers, will become more widespread in the market. Accreditation schemes such as those for gold and diamonds[29] will grow to cover all precious materials and, maybe, some of the consumable materials used in their manufacture. We can expect to see more emphasis on recycling of materials used in manufacture, for example, as well as the old jewellery and precious metal manufacturing scraps that have always been recycled for economic reasons.

This category also encompasses safer product from a health standpoint and, as we have noted earlier, the EU Directive on nickel has been recently tightened. This is bringing new alloy developments in white gold[30] with a view to eliminating nickel as an alloying metal altogether. We may also expect continuing tighter regulation against other metals and materials that are considered undesirable on health grounds. Cadmium and lead, for example, are already being controlled and, maybe, use of metals like cobalt will follow.

There will also be a growth in demand for better service performance of finished jewellery, be it mechanical characteristics, tarnish resistance, quality and finish, or life without premature physical deterioration. Some of these aspects and the implications for the industry have been discussed elsewhere[31], but I will note a need for industry-agreed standard testing procedures of finished jewellery, if progress is to be made.

The trend for customised design, each piece unique to its owner, will grow and current Rapid Manufacturing technologies coming on stream are increasingly facilitating this trend at economic costs [4, 32]. Dean has been a leader here in dynamic design[32].

New Jewellery Materials

a) Colour and surface effects

The market is always demanding new colours and other decorative effects. I believe this demand will develop over the next 10 years. Unusual coloured golds and other precious metals will feature here. Purple gold is, perhaps, the best known of these, but blue, brown and black are also known commercially. The possibilities for all precious metals have been described by Corti[33] and practical technologies for their use have been described by others[34]. These can be accomplished by use of special alloys (known as intermetallics) or by coatings and surface treatments. All can be compatible with Fineness marking/Hallmarking regulations. There are some interesting technologies involved such as laser etching of the surface and nanoparticles.

b) Stronger alloys

We have already mentioned sterling silver with better strength that can be achieved by conventional alloying[9] or heat treatment but there are other possibilities such as microalloying. Bernadin[35] has shown that this concept applies to all precious metals from 24 carat/ 999 fineness downwards. Corti has summarised this technology[36] and Wright has recently explored silver-titanium alloys as the analogue to '990' gold-titanium[37]; this shows some promise as an alternative alloying approach to micro-alloying. There is growing interest in this micro-alloying approach to stronger alloys and we shall see it used more in the future. Whether it is applicable to the Selective Laser Melting process technology remains to be demonstrated but such thoughts are exciting for that technology.

c) Metallic glasses

Another relatively new new alloy development that has many attractions for jewellery manufacturers are the Bulk Metallic Glasses (or amorphous metals), known as BMGs. Both gold and platinum materials have been developed[38]. These alloys of complex composition are rapidly cooled to maintain a non-crystalline state, a condition in which they have extraordinary ductility. Thus, they can be processed at low temperatures as one does with plastics or glass. They can then be crystallised back to a normal alloy. The processing of such materials has been demonstrated recently[39] and they offer great potential as an alternative manufacturing process with unique design opportunities.

d) Shape memory alloys

I will also mention Shape Memory alloys. These are special compositions in which the alloy remembers its form shape when heated after deformation. Besseghini has reported on gold-based alloys at JTF in recent years[40]; they offer interesting possibilities for jewellery application such as the mounting of gemstones and the creation of 'dynamic' jewellery, i.e. jewellery that changes shape depending on ambient temperature. More research needs to be done on the practical application of such alloys and the design opportunities they create.

New & Improved Processes

a) Investment Casting

As one of the most important processes in our industry, the investment casting process will continue to evolve, especially to meet the challenges demanded by CAD/CAM/Rapid Prototyping technologies, i.e to extend it to more difficult shapes, finer wall thicknesses and so on. Hollow casting technology has seen some recent progress[41] and is an interesting area that we shall see being further exploited, again in combination with RP technology and direct casting of resin models. We shall also see continuing improvements in casting machine technology and consumables such as mould rubbers and investment powders, without a doubt.

There is a real need to better understand platinum and palladium casting and the problem of defect formation. Hot isostatic pressing (HIP) provides a partial solution at some additional cost[18]. Computer modelling can assist in providing enhanced understanding. As a consequence, we shall see improvements in the casting technology of both platinum and palladium.

b) CAD/CAM and Rapid Prototyping (3D Printing)

This technology will continue to improve to meets the jewellery industry needs, in terms of model/pattern surface quality, process speed and flexibility. Improved resins will continue to be developed and the prices of machines will fall too, making the technology more accessible. Already, as noted earlier, a cheap machine in kit form is available at a cost of only $3,000. Coupled with investment casting, this technology will grow in application. I can also see this technology being used with electroforming too, which I believe is an undervalued process.

c) Powder Metallurgy and Rapid Manufacturing: Selective Laser Melting

The technology of Selective Laser Melting (or Sintering) is at an exciting stage of development, both in terms of tailored alloy powders and technical capability. It offers great potential in terms of design opportunities, for example, its application to produce tailored lightweight designs, not only from an artistic viewpoint but from an engineering/economic viewpoint. Silva[41] gave an impressive presentation at the 2013 Santa Fe Symposium in which computer-assisted stress engineering analysis ,along with clever design, is used to produce lighter weight, strong cellular structures that mimic that of natural bone – a cellular internal structure where the density of cells (and hence strength) varies according to the imposed stress pattern. This is called bio-mimetics and is an exciting approach.

We could also envisage the use of different coloured gold alloy powders in sequence to produce interesting colour patterns akin to Mokume Gane or the combination of layers of different metals to produce similar effects, as is currently done by diffusion bonding for rings. We can also envisage combining components produced by other techniques such as casting into the process, as is currently possible with the Precious Metal Clays.

The big question with this technology is whether it will become a major manufacturing process or remain simply as a niche technology. I suspect the latter is more likely on economic grounds.

d) Processing like plastic: New processes from other industries

I mentioned in the earlier section on new materials the potential of bulk metallic glasses (BMGs). This allows novel processing techniques as found in the plastics industry. This development has yet to be exploited commercially. Again, it offers a unique design opportunity.

Many of the recent technology developments used in our industry were originally developed in other industries such as automotive and aerospace and later adapted to our industry's needs. Modern investment casting grew out of that developed for the dental industry and laser processing such as cutting, welding and engraving was adapted from engineering, as has CAD, CAM and Rapid Manufacturing. We can expect, therefore, that other new process technologies will be transferred across over the next 10 years.

CONCLUSIONS

This presentation has been a quick journey into materials and manufacturing technologies used in our industry and the progress that has been achieved since the JTF began in 2004. It is a personal view and some of you may see the picture differently. I have also attempted to give you my vision of how manufacturing technology might develop over the next 10 years. I may not be here in 10 years time to see if my predictions have come true but many of you will be!

I can say without doubt that the pace of change will continue and further progress will be made. Our industry will adapt to meet the market needs.

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