QUALITY ASSURANCE IN GOLD JEWELRY MANUFACTURING: IMPLICATIONS OF ALLOY PROPERTIES

G. Raykhtsaum and D.P. Agarwal
Leach & Garner Company
North Attleboro, MA

Abstract.

A general quality assurance program incorporates various tests that are related to incoming materials, processes used in manufacturing, and finished products. In gold jewelry manufacturing QA tests involve the evaluation of chemical, physical and mechanical properties of the materials made with the gold alloys. Often, the instrumentation to run all these tests is not available to a jewelry manufacturer. To ensure a good quality of the product whether this is a cast, stamped, formed, or assembled item, and to optimize the quality assurance, we have to consider the implications of such properties of gold alloys as: gold assay, bulk composition, level of impurities, grain size, hardness, strength, melting temperature range and color. These questions are addressed in this presentation, where we also correlate the tested properties with the manufacturing processes.

Key words.

Quality assurance, testing, jewelry, gold alloys.

Introduction.

The different aspects of quality in jewelry manufacturing have been recently addressed in the presentations at The Santa Fe Symposium [1] and in the publications of Gold Technology [2]. This reflects the general trend in the industry towards the rising quality requirements for raw materials, findings and finished jewelry.

As far as the gold jewelry alloys are concerned, we may define the quality as a combination of the quantitatively measured properties that make the alloy suitable for making a finished jewelry item. Depending on the application, a jeweler may decide to include some of these properties in the material specifications such as hardness, tensile strength, etc. The modern developments in the instrumentation, computers, and software bring the quality assurance on a more sophisticated level, and make the task more effective. The price tag, however, that comes with the new technology is often prohibitive. A few large manufacturers enjoy the luxury of having an in-house analytical lab and testing facility to satisfy the needs of quality assurance in the evaluating of the chemical, physical and mechanical properties. For smaller manufacturers the equipment to run all these tests is not always available. The optimization of the quality assurance, therefore, becomes an important issue that must be confronted. This, we believe, should begin with the clear understanding of what are the implications of different alloy properties, and how are they affected by the manufacturing processes.

In the present paper, we shall discuss the implications of such properties of gold jewelry alloys as gold assay, overall composition, level of minor additions and impurities, grain size, hardness, strength, ductility, melting temperature range, color. These properties can be inter-related, they are not strictly the functions of the original compositional make-up of the alloy, they also can be altered by the manufacturing processes: casting, forming, soldering and heat treatment. We shall suggest several approaches to ensure the consistent material quality.

Gold assay.

Gold assaying is the one of the most critical quality assurance tests in jewelry manufacturing. It is designed to determine the gold content most accurately, and it confirms the karat of the finished product (1 Karat = 1/24 gold content by weight). Gold assay, unlike other alloy properties, cannot be compromised. The implications of gold assay are two-fold: ***legal*** and ***financial***.

- Legally, the gold content in all karat gold jewelry must conform with the regulations outlined in the National Gold and Silver Stamping Act and in the Federal Trade Committee Guides for the Jewelry Industry. For example, no alloy or jewelry article can be called or stamped as "gold" if the gold content is below 10K (41.67% gold by weight). The gold content must not be any lower than of 0.3% without solder and 0.7% with the presence of solder. The violation of these regulations by a manufacturer may result in the $500 fine or three months of imprisonment or both.

- "Giving away" gold is what every manufacturer wants to avoid. The following simple calculation shows how significant can be the financial loss when the gold value is not known by a manufacturer accurately: Assuming the gold price $300/ounce, selling the 14K jewelry at 58.5% gold, whereas in fact the actual gold content is 59.0%, results in the loss of $1.5 per each ounce of product sold.

During the investment casting as much as 0.5% of zinc burns out. This modifies significantly the gold content in the final product above the gold content in the original casting grain. Similarly, some gold upgrade due to zinc burn-out may also happen during making the melt of the gold alloy especially when re-using the scrap. In both cases the gold content of the finished product differs from that of the original alloy compositional make-up. To enssure the nominal gold content, one should compensate the composition of the initial make-up for zinc loss. It is evident, therefore, that knowing the accurate gold content of the initial grain or scrap, and assaying the final product as the quality assurance measures are essential.

Traditionally, the gold assaying is done by fire assaying or cupelation This technique has been used for many centuries and is proven to provide the most accurate gold analysis. In 1993, Sharon Fontain presented a paper on fire assaying at The Santa Fe Symposium. The details of this analysis are also discussed in the recent publications of the World Gold Council [3] and [4].

The best fire assaying claims the accuracy of 0.02% gold by weight. In normal practice, however, we find that the fire assay of gold in the same sample may vary as much as 0.2% between two different labs.

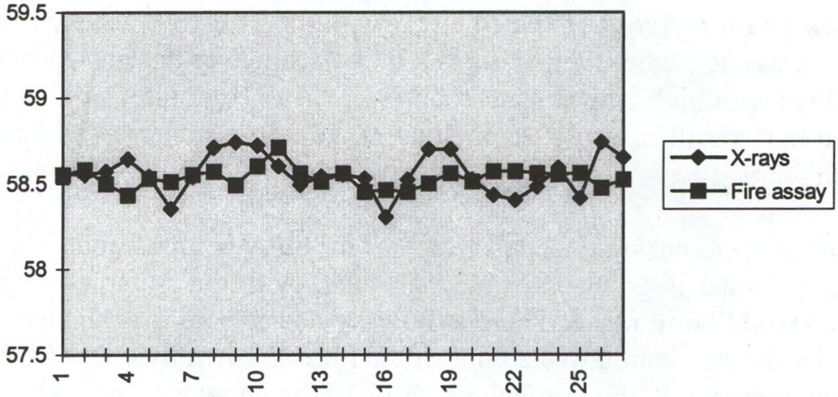
The cost of the in-house fire assaying equipment is considered to be low in comparison with other modern techniques. It requires the operator training. Our personal experience shows that with the minimal training, one can achieve the accuracy of 0.1% in a short period of time.

The fire assaying is associated with the serious environmental and health issues, such as exposure to lead and lead oxide, and handling of the strong acids.

The X-ray analysis is becoming a viable alternative to fire assaying [4], [5]. There are a number of X-ray instruments available on the market (such as Seiko energy-dispersive X-ray spectrometer). It is claimed that when using standards similar in the composition to the unknown, the accuracy of this analysis can approach that of the fire assay. The cost of the equipment is comparable with that of fire assay.

To explore the capability of X-ray analysis we have run in parallel two analyses on the number of 14K yellow gold samples: fire assaying and energy-dispersive X-ray analysis using a well defined standard and a solid-state detector attached to the scanning electron microscope. Figure 1 shows the results of both analyses for 27 samples. The average difference between corresponding fire assay and X-ray is 0.11%. This is in agreement with the results obtained in [4]. This shows that X-ray analysis may become a good quality assurance test, especially when the manufacturer deals with a limited number of alloys.

Figure 1. X-Ray vs. Fire Assay analyses of 14K yellow alloys. Average difference 0.11%.



The X-ray analysis is non hazardous and environmentally safe. It is also non destructive, unlike fire assaying. It should be kept in mind, however, that X-ray analysis provides the information about only the thin surface layer of the sample. One should make sure, therefore, that the composition of the sample surface is representative of that of the bulk.

The gold assay provides the manufacturer with the gold content only. In this respect, all 14K alloys are considered "equal", since they have the same intrinsic gold value. The "equality" ends, however, when other alloy properties besides gold value come to the consideration.

Overall composition.

As we have mentioned above, the final composition of the alloy is not necessarily the same as the original compositional make-up. The main reason is the zinc burn-out. It also can be due to the oxidation of other base metals. We see the following implications of the deviation of the overall composition from the nominal:

- ***The gold assay*** deviates from the nominal value. This has already been discussed above.

- ***The melting range*** of the final alloy shifts. The shift usually occurs towards the higher temperatures. This becomes critical when making alloys with high zinc content such as solders. High rates of zinc burn-out may result in rising the melting range of the solder by as much as 70F.

The best way to ensure the consistency of the alloy composition is a strict control of what is going into the each melt. A proper scrap segregation policy should be in place. There is no easy and inexpensive analysis that can provide the quantitative compositional break down by elements better than the accuracy of the original weigh-up of the known ingredients.

Our experience shows that the accuracy of the energy-dispersive X-ray analysis of the base metals is about 0.5% by weight. For the quality assurance purpose, this analysis can be used as an additional benefit when assaying gold utilizing the same X-ray instrument.

When the instrumentation is available, the measuring the melting range is a good quality ssurance test for solders.

Level of minor additions and impurities.

The specific alloy properties can be improved and enhanced by adding a small amount of certain elements. Two types of additions are usually considered for karat gold alloys: de-oxidizers and grain refiners. The impurities are the contaminating elements which either are already present in the pure metals prior to melting, or have been accidentally introduced to the melt. Since 1987, The Santa Fe Symposium had numerous presentations on the effects and implications of small additions and impurities. A detailed overview with extensive references on this subject is given by Dieter Ott in [6]. Without repeating Dieter we just would like to add two more references which, we believe, are relevant to the topic - [7], [8].

Again, the best way to ensure the consistency in the levels of minor additions, and to minimize the chance of contaminating the alloy with undesirable impurities, is to have a strict control of what is going into the each melt. The de-oxidizers and grain refiners are usually added in the form of a master alloy. The pure metals used in the melt should have known impurity levels.

The Atomic Absorption is probably the most suitable and not too expensive a technique to measure the levels of minor additions and impurities as a quality assurance test.

The negative effect of impurities on the alloy quality can be minimized by decreasing the grain size. This is a part of the discussion in the next section.

Grain size.

Metal alloys have a polycrystalline nature: they are comprised of differently oriented single crystals, or grains, connected to each other by grain boundaries. The process of formation of the grain structure in the alloy during solidification from the melt or by recrystallization and growth during annealing is a subject of a separate presentation. Here we shall mention just a few points that are relevant to our discussion:

- All the impurities and small low-melting phases usually segregate in the grain boundaries. Therefore, the difference in properties between the grains and the grain boundaries is quite significant.
- Unlike grains, the grain boundaries are brittle and weak.
- The grain boundaries have lower melting temperature than the grains.
- Under the exposure to heat (slow cooling after casting, soldering, annealing) the grains grow in size. The growth rate is exponential to the temperature.

The grain size is a fundamental microstructural property of any mateial. The implications are numerous and complex, and we shall mention just those that are practical to the jewelry manufacturing:

- ***Orange peel*** is the most frequently mentioned effect of the large grain size. Normally, a human eye can not resolve individual grains in a material. However, when a strip or wire is bent, and if a grain size is large, the appearance of the surface resembles that of an orange peel. Figures 2 and 3 illustrate the difference in the surface appearance between two jump rings made with the wire of the same 14K yellow alloy: one with the large and another one with the small grain size. The microstructure of these wire samples is respectively shown in Figures 4 and 5. The average grain size of the first sample is about 35 microns, whereas the second sample has much smaller grain size - around 5 microns.

- The small grain size reduces the ***negative effect of the impurities on the material strength***. The same amount of impurities is spread over the larger grain surface area in the material with the smaller grain size. The materials with the large grains show premature breaks along the grain boundaries under the tensile and shear stresses. For example, the prongs in a setting with large grain size are more likely to break during the setting of the stone.

- The alloys with the small grains show better ***ductility, mechanical working*** and ***forming***. For example, the ring, regardless whether it is cast or made from tubing, is easier to size without breaking when the grain size of the material is small.

Figure 2. The surface of the jump ring with large grain size shows orange peel effect.
(original magnification 85X)

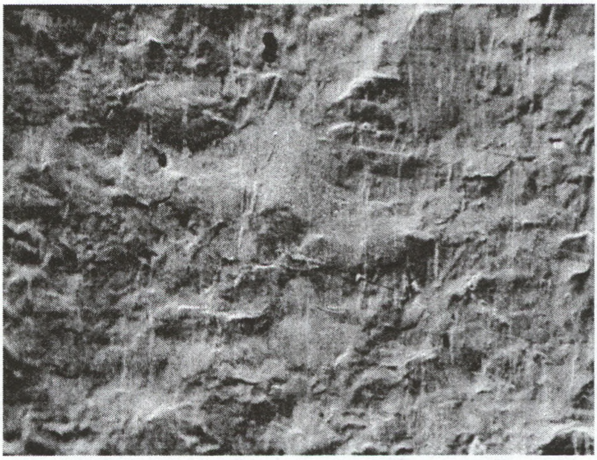


Figure 3. The surface of the jump ring with small grain size.
(original magnification 85X)

Figure 4. The grain size of the wire with orange peel is about 35 microns. (original magnification 800X)

Figure 5. The grain size of the wire with no orange peel is about 5 microns (original magnification 800X)

- The materials made with the alloy containing grain refiners tend to show **slower rates of grain growth** when exposed to heat during annealing and soldering. The grain size can be controlled by using the grain refiners [6], and by the optimization of the annealing conditions. For example, when annealing in the belt furnace, the temperature, the belt speed and the batch size should be considered in order to achieve the optimum grain size and reduction in hardness. The discussion of the details of annealing heat treatment can be found in [9] and [10].

In general, the small grain size yields a material with higher quality. Naturally, the terms "large" and "small" are relative. For wrought products the grain size above 30 microns may be considered as large and even unacceptable, whereas in castings the grain size of 50 microns is considered to be fairly small.

Hardness.

Hardness is a resistance of the alloy to a plastic deformation. This may involve a simple scratching and indentation, or forming and stamping. The implications of hardness are straightforward:

- The hard alloys require ***more force for forming and stamping***. Hard alloys cause a ***premature wear of the tools and dies***. That is why forming and stamping are usually performed on the annealed material.

- The harder the alloy of the finished product, the more ***durable*** is the product - more scratch and dent resistant. That is why the hardenable alloys are becoming so popular: they can be easily formed in the soft condition, and provide durability after the hardening of the finished part [11], [12].

The hardness is a good measure of both the annealing and the hardening processes, and it should be incorporated in a quality assurance test program. The hardness values for different gold jewelry alloys in cold worked and annealed conditions are given in [9].

All microhardness testers (Vickers and Knoop) are equipped with the fairly good optical microscopes that also can be used for measuring the grain size on the polished and etched samples. Therefore, with one moderately priced instrument, one can perform two important quality assurance tests: the hardness and the grain size determination.

Color.

The general description of any jewelry alloy consists of two parts: First, the intrinsic gold value - karat, and second, the aesthetic appearance - color (10K yellow, 14K white, 18K green etc.). The color is a property which is directly related to the alloy composition [13]. There are several implications of color in jewelry manufacturing:

- ***Color of the components*** should be consistent with the overall color of the assembled product. Otherwise, to mask the difference in color, the whole product is usually gold plated. The plating, in turn, has a separate color consistency issue of its own.

- ***Insufficient protective atmosphere*** during the annealing and soldering results in discoloration of the product due to surface oxidation. The restoration of color involves additional labor-consuming finishing operation where the oxidized surface is mechanically removed. The alternative is to subject the product to the cyanide bombing - an operation that requires health and environmental considerations.

- ***The surface finish*** alters the perception of color. For example, the polished and sand-blasted surfaces of the same article appear differently to a human eye.

- ***The perception of color*** is somewhat subjective.

Fairly expensive color spectrophotometers are available on the market, and can be used in color quality assurance. The visual color evaluation is more practical, and may become a reliable test when using the reference samples. The color kit manufactured by AJM [14] is quite useful in this respect as it contains samples that define color ranges for different karat golds.

Strength.

The strength is defined as the maximum load that the material undergoes during the tensile test. The strength is specified mainly for the wire products. Its implications are especially critical for manufacturing chains when solid wire is utilized since the ***chain strength*** is related to the strength of the wire [12], [15].

Establishing good operating procedures on melting, wire drawing and annealing will ensure the consistency in the wire strength. The moderately priced tensile machines are available on the market, and we suggest that wire and chain manufacturers have some sort of quality assurance tensile test implemented.

Conclusions.

Based on our discussions of the implications of the material properties we come to the following conclusions regarding the quality assurance tests:

1. Gold assaying is a critical quality assurance test. For a gold alloy manufacturer it is essential to have this capability in-house.

2. Good melting and scrap handling practices ensure the consistency in gold alloy composition. X-ray analysis can be used as a quality assurance test, especially when the same instrument is used for gold assaying.

3. Similarly, good melting practice including the quality control of incoming pure metals, ensures the effectiveness of the minor additions

and minimizes the impurity levels. Atomic absorption analysis may be used as a quality assurance test.

4. The grain size and hardness affect too many properties and, therefore, should be tested. For quality assurance purposes the grain size and hardness can be determined using one instrument - a microhardness tester.

5. A visual evaluation of color using reference color samples is a good quality assurance test.

6. The tensile test is necessary when manufacturing wire and chains.

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