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In jewellery manufacture, it is recognised that alloys and other materials should meet the needs of the manufacturing processes and that the resulting jewellery should give good service performance when worn by the customer. To ensure these needs are met, it is necessary to know certain properties such as density, tensile strength, hardness, colour, tarnish resistance and precious metal content. It is a balance to ensure that the jewelry meets the needs of being 'fit-for-purpose' whilst keeping costs to a minimum, for example by reducing the weight of metal in the piece. Sometimes we measure the properties ourselves but often we rely on data from external sources such as alloy suppliers and the scientific literature. How much reliance can we place on the values we obtain in property testing? This paper considers the measurement of the properties of jewellery alloys and of actual finished jewellery. It reviews the important properties, how they are measured and what they tell us in terms of their relevance to jewellery manufacture and service performance. Mechanical, physical and chemical properties are considered. The importance of making measurements in accord with international standards and the need for industry-agreed standards for testing of actual finished items of jewellery is emphasised.

PROPERTY MEASUREMENTS: WHAT USE IS IT TO JEWELLERS?

INTRODUCTION

The title, “Property measurement: What use is it to jewellers?” may appear to be a silly question to some. Of course it is useful, they will say, but there will be others who make pieces of jewellery satisfactorily without bothering with any measurements at all apart from dimensions or weight. But when things go wrong, measurements of certain properties are often the sensible way to pinpoint where the problem lies.

In jewellery manufacture, it is recognized that alloys and other materials should meet the needs of the manufacturing processes and that the resulting jewellery should give good service performance when worn by the customer. To ensure these needs are met, it is desirable to know the values of certain properties – chemical, mechanical and physical - such as density, tensile strength, hardness, colour, tarnish resistance and precious metal content. It may also be necessary to ensure that the jewellery and the manufacturing processes meet legislative requirements, for example release of toxic metals such as nickel, cadmium, silicon and lead. It is a balance to ensure that the jewellery meets the needs of being ‘fit-for-purpose’ whilst keeping costs to a minimum. This cost minimisation may be simply achieved, for example, by reducing thickness or by reducing the weight of metal in the piece or by altering the alloy composition to reduce density and hence weight. Often, it is achieved in more complex ways, for example by selection of process route, type of equipment and by choice of alloy to suit the process, improve yield and reduce finishing requirements and so on.

Sometimes we measure the properties ourselves on the actual materials we will use but often we rely on generic data from external sources such as alloy suppliers and the scientific literature. How much reliance can we place on the values we obtain in property testing? This, in itself poses further questions: Are we measuring the property correctly? Are we measuring the right properties? The bigger question is what can property measurements tell us in terms of their applicability to the manufacturing situation or customer service performance? We need to understand not just the values we measure but the limitations of the measuring technique too.

The purpose of this paper is to consider the measurement of the properties of jewellery alloys and consumable materials involved in the manufacture of jewellery and of actual finished jewellery. It reviews some of the important properties, how they are measured and what they tell us in terms of their relevance to jewellery manufacture and service performance. Mechanical, physical and chemical properties are considered. The importance of making measurements in accord with international standards and the need for industry-agreed standards for testing of actual finished jewellery is emphasised.

BASIC MEASUREMENTS

It is appropriate to start with basic measurements, such as weight, volume and temperature[1,2]. If we don't get these correct, we are handicapping ourselves from the outset. We have a tendency to believe what is printed on the label or what the 'black box' display says. If the electronic display tells us the temperature of the furnace is, say, 417°C, that is not necessarily the value we actually have where we want to measure for several possible reasons. This problem has been highlighted several times at jewellery technology symposia with respect to flasks in burn-out furnaces used in investment casting[4]. If the packet of investment powder has a label saying the contents are 5 kg, can we assume that is accurate? If a gold bullion bar is stamped as being 995 purity, are we sure that is accurate too? Is it exactly 99.50% gold or possible a little higher or lower? That knowledge could be vital if we wish to make jewellery that conforms to hallmarking regulations.

We need to check such measurements ourselves. We also need to ensure that the measurements we make are done with calibrated instruments or machines to recognised standards and procedures. From all this stems a basic lesson to be learned: do not believe values unconditionally. It is important to make checks to give us confidence and to recognise limitations.

MECHANICAL PROPERTIES

When we talk of mechanical properties, we often refer to just tensile strength or hardness and ductility, but we are usually interested in strength and deformability under a range of conditions, such as bending, cupping and deep drawing. Are tensile measurement data valid under such conditions? What about data from alloy manufacturers or from the literature, such as the Gold Alloy data published in *Gold Technology* journal[4]?

1. Tensile Testing

The measurements we use most often are those derived from simple tensile testing. If we obtain data from our alloy suppliers or from the literature, how is it measured and what reliance can we place on it? Figure 1 shows a typical tensile test result schematically. From this, we can determine several parameters of interest: yield strength (often taken at 0.2% strain, also called proof stress or flow stress), work hardening rate, tensile strength (formerly known as Ultimate tensile strength), modulus of elasticity (Young's modulus) and elongation as a measure of ductility. If we determine the area under the curve, we can get a measure of fracture toughness too.

We should also be aware that temperature will affect the property values we measure. As a general rule, strength and hardness decrease with increasing temperature. If we are hot working a material, the tensile data measured at room temperature are not valid. For the precious metals in jewellery, we normally measure properties at ambient temperature.

However, there are a number of issues we need to be aware of with regard to tensile test data. Firstly, some basic points:

1. Tensile testing should be done according to national /international standards, e.g. ASTM standards. This involves test sample size, geometry and quality of surface finish and rate of loading the specimen. The way the test specimen is gripped by the machine is also important. Non-aligned rigid grips may impart some bending stress.

2. Most tensile testing machines need to be calibrated before use
3. There are ‘hard’ and ‘soft’ machines, meaning how much the machine itself deforms under load. Soft machines will deform more and may give a distorted value of elongation or strain, unless it is measured directly on the gauge length of the test piece. They will also give a distorted value of Young’s modulus.

In addition, there are other aspects to be aware of.

4. The values obtained will depend on the material form. Flat test pieces cut from thin sheet will give different values from test pieces machined from thick solid material or from thin wire test specimens. One major reason why is grain orientation effects, discussed in the paragraph below. Grain size and grain shape also have an effect.
5. Cast specimens will give different results from wrought test specimens. This is due to both differences in microstructure and to the presence of defects such as porosity. Thus more scatter in results will be observed in cast test pieces.
6. Surface finish of the test piece will affect results. Rougher surfaces will give lower values than well polished surfaces. Where rectangular specimens are cut or machined from sheet, the sharpness of the edges will also impact the results obtained.
7. The rate at which load is applied will affect the result. Applying load slowly will give a lower result to that obtained by applying load suddenly. This is the strain rate effect, where the flow stress, σ is defined :

$$\sigma = \dot{\varepsilon}^m$$

where $\dot{\varepsilon}$ is the strain rate and m is the strain rate sensitivity, typically with a value of 0.15 to 0.25

8. There is inevitably a variation in results from test piece to test piece, even if they are nominally identical and from the same batch of material. This is due to several factors such as material defects within the test piece, to surface condition (scratches, etc) and alignment in the machine grips. Normally, we prefer to test at least 3 test pieces and average the results.

The values of tensile data we obtain from tensile tests, therefore, depend on several factors. Additionally, we can expect them to vary from the values pertaining to the actual situation in manufacture or in use as jewellery, where strain conditions vary from the uniaxial situation of simple tension. Thus, these values must be taken as approximate to the real situation, not as absolute values. The manufacture of chain from wire by machine is done at a high strain rate so the flow stress in practice will tend to be a little higher than the value obtained in a tensile test, as discussed by Wright & Corti[5] in 1997.

The tensile test curve also allows us to calculate the modulus of elasticity (or Young’s Modulus). The initial straight line section up to the yield point is the region of elastic deformation. In this part of the test, removing the stress at any point results in the specimen returning to its original length. The slope of the line, i.e. stress divided by the strain, is a constant which is the modulus. This is an important property and indicates the stiffness of the material. Ideally, springs should have a high value of modulus. In setting gemstones, ‘springback’ of claws can be a problem and is due to the elastic deformation within the claw being relieved on removal of the force being used to bend it around the stone.

Microstructural texture: I indicated earlier that there are grain orientation effects that cause differences in tensile data values and it is worth discussing this a little more. As we are aware, most metals and alloys are polycrystalline, comprising lots of crystals (or grains, as we metallurgists call them), each oriented in different directions at random. When metals and alloys are deformed, the crystal planes of each grain slide over each other to accommodate the imposed shape change. This slip is facilitated by crystal lattice defects called dislocations. We should note that certain crystal planes within the lattice are more close-packed with atoms and spaced more widely from the adjacent planes than others and so are preferred planes within the crystal lattice for slip to occur. As a consequence, as deformation proceeds, there is a tendency for the crystal orientations to rotate towards the lowest energy configuration for slip of the planes to occur under the imposed stress. The spectrum of orientation of grains becomes non-random. A 'preferred orientation' or 'crystal texture' is developed, Figure 2, so that the tensile properties are no longer isotropic. The values will vary with direction of the material relative to the imposed stress and direction of deformation. The preferred orientation or texture developed will depend on the deformation mode (and crystal lattice type). We get different textures from rolling, for example, than from deep drawing or forging, because they involve different stress systems.

The texture developed can be manipulated by the processing imposed. In cold rolling, we can either roll in one direction entirely or cross-roll with alternate passes. The latter will give less anisotropy than straight rolling. When such materials are annealed after deformation, a different texture results from the recrystallisation, but its effects still impact any subsequent deformation. A good example of texture effects in deformation is seen in deep drawing of cups from thin sheet, where 'ears' form at the top of the cup, Figure 3.

When we take tensile data from the literature, the nature of the material tested should be taken into account. Much of the gold alloy data found in *Gold Technology*journal, for example, was obtained from testing of wires. Wire drawing can cause a significant texture to develop that will differ from that found in rolled sheet and hence different values of tensile data will be measured. These differences will be small but significant.

Needless to say, tensile data are useful and serve as a guide, if we remember they are not *absolute* values. As with hardness, discussed in the next section, tensile measurements can be useful in understanding what the metallurgical condition of a material is and how it may behave in subsequent processing by deformation.

2. Hardness

The measurement of hardness has been discussed at length at recent technology symposia[6-8] and so will not be discussed here in detail. However, measurements should be done according to the standards for hardness tests for the values to be meaningful and an average of several measurements taken, as there can be considerable scatter in individual measurements due to local microstructure and texture effects. Hardness is not an absolute property but a comparative one. A difference of a few hardness units between two materials should not be seen as significant.

The hardness value of a material is a good guide to its metallurgical condition, i.e. whether it is in the as-cast or annealed state or work-hardened from working or in the age-hardened condition. If something goes wrong in manufacture or in service with the customer, measuring the hardness is often the first test performed to try & understand what the cause might be. It is a simple and quick test to do. As discussed previously, hardness is a good indication of wear and scratch resistance of a material. Soft materials wear and scratch more readily. For jewellery, we ideally want an alloy with a high hardness if we want it to resist wear and distortion, but it will be more difficult to mechanically work in fabrication. For a stamping die, we need a die steel with a very high hardness, to prevent deformation under load, which causes distortion of the shape and dimensions we want, and to minimize wear.

3. Deformation of sheet metal

The tensile and ductility data obtained from uniaxial tensile tests do not necessarily give a good indication of how a metal will behave in working processes, such as rolling or sheet metal forming. There are other mechanical tests that are more useful, for example cupping and bending tests, to determine anisotropy in drawing and malleability in sheet metal forming. The stress system in such processing can be complex causing non-uniform deformation. Getting the processing parameters optimised can be considerably aided by such measurements.

There are tests that can better simulate the conditions of deformation, such as the Erichsen cupping test (ASTM standard E 643-84), Figure 4. In this test, an annealed sheet sample is clamped between a die and blankholder using a standard clamping load. A spherical standard punch is pushed into the sheet so that is stretched over the punch and forms a dome or cup shape. The deformation is continued until the sheet cracks and ruptures. At this point, the depth of the cup formed is recorded as the Erichsen cupping value (in millimetres). This value serves as a guide only. In the deep drawing of cups, for example, the clamping pressure is lower and the sheet metal can slide inwards as deformation proceeds. There is little stretching of the sheet, more a change of shape. Stamping of sheet is different again, involving some stretching and some deep drawing.

4. Other mechanical tests

Fracture toughness: We tend not to be too interested in fracture toughness testing as most precious metal alloys used in jewellery have good toughness and so poor toughness is not usually a problem in our industry. Measurement of fracture toughness involves complex specimen preparation and test techniques.That said, Fischer-Buehner[9] discussed an interesting development of a simple test to examine the comparative fracture resistance of brittle, colored intermetallic alloys in 2009. Its use in developing less brittle materials was critical and avoided the need for much more sophisticated and expensive test methods.

Fatigue: One property we do not tend to measure in the precious metal jewelry industry is fatigue strength. Fatigue is where a material is subject to alternating stresses below its yield strength and is measured in terms of the number of cycles before fracture for a given level of alternating stress. Typically, for many alloys, there is a stress below which failure does not occur – known as the fatigue strength. The value of the fatigue strength can be typically half the tensile strength for many alloys. However, fatigue can be a significant problem in spring components in jewellery, for example in catches and in wire bonds in electronics. There is virtually no published literature on the fatigue behaviour of jewellery alloys. This makes development of improved spring alloys more difficult.

Wear and scratch resistance: The resistance to scratching and wear is usually measured by laboratory tests that attempt to simulate the real situation. Typically, abrasive wear is measured by rubbing of material under constant load against a standard hard material. This may involve continuous movement in one direction, such as Pin-on-Disk methods, or by reciprocating movement, whereby the test sample moves back and forth over the test substrate material. Another technique involves tumbling with polishing media in a tumbling barrel, which involves more random movement and loading. Generally, such wear is measured by loss in weight of the test sample. Real life tests have also been used, whereby actual jewellery, such as rings, are worn by several individuals and average weight loss determined for each test alloy. This recognizes that different individuals lead differing lifestyles and so wear may vary depending on whether the individual is 'soft' or 'hard' in terms of lifestyle. In one case, a research scientist regularly weighed his 18ct gold wedding ring over a period of one year to determine the rate of wear and how his lifestyle at different periods may affect the wear rate[33]. He found abrasive wear was dominant (wear from corrosion by sweat was insignificant) and did vary according to type of activity. But overall, the wear rate stayed relatively constant over the period, Figure 5. As noted previously, wear rates generally improve with increased hardness of material. Soft materials wear faster.

PHYSICAL PROPERTIES

1. Density

The density (or specific gravity) of jewellery alloys is a useful property to know and its value can vary considerably, depending on chemical composition. Knowledge of an alloy's density helps us determine how much alloy we need to melt for investment casting of wax trees, for example, and, indeed, what the capacity of a melting crucible will be for different alloys. Knowledge of the density of a piece of jewellery serves to tell us what the likely caratage of a karat gold alloy is or whether the white metal is silver, palladium or platinum based. Much of the time, we rely on alloy manufacturer's data for these values, but occasionally we need to measure this property for ourselves.

If we know the alloy composition reasonably well, we can calculate it's density by a 'law of mixtures' approach with moderate accuracy:

$$100/D = W_A/D_A + W_B/D_B + W_C/D_C + \ldots$$

Where D is alloy density, W_A is weight of metal A in %, W_B is weight of metal B in %, W_C the weight of metal C, etc and D_A, D_B, D_C etc are densities of metal A, metal B, metal C, etc respectively.

The preferred way of measuring the density of a piece of alloy (or any solid material such as a gemstone) is by weighing it in air and in a liquid, using Archimedes Principle. It is a simple calculation to determine an average density of the piece we measure. Whilst we can measure weights accurately, we must be aware of the limitations of the technique. If we have any porosity or inclusions in the sample, we will get a false (low) value. We also have to ensure there is no air trapped on the sample when immersed in the liquid.

There are some who believe you can use density measurement to determine the chemical composition of carat gold alloys. That is true only for binary alloys. For most commercial alloys, these comprise at least 3 or more metals and different alloys can have the same density value; so, density cannot be used to determine composition[10].

2. Colour

Colour is an important property in jewellery, particularly for carat golds. The human eye can detect small differences in colour and so, for example, solder lines can be clearly seen in some instances where the solder colour differs slightly from the parent alloys. As we should be aware, colour can be measured quantitatively, and the CIELab system of measurement is now standard in our industry[11]. This measures 3 components of colour: a*, b* and L where a* is the red – green component, b* is the yellow-blue component and L is brightness (from black to white), Figure 6. We can display the values of these 3 co-ordinates graphically and so can compare the colour of different alloys in an easy-to-understand way. More importantly, we can send the values measured across the world and the recipient of the data will know exactly what colour we need.

With modern spectrophotometers, measuring colour is quite easy and we can quickly obtain the colour co-ordinates of the alloy sample under test. However, we need to be aware that the surface finish of the sample needs to be smooth and consistent and that the nature of the incident light plays a significant role in the colour we see. Change the light source and the colour of a sample will appear different and measure differently in terms of the values of the colour co-ordinates. This effect is known as *metamerism.* It can be a problem in real life, for example displaying goods in retail shops, where lighting can vary considerably. Colour co-ordinated items, e.g. ladies fashion, can appear non-matching under different lighting conditions. Thus, it is important that colour measurements are carried out under standard lighting conditions and the standard for our industry is known as Illuminant C (Illuminant D65 is a close approximation). For meaningful values, measurement must be performed under industry standard test conditions.

Such colour measurements are invaluable in our industry as it enables us to define precisely what colour we require to suppliers and customers. What do we mean by a standard 3N yellow 18ct gold or 5N red gold in terms of colour? We can define these precisely in terms of their colour co-ordinate values.

The relevance of colour measurement in jewellery alloys came to the fore back in 2003 with regard to defining the colour of white gold. The issue was “What is a white gold?” as up to that time there was no agreed definition of ‘white’ in the industry. When did a white colour stop being white and become a pale yellow? Where was the boundary? As much white gold jewellery was traditionally (& legally) electroplated with rhodium to hide an imperfect whiteness, this was not a trivial question, as rhodium-plated yellow gold being called white would constitute deception if not fraud.

As many of you know, the MJSA and World Gold Council set up an industry task force to define white[12] and much of the technical groundwork was carried out in the UK[13]. A simple colour parameter, the *Yellowness Index: D1925*, was adopted to define white, where a value of 32 or less is accepted as white. Within this, 3 grades of white were defined, premium, standard and off-white. These boundaries can be interpreted in terms of the CIELab co-ordinates (see fig 5 in reference 12, for example). We note that many alloy suppliers in the USA, Europe and elsewhere now describe their white gold alloys in terms of these 3 grades. The platinum and palladium jewellery industry also use this measurement approach to assert that their products are whiter, as do the rhodium plating salt manufacturers. At each jewellery show I visit, I see new rhodium plating products described as being ‘even whiter’, based on colour measurement data.

3. Thermal properties

I include properties such as thermal expansion, specific heat, thermal conductivity and thermal diffusivity in this section. Whilst most jewellers would not consider them of direct interest, they are properties of both the alloys and some of the consumables that have importance in some of the manufacturing processes we use. John Wright has discussed why platinum is easier to laser weld than gold and silver in terms of their differing thermal diffusivities[5,14]. Values vary from 1.7 – 1.15 for silver and gold compared to only 0.25 – 0.3 for platinum. Thermal diffusivity is defined as the thermal conductivity divided by (specific heat x density). So density has a minor role to play here too.

For normal jewellery manufacture, the thermal properties of the alloys tend not to be of interest, apart from the effect they have on joining processes such as welding, where heat flow away from the joint dictates the heat power we need to apply. Heat flow through the mould material is also important in the progress of solidification in casting (my Basic Metallurgy presentation[15] demonstrates how it influences the alloy macrostructure that develops).

Heat flow and heat capacity are also important in investment casting and the use of computer simulation modelling has highlighted the need to measure such physical properties on actual materials[16], both the alloys being cast and the ceramic investment mould, as such data do not exist in the literature.

Thermal expansion of alloys, mould rubbers, waxes/resins and investment mould materials is also important in determining finished dimensions of castings and whether defective castings will result due to thermal stresses arising during solidification. Teresa Freyé[17] and Andy Andrews[18] have discussed the influence of thermal expansion of RP resins and investment moulds at recent symposia in achieving good castings. In both studies, measurements of expansion were undertaken to determine the cause of poor casting quality. The thermal expansion characteristics of gypsum-based investments have also been highlighted in several presentations[19] as the basis for determining the burn-out cycle of moulds.

So we can conclude that thermal properties are important, even if we do not consciously utilise them in the normal manufacture of jewellery.

CHEMICAL PROPERTIES

There are several chemical properties that we take advantage of when making jewellery. Clearly, the resistance of jewellery metals to acids is important in cleaning dirty, oxidised materials such as scrap for recycling and their solubility is important in the processes used in refining them. However, the properties we particularly consider in relation to jewellery manufacture and customer use is corrosion and tarnishing behaviour, especially of silver and gold alloys. Metal release, such as nickel from white gold, is also a corrosion phenomenon and is relevant in today's world where health and safety aspects now assume some importance. As has been noted previously, tarnishing is a form of corrosion. Stress corrosion cracking of carat golds also requires a corrosive environment.

To determine corrosion/ tarnishing and metal release behaviour, we employ accelerated testing in the laboratory to simulate the real situation and laboratory tests are also employed to test for susceptibility to stress corrosion cracking. There have been several presentations on tarnish testing at previous symposia, of which only a few are referenced here[20-23]. These have all demonstrated that simulated tarnish tests do not – and cannot- perfectly simulate the real situation. The various tests give different results and these, in turn, often differ from reality. One alloy can be shown to be superior to another in one test but inferior to it in a different test. At best, such test data can only be a guide to real behaviour. The same is true for metal release testing[24-26]. But we still need to undertake such tests and obtain comparative data, particularly when there is a need to meet legislative requirements such as the nickel release legislation in Europe. Here, the test methodology is specified and the value of metal release obtained must meet the limits defined. But the values do not necessarily relate to those pertaining during wearing of the jewellery by consumers, neither do they guarantee that alloys that meet the test criteria will prevent consumers who are nickel-sensitive from suffering skin rash!

WHAT USE IS THE MEASUREMENT OF PROPERTIES?

Some of my remarks in the earlier sections have shown the importance of certain properties in the manufacture of jewellery as well as determining the service performance of it when worn by the consumer. We may not consciously measure such properties on a day-to-day basis but we certainly need to be aware of their values and the implications of the values, if we want to produce good, sound jewellery that will be fit for purpose. Knowledge of them helps us to select the correct alloy or consumable material or process conditions for the manufacturing processes and for the end application. They also ensure that we produce efficiently and cost-effectively. Good control of properties within tight tolerances will lead to better consistency of production too. I have also emphasised the importance of carrying out such measurements according to industry testing standards, both national and international, so that the values we measure have validity and are comparable. We have also noted that these measured values may have limitations and so need to be interpreted and applied with some care and, in some cases, with a degree of caution.

I started with the measurement of basic properties such as volume, weight and temperature and remarked that we ought to be able to do such measurements properly and accurately. As an example, I will highlight their importance in investment casting.

Firstly, the mixing of investment powder: The manufacturers recommend the amount of water and powder to mix to ensure we get a good investment mould with adequate strength and good surface. Both the volume of water and the weight of powder should be measured accurately; otherwise, the liquid mixture may not yield a good investment mould. Carter has demonstrated [27] the effects of altering the powder/water ratio on a number of important investment properties such as pour time, fluidity, green strength and fired strength. Small variations can have a significant effect. Carter has also shown that water temperature is important too[28].

Temperature is important in other parts of the investment casting process: the burn-out of the mould must follow a defined cycle with a limit on the maximum attained and both mould and molten metal temperatures are important in the casting of metal into the mould for minimising defects, especially porosity, and for getting good mould fill and surface quality. Accuracy of temperature measurement is vital for achieving quality and consistency of castings.

TESTING OF FINISHED JEWELLERY

How do we know that a piece of jewellery that we have produced meets legislative requirements and is 'fit-for-purpose' with adequate scratch and wear resistance, sufficient mechanical strength and ductility, able to withstand the knocks and other stresses imposed when being worn. Will the springs in the catches work for a lengthy period or will they fail prematurely? Will the ring withstand knocks and rubbing against adjacent rings or will it distort? Will the locket or pendant tarnish prematurely? Does it meet the EC regulations on nickel release? Will it crack from stress corrosion cracking? These and many other factors are relevant to defining the item as being fit-for-purpose.

We can only know the answers to these questions by testing certain properties. Some of these are materials related but others require measurements on actual pieces of jewellery. In my presentation[29] at the 1998Santa Fe Symposium, entitled, "Quality in Jewelry Manufacturing – Beyond 2000", I discussed quality in terms of service performance. How well a piece of jewellery will perform when worn by the consumer is difficult to ascertain as the quality in terms of performance in service is not readily visible. It may contain manufacturing defects or design flaws. Some factors are use/time-dependent and others are manufacture-dependent. Wear is one factor that is time dependent whilst loose gemstones or chain failure may be due to manufacturing defects.

These aspects can only be ascertained by product testing in the quality assurance laboratory. Many manufacturers have developed their own special in-house tests to measure such factors. Agarwal and Raykhtsaum have discussed testing of product, especially chain, and the tests developed at Leach & Garner[30,31] in 1995 and 1997. More recently, Auberson has reported[32] on several tests developed at Cartier to measure service performance, including a novel 'handbag' test, Figure 7, which highlights factors such as manufacturing defects as well as impact damage and scratch and wear resistance. Other manufacturers have also developed in-house tests but many are confidential and not publicised.

Admirable as these tests are, the point I wish to reiterate here is that the results of such tests are not comparable between manufacturers as each has their own test method and procedures. I made the point in 1998 that the industry as a whole needs to develop and agree standard test methods and procedures for jewellery products that all should use[29]. I am not aware that any progress has been made to date to achieve industry-wide standardised test methods. Who will pick up the baton and drive this forward? The benefits to the industry should be obvious! Without measurements of such properties, no manufacturer can be certain their products meet legislative requirements and are fit-for-purpose! If involved in litigation over quality issues, how can the manufacturer be sure his in-house quality assessment tests would be accepted in court, if they are not industry agreed standard methods?

CONCLUSIONS

1. I have attempted to demonstrate that knowledge of many properties of jewellery materials and consumables are important, if not essential, to jewellers in the manufacture and subsequent use of precious metal jewellery.
2. We should note that the values obtained from testing may not be absolute values that can be applied directly to the manufacturing or service situation. Values of properties need to be interpreted and applied with care and caution.
3. Measurements need to be made according to national and international test standards, so that measured values are comparable and valid. We need to understand the limitations of the test method and the resulting values obtained.
4. Results of measurements from accelerated laboratory tests may not be directly comparable to the real situation in practice. They can be a guide at best. Often, several types of laboratory test need to be made to obtain a more meaningful assessment of likely performance in practice.
5. Jewellery needs to be made 'fit-for-purpose'. To ascertain this, testing of actual finished jewellery pieces is essential. Whilst several manufacturers have developed suitable in-house test methods, there is no agreed industry-wide standard test methods; this limits comparability of test results. The industry needs to address this deficiency!

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