

Engineering approach to gold jewellery manufacture

DR. JOHN C. WRIGHT, *Consultant, Solibull, UK and*
DR. CHRISTOPHER CORTI, *World Gold Council, London*

Abstract

Performance of precious metal alloys can be usefully compared by applying engineering design theory and heat-flow properties to small-scale jewellery. The mechanical and physical properties of carat golds determine the possible processing routes and their limitations in manufacturing gold jewellery. Property data of some carat gold alloys are published, but seldom related to jewellery manufacture through the application of engineering design principles. This paper demonstrates how alloy properties impact on some important processes used in the manufacture of gold jewellery. Examples include stone setting, ring band design, chain-making, and localised heating for annealing or joining. This type of design approach requires a more analytical interpretation of alloy properties data than has been traditionally employed. The influence of the alloy composition and of cold working on the limitations imposed on design and on processing is illustrated. New developments in quality controlled jewellery making, such as powder metallurgy, metal injection moulding and electro-forming are more likely to result from a technological approach than a traditional approach.

Introduction

Few, if any, courses on jewellery design and manufacture start with a product design specification, detail a materials specification and then optimise the production-ability, which is the usual procedure for engineering components. A critical engineering design integrates the mechanical design (e.g. stress bearing ability) with the materials' mechanical, physical and chemical properties and with the requirements of the production process [see box], but the whole has to operate under an acceptable economic

The Engineers Approach to Design and Production

An Engineering Designer:-

- Calculates (elastic) stress distribution
- Chooses a safety factor
- Fixes cross-sectional area and shape
- Decides on material and condition
- Selects production processes to enhance design and productivity

A Production Engineer:-

- Selects mass diverging processes (cutting processes such as lathe, grinding, laser, electrical discharge and electro-chemical)
- And/or mass conserving processes (such as casting, drawing, extrusion, forging, injection forming, rolling and spinning)
- And/or mass converging processes (such as adhesive bonding, brazing, diffusion bonding, soldering, welding and mechanical fastening (*screws, nuts and bolts, rivets, etc*))

The Jeweller's Approach to Design and Production

Most jewellery designers:-

- Empathise with another designer, catalogue line or an historical style
- Choose a price range
- Select a material mostly on price value
- Select a process according to batch size

Some jewellery designers:-

- Master a particular process (investment casting, electroforming, stamping)
- Develop designs to make good use of that process

Very few jewellery designers:-

- Are concerned primarily with:
 - Component strength and related state of materials
 - Easing production by adjusting state of materials
 - Computers to 'draw' and 'control' production of the shape

and environmental framework. Most of the jewellery industry takes a more traditional view, uses a narrow range of processes and materials and favours one-off, few-off, and batch processing, rather than mass production. There are a few large-scale operations such as bullion production, refining of scrap, chain making, but the approach to design and production of most jewellery is quite different from general engineering [see box].

The market perception of what

constitutes precious metals, and the consumer protection rules that follow in most countries, are further constraints. This jewellery industry shape has some far reaching consequences for costs of production, skills required and training, and the attractiveness or otherwise of costly research and development of materials and methods. Technical developments in the jewellery industry have not been completely inhibited but the

tendency is to adapt and modify alloys and processes developed for more engineering oriented applications. Some jewellery design calculations cannot be completed satisfactorily because data is either unavailable or inaccurate. While this applies initially to “manual” calculations, it also inhibits computer aided design (CAD) and production (CAD/CAP) in the jewellery industry.

In general engineering, computers:

- enable finite element stress/strain and heat flow analysis
- automate shape drafting
- create prototypes
- predict fluid flow into moulds
- improve quality
- raise productivity
- decrease time to market
- reduce costs.

Jewellery related CAD applications are known. Stuart Devlin uses a 3D modelling system for a range of his work (1), but this does not appear to need stress/strain analysis. Mechanical design theory and heat flow theory can be applied on a small scale to design and influence production strategy for a line of jewellery. We can select a design formula, or model, input mechanical or thermal properties and size data, and solve the equation to give the loads, strains or heat flows that are likely to result in practice. This paper explores a few examples of relationships between alloy properties and jewellery design and production. Some sound traditional craft solutions are explained in terms of the most important properties that apply and the difficulty of developing ideal properties, particularly in high carat alloys, is illustrated.

We have tried to add a more quantitative view to the approach made typically by the Santalás (2). If a mechanical engineer’s design view and a production engineer’s process optimisation view is applied to jewellery design and production, it is just possible that some thought provoking ideas will arise. However, some new jewellery technology, such as High-Strength Pure Gold, electro-forming, high speed chain-making and powder metallurgy, have been developed towards jewellery from general engineering, often not on precious metals originally. It is very likely that jewellery designers adopting an engineering approach

will have to take a more critical view of mechanical properties and it will be necessary to standardise testing procedures and entries into precious metals databases.

Applying mechanical theory to jewellery

Most engineering design does not fundamentally depend on the actual size of the component but some assumptions have to be reviewed carefully when the scale is reduced significantly. For instance, most simple design theory assumes that materials are isotropic, but on a microscopic scale, most crystallographic materials show anisotropy in some properties. The effect of stress raisers in causing failure more prematurely than simple smooth design suggests is also very important. A 0.25 mm deep scratch in an oil-rig leg is unlikely to be important but it is obviously much more important in the surface of a 1 mm diameter earring post. However, provided we consider **significant** differences in size and between materials, there is no reason why we should not apply mechanical design theory directly to jewellery. This paper **compares** jewellery materials in a

strength-design context. Typical materials data have been used to calculate the likely loads that a piece of jewellery can withstand. The calculations produce a practical load result but, having established a realistic answer, some of the calculations are plotted as general trends. The analysis starts with elastic to plastic bending of a beam. This simulates what happens when setting a claw or prong against a stone. Then a ring shank is considered as a pre-bent beam. The properties that control the ease of forming and joining chain-links are almost the opposite to those required for high load bearing chains. Does this matter in jewellery, or should we compromise or alter the properties after chain making? This is considered in a later part of the paper. We also look at heat flow.

Table 1 summarises **representative** mechanical and physical properties for the jewellery alloys cited. Most properties are very dependent on the composition and production history of the component and on the method of testing, so it is virtually impossible to compile a strictly comparable set of properties for a wide range of alloys. To illustrate the argument, a narrow range of fine and carat golds is used;

Table 1. Representative properties for typical jewellery alloys

Gold Alloy Type	Cold work %	E GPa	Yield point N/mm ²	Tensile Strength N/mm ²	Elongation %	Hardness Hv
24ct Y	0	80	70	122	45	25
	20	80	144	160	15	46
	40	80	181	195	5	54
	60	80	205	216	4	58
22ct Y	0	92	110	280	35	65
	20	92	265	365	10	100
	40	92	365	450	2	135
21ct Y	0	94	212	363	37	100
	30	94	559	580	0.7	176
	70	94	638	688	0.6	194
18ct R	0	96	236	474	45	165
	20	96	550	700	7	200
	75	96	800	950	1.5	240
14ct Y	0	102	328	535	34	135
14ct W	0			660	30-45	85-150
9ct Y	0			545	25	115
9ct W	0			686	35-40	45-160

R - red Y - yellow W - white

starting with 24 carat wrought gold and progressing with increasing copper/silver ratio so that the 21 carat example is pink-yellow and the 18 carat is reddish yellow. It is surprisingly difficult to assemble absolutely compatible data at present. For instance, there are several references to the properties of electro-formed golds being “better” than the equivalent wrought form, but it is not always clear what constitutes “better” (3). Comparable values for Young’s modulus, E, are particularly difficult to obtain because the value is often affected by the method of testing.

There is an obvious tendency to test **miniature** precious metal test-pieces on small scale tensile test machines. This combination is not ideal for separating the elastic properties of the test-piece from the elastic response of the machine although it gives reasonable tensile strength and elongation results. Unfortunately, these are the least important properties from an elastic to plastic strain point of view. Obtaining Young’s modulus by vibration and damping capacity testing methods may give more comparable results. When we compare fine golds, we need to note the significant effect of impurities on some properties with finenesses varying from 980 to 999.9 which, in some countries, would all be classed as 24 carat! Finally, strain rate and temperature can have a significant effect on the measured properties, particularly on high carat golds.

Before considering some jewellery applications, it would be useful to define certain terms in the context of the most familiar mechanical test, the tensile test. Figure 1 shows a schematic tensile test curve, the parts of which are:-

- OE is elastic deformation. The slope is exaggerated but is numerically equivalent to Young’s

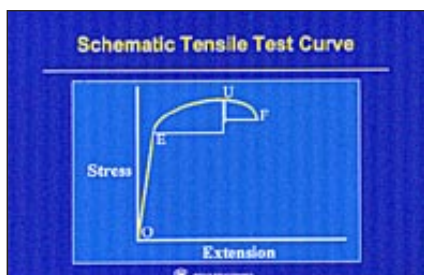


Figure 1 - Schematic tensile test curve



Figure 2 - Forces involved in bending a prong around a gemstone (schematic)

Modulus.

- E is the elastic limit or limit of proportionality and marks onset of plastic deformation.
- EUF is almost entirely plastic deformation (but hides some elastic deformation too).
- U is the (ultimate) tensile strength, at the highest **load** experienced by the tensile test machine.
- fracture takes place at an apparently lower **load**. As we shall see later, fracture does take place at the highest **stress** experienced by the test-piece but the cross-section has usually decreased significantly by this time.

Setting prongs - considered as beams bent beyond their elastic limit

The cross-section of prongs for setting gemstones into precious metal findings varies: round, rectangular, roughly triangular. The moment of inertia varies with the cross-section, but we can make the initial comparison of various precious metals using a simple rectangular section and then modify the argument as necessary. If we keep the comparison between materials on the same basis, we do not need to know the applied stresses precisely; the order of comparisons will still be valid. Let us assume that claw bending is similar to a beam supported at both ends and the force of the girdle is applied in the opposite direction in the middle of the beam as shown in Figure 2.

The formula for the **elastic** deflection of this type of beam is: -

$$\Delta = FL^3/48EI$$

where F is the force for maximum **elastic** deflection Δ , at the elastic limit and the maximum bending moment $M = FL/4$. E is Young’s modulus. The second moment of inertia, I, for a rectangular section

beam is $bd^3/12$. Length, breadth and depth (or thickness) of the beam, L, b, d, are listed in millimetres in this paper but in most engineering design they enter into the calculations as metres. The two parameters E and I are in the denominator and so increasing either or both will decrease the amount of elastic deformation. In other words, the component will become stiffer.

It is unusual to consider beams as small as jewellery prongs but suppose we use dimensions 20 mm long (L) by 2 mm (b) by 1 mm (d) rectangular section. This is a large prong, but it would only make a swivel ring or chain link rather than a finger ring, so it is a reasonable compromise between the two applications.

The graph, Figure 3, compares the force necessary to bend gold jewellery **beams** of this size, **elastically**. The top line is for 24 ct gold and the bottom line is for 14 ct gold with the other caratages (lines not drawn) fitting logically in between. The elastic slope is an indication of the stiffness of the alloy. Note that 14 ct gold is about 25% stiffer than 24 ct gold. The softer alloys would not sustain purely elastic deformation within the range of force shown in figure 3; they would yield. The limit of elasticity or “yield” (we normally use 0.2% proof stress) marks the stress that has to be exceeded before a permanent bend can be made in the prong.

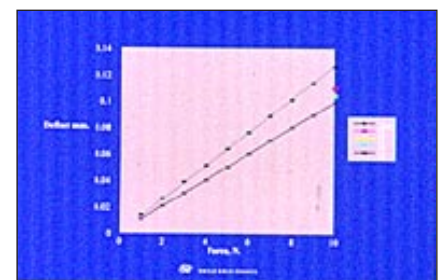


Figure 3 - Force necessary to bend a beam, 20mm x 2mm x 1mm, elastically showing the influence of composition on the modulus of elasticity.

In Figures 4 and 5, the graphs show how alloying (decreasing caratage/gold content) changes the slope of the elastic part of the curve a little but, more significantly, increases the elastic limit. This is because Young's modulus is not changed as much by alloying as is the limit of elasticity. Alloying increases the work-hardening characteristics of a pure metal quite differently depending on the combinations and amounts of the alloying elements. The slope of the plastic part of the curves in Figure 4 is not meant to be accurate. In practice, none of the claws would change from elastic to plastic type of bending as sharply as the figure suggests; there would be a mixture of elastic and plastic deformation over the cross-section of the claw as the limit of elasticity is reached first at the outer surface of the bend. The interdependent effects of alloying and cold work on yielding are shown more clearly in Figure 5. The rate of work-hardening of the prong is also important because it determines the stress needed to straighten the prong again. In other words, a high work-hardening rate raises the yield stress and makes it more difficult to open the setting again, so it holds the stone more firmly. That argument is better illustrated later.

Small changes in the dimensions of the prong can have a bigger effect than changes in either cold work or alloy content. In Figure 6, if the relatively wide (2 mm), thin (1 mm) prong is changed to narrow (1 mm) and deep (2 mm) by turning it sideways, the second moment of inertia and the force to yield is increased by a factor of four. In doing this, we may be making the prong a more obvious part of the overall design. The revised shape favours notched prongs which receive the

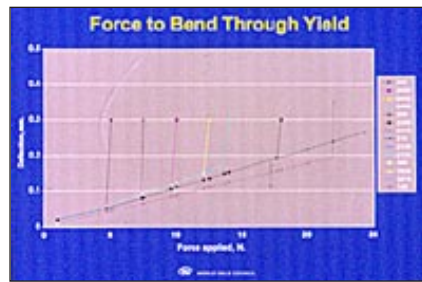


Figure 4 - Force necessary to bend a beam through yield, showing the influence of composition and cold work; the first figure is the caratage and the second figure is the % cold work, e.g. 24/40 = 24ct, 40% cold worked.

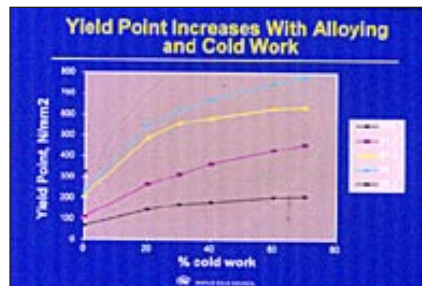


Figure 5 - Effect of composition and prior cold work on the yield point

girdle of the stone by springing it into place rather than by bending the prongs over the girdle. This is also the principle on which the tension ring design is based and where the split ring acts as a pair of prongs.

Two design points that closely relate to mechanical properties are illustrated in the Figure 7 (a-c). This shows 2 examples of cast 14 ct gold pendants with *cast* safety catches produced by Anthony Eccles. Fig. 7(a) shows the separate components; Fig. 7(b) shows the safety catches hooked onto the pendant parts and Fig. 7(c) shows the safety catches pushed into the locked position. Selecting the alloy composition, its mechanical state and then effecting a

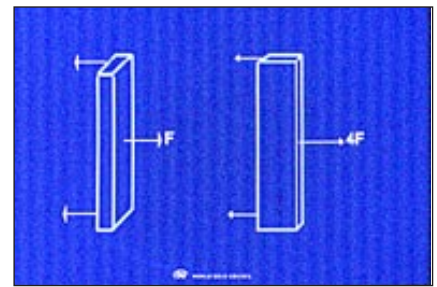


Figure 6 - Effect of beam orientation on the force to yield

compromise between a spring cross-section that is easy to cast but still has adequate springiness is an interesting design problem well solved.

Rings, round or oval: elastic instability

We can use a similar argument to compare the strength of rings. The strength of a ring is suggested by the way it resists being squeezed (deformed) from a round to an oval shape. A simple design formula relates force to the corresponding decrease in diameter in one direction, and expansion in the diameter at right-angles, to assume an oval/elliptical shape. Design theory treats a ring as if it were a beam bent into an arc and joined at the ends. Bearing in mind the arguments used for small beams, it is not surprising that the result for a ring also depends on Young's modulus and the modulus of section up to the limit of elasticity and on work hardening beyond that point.

The formula for elastic strain in the diameter of a ring is: -

$$D_v = -WR^3 (\pi/4 - 2/\pi) / EI$$



Figure 7 - Two cast 14 ct gold pendants with cast safety catches: (a) the separate components, (b) the safety catches hooked onto the pendants, (c) the safety catches pushed into the locked position (Courtesy of Anthony Eccles)

In Figure 8, D_v is the **decrease** in diameter of the ring loaded vertically with load W at position 'a'. R is the radius of the centroid of the cross-section and M_a the moment at "a". For permanent ovality, the elastic limit must be exceeded to cause permanent plastic deformation. This is similar in principle to the situation in Figure 4 although the forces will be different. At the two extremes, the elastic slopes for 24 ct gold and 14 ct gold are significantly different. In other words, 14 ct gold has a markedly higher **stiffness** than pure gold. The sort of force that can be exerted between a thumb and finger is about 4 to 6 kg. If we consider a ring only 1 mm thick by 2 mm wide rectangular section and the diameter 20 mm, we can show that the "finger and thumb squeeze" will be comparable with yield for a pure gold ring but a little lower than that for a stronger lower carat gold ring. So, at about 1mm by 2 mm by 20 mm diameter, the ring size is about the smallest section we would consider for a finger ring. It would just be made permanently oval by squeezing between the fingers if it is in soft gold but not in hard worked 14 or 9 carat gold. Normally, we would use a greater cross-sectional area and the section shape may be more square with rounded corners, or D- shape. These sections will then require more force to produce a



Figure 8 - Force to make a ring oval (schematic)

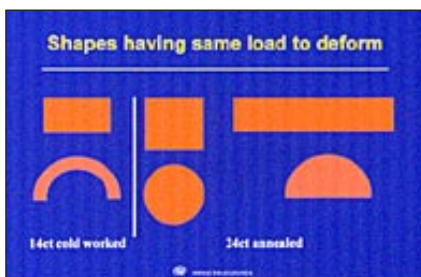


Figure 9 - Cross-sectional shapes requiring the same force to deform to a permanent distortion (bending of a beam)

permanently oval ring but the relative superiority of cold worked and lower carat golds over 24 ct gold of similar section will not change.

The cross-section of the ring can be changed to slim down the section **without sacrificing strength**, or the same cross-sectional area (and so weight and cost) can be retained but the strength can be **increased**. If we wish to conserve weight (and so cost), we can decrease the cross-section, change the shape, but still keep the same strength.

The main principle is that material added in the **thickness direction** is much more effective from a strength point of view than material added to the width. This works quite well for prongs but simply changing a rectangular ring section from flat (in contact with the finger) to edge-on is not so comfortable so one is tempted to try more complicated sections! Slimmed down sections do not need to be solid rectangular; the cross-section can be redistributed by hollowing out the part of the section nearest to the finger. This removes material from the location that has the least effect on the second moment of inertia. The economic section will be a compromise between that which has the highest value of I for a given area (probably a T-section) and that which can be manufactured economically, depending on whether the ring is cast, rolled, or drawn/welded/soldered. A C-section would be a logical substitute for a solid D-section. Figure 9 compares several different section shapes but all requiring the same level of load to produce plastic (permanent) distortion. Note the significantly larger cross-sections in pure gold, particularly when there is no thickening of the band [it now becomes evident why we should examine carefully the development of enhanced properties in the new micro-alloyed high-strength pure golds].

Chain Making

It is worthwhile to consider that chains are, in effect, a series of inter-linked rings. The principles outlined for bending prongs and forming rings apply. The manufacture of most jewellery chain stock is a specialised process using high-speed machines but many craft jewellers enjoy chain making by hand and can perhaps more readily appreciate the

differences in response brought about by changes in cross-section of the wire used and the effect of various types of carat golds. The chain machine designer and operator has to consider some additional effects. For instance, the speed of chain making imposes both temperature and dynamic stress effects on the alloy and on the properties of the resulting chain. The operation is often a careful compromise between alloy and working conditions such that the chain is produced economically with limited die wear (dies are expensive to replace and regrind) and making the chain strong enough to use in jewellery.

The production of chain on modern automatic machines is the only real continuous mass production process in jewellery. It is based on the chopping, bending and twisting of gold alloy wires around dies or formers into a continuous series of intertwined links, Figure 10. The dies can be changed to alter the style and size of chain produced. The



Figure 10 - Chain making involves bending and twisting of wire

wire is usually in tension in the process and there are additional tensile and torque forces on the outer surface during the bending or twisting operations. The basic deformation is analogous to that of setting prongs, but chain making is done at relatively high speeds, typically 50 to 500 links per minute, so deformation rates are relatively high. If a wire of 1 mm diameter bends around a former (die) of 4 mm diameter, then the surface strain on the outer edge is about $\epsilon = 0.33$. Thus, the wire can experience a deformation rate, $\dot{\epsilon}$, in the range 3×10^{-1} to 3×10^{-2} per second. The significance of this is that the flow stress σ , is strain rate dependent:

$$\sigma = \hat{\epsilon}^m$$

where m is the strain rate sensitivity and for normal, non-superplastic metals, including carat golds, is typically about 0.15 to 0.25. On this basis, the flow - or yield - stress required to deform the wire will tend to be a little higher than conventional tensile data would imply, although this may be more or less offset by the local temperature rise of the alloy caused by the fast deformation rate. As the wire is deformed, it will work harden, particularly on the outer surface where the deformation is greater; thus raising its fracture stress. However, if the rate of deformation exceeds the rate of work hardening, there is a risk that the wire will fracture during the process of shaping the links or in subsequent operations such as hammering or stretching to restore flexibility. Use of partially work hardened wire ('half-hard' or 'hard' conditions, for example) will raise the yield stress of the wire but reduce residual ductility, the limit of which may be reached in subsequent forming operations such as imparting twists or during wear by the owner. For most carat gold alloys, the bulk of chain designs can be made satisfactorily provided the tooling is correctly set to prevent snatch loading. However, for 24 carat, or fine gold, the low yield stress and low rate of work hardening (recovery processes in pure gold can occur at room temperature) can give rise to difficulties in some chain designs such as Venetian Box where high local strains can occur. Use of

the new high strength micro-alloyed 24 carat alloys developed in Japan or the '990' gold-titanium alloy gives a greater freedom in 24 carat chain design.

Failures in tension

The engineering design principles applied so far to jewellery items have depended on elastic stiffness and yield stress leading to plastic deformation. Generally speaking, we try to avoid exceeding the yield stress in the design and wearing of a piece of jewellery, but, as we have seen for chain, we cannot manufacture jewellery alloys by mechanical means **without** substantially exceeding the yield point! During wear, hollow jewellery such as bangles or lockets are liable to denting or distortion if subjected to knocks or squashing, as a result of the yield stress being exceeded.

Occasionally, jewellery items fail by unacceptable shear distortion or simple tensile fracture. Open tensile failure can occur with chain links, swivel rings and pendant findings. It is not the dead weight of the jewellery itself that dictates the thinnest section that should be used but the risk of a sudden snatch stress. This often results in the most common perception of strength (or failure of strength), **tensile strength**. By definition, an alloy cannot fail by tensile fracture at a stress below the yield point. With the exception of a few brittle cast alloys, most jewellery alloys have an ultimate tensile strength considerably in excess of their yield stress, mainly due to good work hardenability. However, the best combination of properties is to have a high yield point **and** a high rate of work hardening which together raise the ultimate tensile strength to high levels. This is "best" from a wearing performance point of view. From a mechanical working point of view, a low yield and rate of work hardening is usually better. There is a necessary compromise in designing the alloy. It is not difficult to raise the yield stress by cold working the alloy but, if this is carried too far, the further work-hardenability is very limited and the hard alloy then appears **brittle**.

These various properties of jewellery alloys may be compared by using tensile test results. Unfortunately, test conditions vary

significantly and this reduces the comparability of data. However, one feature of a tensile test curve that relates more or less directly to jewellery performance is the ultimate tensile strength (breaking of chain links) and it is possible to make performance index comparisons by analysing other parts of the curve. Figure 1 placed the various tensile test properties in context. The elastic part of the tensile curve depends to some extent on the rigidity and sensitivity of the tensile test machine. This is why Young's modulus, determined from the slope of the elastic part of the tensile test, can be inaccurate (vibration frequency testing gives more accurate results), and why we choose a relatively high (0.2%) proof stress to **represent** the limit of elasticity. The plastic deformation part of the tensile curve is less dependent on test conditions, although temperature and strain rate affect the results. It is possible to reduce the shape of most tensile curves to a single number to represent work hardening rate. This can be an over-simplification that requires further analysis for some alloys but the curve can generally be represented by, first, converting the values to true stress and true strain, and then: -

$$\sigma = k\epsilon^n$$

If we plot this equation on a log-log basis, we have: -

$$\log \sigma = \log k + n \log \epsilon$$

The intercept on the Y-axis, k , is an approximation of the elastic limit, and n , the gradient of the log-log plot, is the index of work hardenability or work hardening rate. It varies between about 0.1 and 0.2 for typical carat golds and we could make more use of it in explaining and developing deformation processes in jewellery. The analysis of a typical tensile test curve is shown in Figure 11 (a-c).

It is still very true that the strength of a chain is the strength of its weakest link. This implies that a consistency and relative freedom from defects is more important than outright strength. Defects are often local stress raisers and initiate cracks prematurely. Sometimes, internal or -

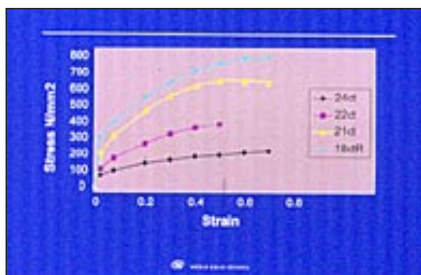
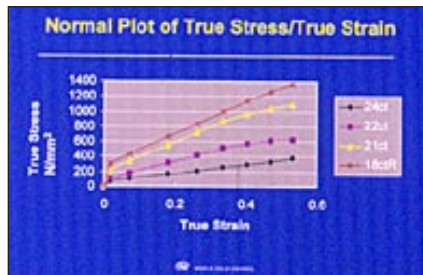


Figure 11 - Tensile test data:
(a) normal stress-strain plot,



(b) true stress-true strain plot,



(c) log - log plot of true stress-true strain

worse - surface defects occur at a point where maximum stress is combined with maximum tight bending and thus a chain, which otherwise might have been just within its design limit, fails as shown in Figure 12(a). At higher magnification, Figure 12(b) shows where failure was initiated.

A note on the effect of heat diffusivity of jewellery alloys

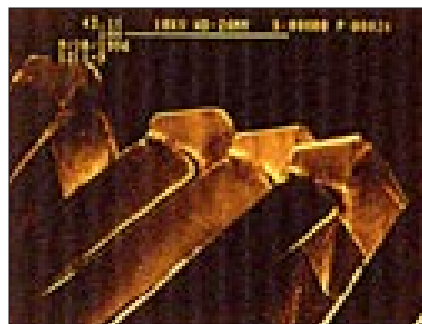
Several times in this paper, the effect of temperature and strain rate (and these can be interrelated) has been mentioned. The thermal conductivity of most precious metal jewellery alloys is high, compared with steels, for instance. While conductivity obviously affects heat flow in precious metals, it is the rate at which heat is transferred through a volume of metal whose two ends are at different but constant temperatures - the steady state. What matters more in practical workshop technology is how the heat is transferred from a hot-spot such as a welding torch, through a mass whose temperature rises as a consequence, so the low temperature end is not at constant temperature. This property is best described by thermal or heat diffusivity, which is still very dependent on conductivity but modified by the specific heat of the metal on a volume basis.

$$\text{Thermal diffusivity} = \frac{\text{Conductivity}}{(\text{specific heat} \times \text{density})}$$

If we compare all jewellery alloys on this basis, silver has the highest thermal diffusivity, gold alloys are a little lower but platinum has a surprisingly low thermal diffusivity. The immediate effect is that heat is more localised around hot-spots when welding or very locally heat treating platinum, compared with gold and silver. The units used in



Figure 12 - (a) Tensile failure of a herringbone chain



(b) Initiation of failure, at higher magnification (Courtesy of Leach & Garner)

table 2 below are in the c.g.s. system because they fit the scale of jewellery alloys better than official SI (thermal diffusivity in m²/s) and we are mainly interested in the order of the effect rather than calculating actual heat flow. The figures for the alloys are only approximate; they depend on alloy composition and are calculated from near room temperature data whereas we are more interested in near melting point temperatures.

Table 2. Calculation of thermal diffusivity for various alloys

Alloy	Conductivity (cal/cm ² /s)/(°C/cm)	Sp. Heat cal/g/°C	Density g/cm ³	Diffusivity y cm ² /s
Pure silver	1.001	0.056	10.5	1.702
Sterling silver	1.0	0.06	10.4	1.65
Pure gold	0.70	0.0304	19.3	1.193
22 carat gold	0.72	0.035	18	1.16
Pure Platinum	0.17	0.0323	21.4	0.246
Standard Pt	0.2	0.03	20	0.3



Figure 13 - Anticlastic raising - an example of an engineering approach to slender design

Conclusion

Engineering design has been applied on a small scale to jewellery and typical jewellery alloys using mechanical properties in a rather more analytical way than is normal in most commercial and craft jewellery production. Some of the arguments have been oversimplified but applied equally to various alloys. The overall result is that, where the important properties are elastic modulus and elastic limit stress, performance is improved by alloying (which raises both) and/or cold working (which raises the limit of elasticity) the precious metal. This assumes that the extra properties can be used to advantage. In practice, it may be more useful to trade off the improved performance in properties by using more slender designs or hollowed out sections or anticlastic raising, Figure 13, (4,5). This type of analysis could be usefully extended to a wider range of jewellery design and production processes, but it would be helpful to have greater standardisation in testing and reporting data on jewellery alloys. When working jewellery alloys, the ordinary engineering stress/strain curves can be usefully analysed more fully to predict working performance. The properties needed to strengthen a delicate design are often the inverse of what is preferred for easy working in jewellery manufacture.

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