INTRODUCTION TO JEWELRY FORENSICS

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INTRODUCTION

Despite Much as a gemologist goes through an iterative process to identify an unknown gemstone, there is also an iterative process for applying jewelry forensics, which requires systematic observations to formulate a hypothesis, followed by a thorough examination to find any contradictions to the proposed theory (i.e., test the hypothesis with what can be observed). Subsequent observations might cause an assessor to repeat steps or re-think early conclusions at any point during the process. Ultimately, the assessor must address whether the item is Fit for Purpose.[1]

Fit for Purpose

Designed and made to suit the application for which it is intended.

Acknowledgments

By its nature, Jewelry Forensics is a very wide subject that is beyond the scope of most individuals because of the various specialty areas involved. There are many to thank, and the list includes Jill Burgum (Director, Fine Jewelry at Heritage Auctions), Dr. Christopher Corti (director of COReGOLD Technology Consultancy), Mark Mann (former GIA Director, Global Jewelry Manufacturing Arts), Danusia Niklewicz (One of the founding Directors for the Hallmark Research Institute), Master Goldsmith Alan Revere, Joanna Joy Seetoo (JMA Program Manager, GIA), Gina D'Onofrio (Co-Director of Fine Jewelry, Heritage Auctions), Jack Ogden (British Jewelry historian), Michael Turinetti (former JMA Instructor, GIA), Elizabeth Brehmer Watts (former GIA Technical Advisor of Jewelry Manufacturing Arts), Javier Zavala (former JMA Instructor, GIA).

Iterative Process

There are several steps in this process:

1. Ask systematic questions about what can be observed in the item,
2. Formulate a hypothesis and form assessments as you work through the questions,
3. Test your assessments by examining the item thoroughly for any inconsistencies with the hypothesis and revise your theory if necessary.
4. Finalize your conclusions and note any constraints.

The guided series of 12 questions "forensically" examines jewelry through an investigation that leads to conclusions. For report writing, it would be appropriate to say, "Based on XYZ evidence, the manufacturing process is believed to be..."

12 questions

METAL

1. Is there a fineness mark? Is there a responsibility mark?
2. What is the color, and is the heft (feel of the weight) consistent with the fineness?
3. What is the condition of the finish on internal/external surfaces?

MANUFACTURING

4. Are joints clean and consistent with other surfaces?
5. Are indications of previous repairs or retrofits visible?
6. What manufacturing method was used to make the item/components?

GEMSTONES

7. If gems are present, are they set securely?
8. Are the settings the correct size for the gems?
9. Is the condition of the prongs and bearings appropriate?

ITEM QUALITY

10. What is the condition/functionality of any mechanical com ponents?
11. Is the item well-made and structurally sound?
12. For which market was the item made? Is it fit for purpose?

It is also essential to use this process to identify the risk of physical loss or damage to a piece. If not correctly characterized, those quality and condition risks may cause the assessor a loss of credibility. Additionally, the assessor may be responsible for the customer's or insurer's financial loss.

Primary Elements you need to know to employ jewelry forensics.

1. Precious metals
    a. Properties of precious metals: hardness, malleability, ductility, density, color, strength, melting point, patina/tar nish/oxidation.
    b. Hallmarking, stamping, and precious metals testing.
2. Major Jewelry manufacturing methods and the traces used to identify those methods.
    a. Hand-fabrication, various methods of casting, CAD/ CAM, die-striking or stamping, machining and computer numerically controlled (CNC) machining, surface finishes and embellishments, and electrodeposition (electroplating and electroforming).
3. Assessment of quality and workmanship
    a. Proper engineering. Metal that is too thin or prongs that are too short are examples of poor engineering.
    b. Where risk and appearance are affected, such as set tings, soldering or laser welding, and final finish.

c. Condition, repairs, and alterations.

Examples of indicators for three of the methods of manufacture.

Hand-fabricated[2] (quality dependent) Indicators

- Slight asymmetry of shapes and patterns.
- Solder joints are where assemblies of parts or components take place.
- Tool marks abrasive marks in recessed areas from saws or gravers or finishing.
- The use of precious metal sheets and wire for fabrication results in fewer metal defects, such as overall pitting, metal shrinkage marks, or part lines, all characteristic of cast items. This results in very consistent part thicknesses.
- No evidence of other manufacturing methods (casting skin, shear lines, etc.)

According to FTC guidelines, the term “handmade” has a very strict definition. It should be used with care when describing the manufacturing of a piece of jewelry. “The entire shaping and forming of such product from raw materials and its finishing and decoration were accomplished by hand labor and manually-controlled methods which permit the maker to control and vary the construction, shape, design, and finish of each part of each individual product.”[3]

Hand Fabrication

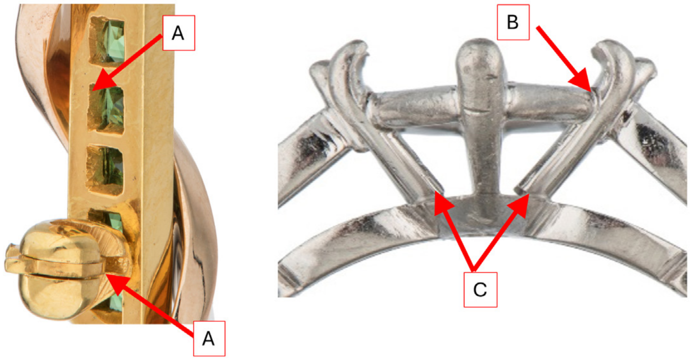

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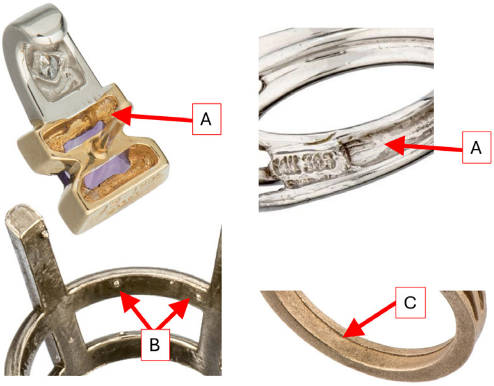
Figure 1: Indicators of hand fabrication include (A) saw or filing marks, (B) solder joins, and (C) asymmetries of various elements

Casting[4] Indicators

- Casting skin on surfaces from the process that is not entirely removed
- Porosity of the metal indicating casting defects
- Nodules of metal
- Flashing or metal fins in recessed areas that have not been removed
- Junctures, angles, and edges that are more rounded than they would be if assembled
- No visible solder/laser joints or difference in metal coloration
- Evidence of wax or manufacturing marks from 3D printing (rapid prototype lines), hot wax working, or wax milling on the inside or outside
- Metal flow or shrinkage marks on the surface of the jewelry
- Mold lines or model marks on the end items or in recesses
- Lack of fine detail or definition of fine patterns/details on or in surfaces of items
- Stones cast in place, leaving unfinished surfaces under the edges of gems and in pilot holes
- Lines from printing
- Older cast items (particularly platinum) can be tool-worked, and almost all indicators of casting can be removed; check all tight areas.

Indications of Casting



Photos by Emily Lane, ©GIA

Figure 2: Indicators of casting include (A) casting surface inside irregular recesses (granular surfaces or polished), (B) nodules on casting surfaces, and (C) parting lines, which are remnants from molds.

Die-striking[5] Indicators

Die-struck components can be hand-finished to remove shear lines. Look at all areas. Complicated older pieces may have a few indicators remaining. Be familiar with the standard die-struck components that are currently available.

- Items that were stamped and assembled from sheet.
- Break or shear lines on edges from the metal shearing; Strike lines on sides before and after shear lines.
- Clean, crisp edges and sharp, accurate angles; Surfaces that seldom contain pitting or surface defects.
- Higher density; little variance in weight from item to item; very predictable and standard.
- Shapes or objects that are precise in shape and repeatable form are common in mass production.

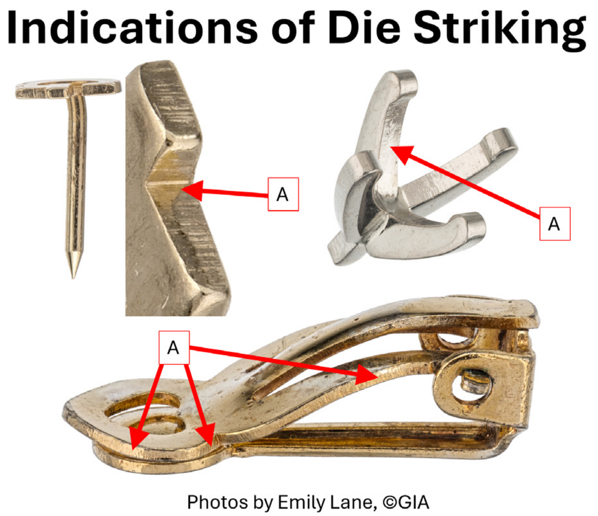


Figure 3: Indicators of Die Striking include (A) break lines and shear lines. Other indicators are sharp edges and precision in shape.

Discussion: Summary of Traces

Remember that an assessor must gather evidence to determine the type of manufacture by examining the item under magnification for indications of cast surfaces, hand-working, die-striking, or machining. Here are some key methods to employ to find those traces: Look at tight spots not easily reached by tools (where galleries, rails, or other supports meet), for example:

- Inside curls of metal.
- Inside edges of galleries.
- Hallmarks and karat stamp surfaces and edges.
- Inside angles where they meet: if they are sharp and bright (no fillets) and the same as outer surfaces, they indicate assembled or fabricated. If they are sharp and have tool or abrasive marks, they also indicate assembled or fabricated.
- Inside areas have cast surfaces: cast.
- Walls, inside or out, may have shear marks from die-striking.
- Machining can't get into tight spaces.

Solder joints may be clean and difficult to see; use reflected light off surfaces to look for joints and any color differences at the solder joint. Why is there a solder joint? Was it to repair an item or join different parts? What method of manufacture was used for the other parts?

Solder surfaces (inside) can be confused with casting indicators when they aren't finished. Be careful and thorough.

- Solder joints may have pitted due to metal not being clean when soldered or overheating of solder
- Casting skin can indicate molding an item that has soldered joints.
- The original item may have had a pitted surface, and the mold can capture it

Laser welding leaves small, progressive divots on the surface of the metal. A skilled jeweler backfills (or refills where the material has been removed), files, and finishes the excess metal to match the surface geometry of the surrounding areas, making the repair seamless and essentially invisible.

Higher quality hand-worked or hand-finished (not necessarily hand-fabricated):

- Removal of casting skin in azures, inside mountings, and below stones
- No tool marks.
- All flat surfaces show no distortion.
- Metal polished under all stones.

With enough hand-working, almost all indicators for various processes can be removed. Examine the whole piece if you find a remnant of a process (e.g., casting). Is that consistent with other traces? Are multiple or single components made using that method and then assembled by hand? (For example, a die-struck shank can be assembled to join a die-struck or cast head.)

There is an apparent difference between risks of loss due to wear over time compared to errors in workmanship and engineering. Wear-over-time issues can usually be identified and repaired by the jeweler. Errors in workmanship, design, or manufacture also need to be called out and, if possible, corrected. For example, porosity throughout a ring weakens its structure and cannot be repaired.

Familiarity with various manufacturing methods and the application of the investigative process provides the framework to use the assessor's knowledge to analyze a piece of jewelry and consider its design, engineering, workmanship, and other factors in the practice of Jewelry Forensics. The assessor needs to continue to add to their knowledge of how jewelry pieces are made (design and engineering as well as new types of manufacturing and their traces), how to identify underlying causes of jewelry failure and damage, and how to practice identification to be effective.

Understanding jewelry metals (Basics)
Precious Metal Alloys

An alloy is a combination of two or more elements, generally metallic. A baser metal is mixed or combined with a finer one to reduce the latter's purity and/or to change properties such as color, grain refining, flowability, strength or hardness, melting range, and tarnish resistance.

- **Hardness** is the resistance to penetration by an indenter of a specific shape and dimensions under a specific load.[6,7]
- **Malleability** is a characteristic of a metal or alloy allowing it to be deformed without cracking or fracture, e.g., rolled or hammered into a thin sheet without cracking.[8]
- **Ductility** measures the amount of deformation that can be imparted to metal without cracking or fracture—the abili ty of a metal to be drawn into fine wire.[9]
- **Density** is the ratio of the mass of an object to its volume, its specific gravity.
- **Strength** is the capacity to resist either a permanent distort ion or fracture when a force is applied.[10]

Precious metal alloys are engineered for specific jewelry operations, functions, and performance since each alloy has desirable characteristics and drawbacks for use in jewelry.

Gold

Pure gold is a highly malleable metal; it is also ductile. One ounce of pure gold can be drawn into 50 miles of thin gold wire, about 5 microns in diameter.

Pure gold is too soft and malleable on its own and is rarely used for jewelry. Gold's lower karats have been hardened by adding certain alloying elements, usually copper, silver, nickel, palladium, and zinc (see Table 1).

Table 1

Gold	10K	14K	18K	24K
Precious Metal %	41.7	58.3	75	99.99
Parts per Thousand	417	583	750	999

Alloying gold generally increases its strength and hardness, with some reduction in malleability and ductility. This is because atoms of alloying metals are different sizes than a gold atom. The copper atom has a more significant effect on strengthening gold than silver, as its smaller size distorts the gold crystal lattice more. Table 2 lists some of the common metal alloy ingredients.

Table 2[11]

Gold Color	Some Common Ingredients
14K Yellow	Gold, copper, silver, zinc
18K Yellow	Gold, copper, silver, zinc
Green	Gold, copper, silver (with silver increased)
Rose (Pink)	Gold, copper, silver (with copper increased)
White	Gold, nickel or palladium, copper, zinc

White golds, available up to 21K, were developed as a substitute for platinum for use in jewelry. Adding any white metal to gold will tend to bleach its color—nickel, palladium, and platinum are strong bleachers; silver and zinc are moderate bleachers.[12] All other metals used to whiten gold are moderate to weak in effect. There are two basic classes of white gold: nickel whites and palladium whites.

Although copper does not act as a bleacher, it is added to many white alloys to improve ductility.

A gold-silver alloy is quite white and ductile at the 9K (37.5% gold) level. Although soft, it is used for jewelry purposes.

Vickers Hardness[13,14]

Design and engineering decisions must consider the type of precious metal alloy used and its specific properties. This will enable the designer to properly engineer the appropriate dimensions of prongs, galleries, chain links, and shanks. For example, a design suited for nickel-based white gold alloys may be dimensionally too thin and lightweight to be made in sterling silver, as the sterling silver alloy is much softer, far more malleable, and less dense. Metal hardness is measured by the Vickers Hardness scale, in which harder metals receive a Vickers Hardness (HV) measurement. It is generally accepted that a gold alloy (and any jewelry metal) used for mainstream jewelry should have a minimum hardness of 120HV (and 150 HV for prongs) to perform well over time. Table 3 shows some common alloy hardnesses as cast (except as noted).

Table 3

Metal	HV	Metal	HV
Sterling Silver	75	14K Yellow	140
999 Pure Gold - annealed	20	14K White	165
999 Pure Gold - hard	58	14K Red	125
22K Yellow	60	9K Yellow	120
18K Yellow	125	Platinum-Iridium	115
18K White	155	950 Platinum-Ruthenium	130
18K Red	160	950 Palladium	125
18K Pink	195	Rhodium Plating	400 - 800

Reducing gold from 24K to 18K yields notably harder and stronger alloys. But alloying gold from 18K to 9K doesn't change hardness or strength much. The difference is so slight, 125 HV versus 120 HV, that in practical terms, 18K and 9K are much the same in hardness. However, 9K is more difficult to bend and is a little springier than 18K gold. Therefore, a fine 9K ring may be less likely to bend out of shape than a fine 18K ring. Neither metal will likely bend out of shape if the ring is of a good sturdy construction.

Note the hardness of rhodium plating in the above table, which is also a function of the plating thickness. The thicker the plating, the more resistant to dents and scratches, which prolongs wear. White gold prongs are often rhodium-plated. Rhodium plating is typically 0.5 microns on rings but can reach up to 3 microns. The electroplated deposits tend to be highly stressed internally, so thicknesses over 3 microns tend to be brittle and prone to fracturing and spalling off or chipping.

Annealed and Cold-Worked Hardness

Precious metal is at its softest or most malleable when poured into an ingot or cast. When metal is hammered, bent, stressed, or otherwise "worked," its hardness changes as the metal atoms are pressed more closely together. This causes a loss of flexibility, and as the metal continues to be worked, it becomes more brittle or fatigued and can crack or break. Metal fatigue is common when repeated stress is applied to the metal.

Hardness tables from some manufacturers or in textbooks will often list several hardness values, first as the annealed or as-cast condition, then with a small percentage of work (usually around 20%), and finally, a high amount of work (often 70 or 75%). As the metal is "cold worked"—hammered, drawn, formed, shaped—it becomes stiffer, more difficult to work, and subject to breaking. So, bench jewelers will stop, reheat, and "anneal" the metal during the metalworking process, allowing the metal atoms to relax and soften. Work-hardened metal is more resistant to wear, so bench jewelers often work to harden the metal to some degree.

The table below compares the hardness of two alloys as cast (after casting, before any working or annealing), after different amounts of cold working (performed on cold metal, such as hammering, drawing, forming), and annealing (heating worked metal to allow it to soften and relax into workability). Manufacturers of fabricated metal alloys (such as sheet, wire, or casting grain) test their alloy's compositions and document their HV values for customer use (see examples in Table 4).

Table 4[15]

Gold Alloy	Condition	HV
Yellow Au750 Ag125 Cu125	Cast	170
	Cold worked 20%	190
	Cold worked 75%	225
	Annealed	150
Green Au585 Ag300 Cu115	Cast	147
	Cold worked 20%	226
	Cold worked 75%	252
	Annealed	150

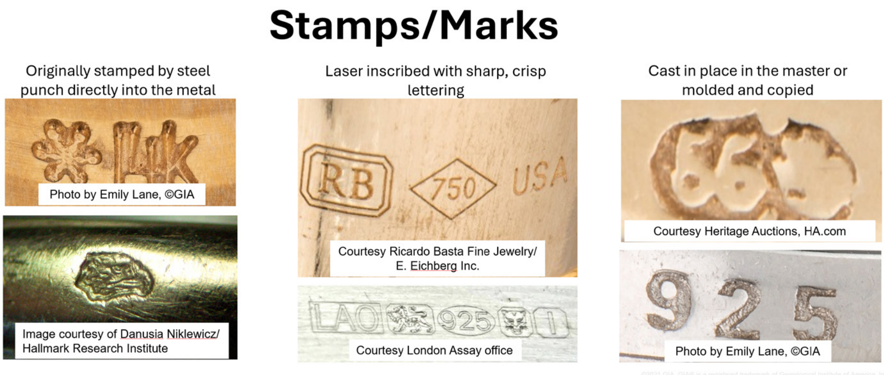
Quality Marks (or Hallmarks)

A fineness mark indicates the amount of fine precious metal in the alloy. It can be described in the karat system (K) or parts per thousand (PPT).

With the amendment to the U.S. Gold and Stamping Act in 1961, a fineness mark in the U.S. must also be accompanied by the designer's or manufacturer's mark (responsibility mark).

In many European countries, a hallmark is a country or town-specific mark stamped or laser inscribed on a precious metal item representing the independent assay results conducted on that item.[16] Hallmarks can be mandatory or voluntarily applied by legislated entities, either a government department or an authorized independent assay office, that, after testing, guarantees the item meets the standard of fineness as prescribed by law. Hallmarks applied at an assay office are stamped or laser inscribed. When the mark is part of the mold, it can be reproduced but the interior of the mark will have a casting surface.

Figure 4: Three types of marks



Gold

While gold is usually stamped or hallmarked for its quality (as required by that country's government), it is not unusual to find that marks can be lost through wear or repair. (Examples of some fineness marks are listed in Table 5.)

Table 5

Gold	Fineness (PPT)	Fineness (%)	Market
8K, 8ct	333	33.3	Usually European
9K, 9ct	375	37.5	Mainly British commonwealth
10K, 10ct	416	41.6	Minimum U.S. standard until 2018
12K, 12ct	500	50.0	Usually, old watch cases, rarely seen
14K, 14ct	585	58.5	Many countries (US and Russian 583)
15K, 15ct	625	62.5	British Commonwealth (discontinued 1935)
18K, 18ct	750	75.0	Minimum Italy standard
21K, 21ct	875	87.5	Asia
22K, 22ct	916	91.6	Asia, Middle East
24K, 24ct	995 and 999	99.5-99.9	Asia

When looking for gold hallmarks, make sure that certain marks are not on the piece—EP (electroplate), GP (gold plate), HGP (hard gold plate), and "rolled." As the names might suggest in Table 6, these are not solid gold.

Table 6: Marks indicating small amounts of Gold[17]

Stamp	Description	Stamp	Description
EP	Electroplate	KGB	Karat gold bonded
GE or GEP	Gold electroplate	RG	Rolled gold
GF	Gold-filled	RGP	Rolled gold plate
Gold Clad	Gold plate	TB	Technobond: gold layer bonded to base metal
GP	Gold plate	Vermeil	Gold plate over sterling silver
HE or HGE	Heavy gold electroplate	WGP	White gold plate
HGP	Hard gold plate	YGP	Yellow gold plate

Gold-filled and rolled gold are very thick coverings. These interchangeable terms refer to the same manufacturing process: a thin sheet of gold is laminated or bonded to a lesser metal (usually brass). The two layers of metal are heated under pressure to fuse them together. The result is a piece of jewelry that (in most cases) has a gold covering with 5% (1/20th) of 12K gold, compared to gold plating with a tiny gold covering of about 2/1000th of an inch.

Sterling Silver

Sterling silver is the most common jewelry alloy. It is alloyed with copper for hardness: typically, 925 PPT (92.5%) silver and 75 PPT (7.5%) copper. Sterling silver's annealed hardness is 66 to 76 HV. It can be marked Sterling, Ster., or 925. Due to its chemical composition, sterling silver is subjected to oxidation, tarnish, and patina.

- **Oxidation** is the darkening of a precious metal alloy due to the reaction of the alloying metal (commonly copper) with oxygen in the atmosphere.[18]
- **Tarnish** is a common term applied to the oxidation of sterling or other silver alloys. It is the natural or intentional suface discoloration of a metal or mineral caused by the formation of a thin film of sulfur-based corrosion products, e.g., copper/silver sulfides.[19]
- **Patina** is the acquired change to the surface due to age, exposure, and wear.[20,21]
- **Firestain** is a blackening of the surface after heating with a torch that is very difficult to polish out. It is due to internal oxidation that leads to formation of fine black copper oxide particles under the surface.[22]

Sterling is a well-loved jewelry metal. However, its tendency to tarnish can be frustrating to wearers. Fine silver is sometimes used for bezels in jewelry because of its malleability. Rhodium plating can prevent tarnishing until the plating is compromised.

Argentium Silver[23]
The most widely used alternative to sterling is Argentium silver, a relatively new silver alloy often used by artisans. When the element germanium is alloyed with silver, it is said to reduce tarnishing and firestain.
There are two common compositions of Argentium:
- 935 PPT (93.5%) silver and 65 PPT (6.5%) germanium
- 960 PPT (96%) silver and 40 PPT (4%) germanium

Argentium silver should be referred to as such, and the composition being used should be noted. Its annealed hardness is 50 to 70 HV. At this time, there are no required or recommended fineness stampings.

Purported Silver Items
Some stamps on purported silver items are listed in Table 7.

Table 7

Stamp	Description	Stamp	Description
700	Coin silver	Silver filled	Often 1/5th by weight, but also as low as 1/20th
800	80% silver	S80 or 800S	Chinese silver that is only silver-plated
925	92.5% silver; sterling silver	Nickel silver	No silver content; also called German silver
999	99.9% silver; fine silver	EPNS	Electroplated nickel silver
SP	Silver plate		

Density (Specific Gravity) and Heft
Handling a piece of jewelry will give you a sense of the metals involved. As the density or specific gravity increases, there is a sense of the piece feeling heavier. This is referred to as heft.
Alloying can alter density due to different amounts of alloying metals, but it is also an inherent property of precious metals (see Table 8). Platinum, for example, is denser (with an SG of 21.45) than other precious metals and heavier than all gold alloys.

Table 8

Metal	SG	Metal	SG
Sterling Silver	10.2	**18K Yellow Gold**	15.2 – 15.9
Palladium (5% Ruthenium)	11.8	**18K Palladium White Gold**	15.9
14K Rose Gold	13.0	**Pure Gold**	19.3
14K Yellow Gold	12.9 – 14.6	**950 Platinum**	20.1
14K Palladium White Gold	14.6		

Discussion: Metal Basics
The basics of fineness begin with the understanding that precious metals are rarely used in their pure form as they are too soft, so they are mixed with other metals to create an alloy more suitable

for jewelry use. Reference to this purity mix is called the 'fineness.'

Before assessors can identify and evaluate a piece of jewelry, they must understand properties of precious metal alloys and recognize related fineness marks (Tables 5-7). Jewelry items can be stamped, laser-inscribed, hand-engraved, or etched with various marks that can provide insight into the purity of the precious metal, who is responsible for making the jewelry item, and marking the claim of metal fineness. If hallmarked, information about country of origin, possibly age, and more may be present.

Systematic examination of various precious metal jewelry marks makes assessment less confusing. If present, the most straightforward and helpful mark is the metal's fineness mark. Usually, a precious metal object, such as an item of jewelry, will have a fineness mark to note the proportion of pure precious metal used in the piece to the other alloy metals used to create the metal make-up. Once that is discovered, look for the maker's or responsibility mark. Any other marks or Hallmarks[24] that are present can offer additional information.

An assessor needs to understand basic metal properties and the significance of these differences (Tables 1–4, 8). Understanding how different common precious metal alloys work or wear helps identify any inconsistencies with the fineness mark.

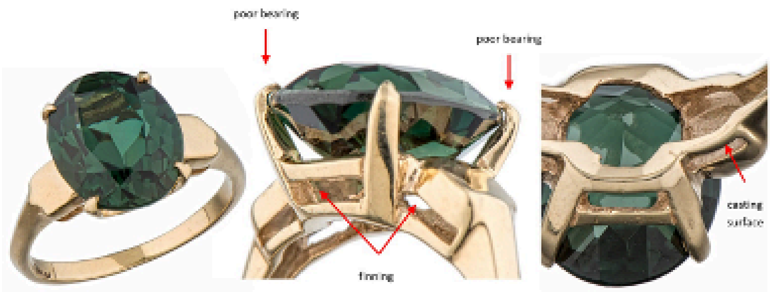
Conclusion

Assessors need this systematic approach with a knowledge base that carefully identifies an item's manufacturing method and condition, focusing on the risk of failure when worn. Whether they are buyers, sellers, repairers, or appraisers, this approach assists in adequately assessing a jewelry item.

Familiarity with various manufacturing traces and applying the Jewelry Forensic investigative process provides the framework for a successful and thorough evaluation. For example, die-struck styles from the 1920s and other eras are reproduced today by CAD/CAM and other processes. Awareness of the differences in traces will assist in correctly identifying reproductions). It is vital that assessors precisely characterize quality and condition risks when evaluating a piece of jewelry, rendering their reports 'fit for purpose."

Conscientious disclosure of the findings identifies potential issues for the customer and protects the assessor from bearing any responsibility for the customer/insurer's financial loss. Remember the difference between the risk of loss due to wear over time, which a jeweler can repair, and those due to errors in workmanship and engineering (which sometimes can be fixed).

EXAMPLE RING—GREEN SYNTHETIC SPINEL



IDENTIFYING CHARACTERISTICS

Metal

1 Stamped 10K. There is no trademark.

2 Yellow gold. The heft is consistent with this lightweight style.

3 The shank of the ring has been finished and polished. The interior under the stone has been left rough from casting with finning. The inside of the basket is not finished.

Manufacturing

4 There is a sizing solder joint in the back of the shank.

5 This ring has been previously sized.

6 This ring has been cast in one piece and not assembled.

Gemstones

7 There is a central oval gemstone, and it is not secure in the mounting.

8 This setting is the correct size for the gemstone. However, the workmanship is poor, placing this stone at risk.

9 Prongs are short at less than 10% coverage, and the bearing seats are poorly cut and inconsistent. The stone is not level.

Item Quality

10 There are no mechanical parts.

11 The overall quality and integrity of the ring is poor—the shank has been thinned.

12 This is a mass-manufactured item for the mid to low-end market segment—not designed for long-term wear.

CBD-JFS/S1-043 *Photo by Emily Lane*

Notes

[1] Corti, C. (2003a), Technology's Relevance to Jewellery Design," World Gold Council, London, UK. Republished at http://www.ganoksin.com/article/technologys-relevance-to-jewellery-design/ (accessed Aug. 26, 2021).

[2] Hand Fabricating is building metal structures by hand cutting, bending, hammering, and assembling processes.

[3] Federal Trade Commission (2018), "Guides for the Jewelry, Precious Metals and Pewter Industries," *Federal Register*, Vol. 83, No. 159, http://www.federalregister.gov/documents/2018/08/16/2018-17454/guides-for-the-jewelry-precious-metals-and-pewter-industries (accessed Aug. 26, 2021).

[4] Casting forms a solid article by melting metal or alloy, pouring it into a mold, and allowing it to cool and solidify. In jewelry, a piece is generally molded to a net (final) shape by the lost wax (or investment) casting process before being finished by polishing, setting, etc.

[5] Die striking is the act of using a die set (tool base and punch) to strike, stamp, or form sheet metal.

[6] Mitchell, J. (2017), "Vickers Hardness Test: What It Is and How it's Measured," http://www.engineeringclicks.com/vickers-hardness-test/ (accessed Aug. 26, 2021).

[7] Grimwade, M. (2009), *Introduction to Precious Metals*, Brynmorgen Press, Brunswick, Maine.

[8] *Glossary of Precious Metal Industry Terms* (1987), published jointly by the International Precious Metals Institute, Allentown, Pennsylvania, and Met-Chem Research Inc, Boulder, Colorado.

[9] Ibid.

[10] Grimwade, M. (2009), *Introduction to Precious Metals*, Brynmorgen Press, Brunswick, Maine.

[11] "Casting Grain Specifications" (2021), Hoover and Strong, http://www.hooverandstrong.com/casting-grain-specifications (accessed Aug. 26, 2021).

[12] Cretu, C. and van der Lingen, E. (1999), "Coloured Gold Alloys," *Gold Bulletin*, Vol. 32, pp. 115–126, http://link.springer.com/article/10.1007/BF03214796 (accessed Aug. 26, 2021).

[13] Mitchell, J. (2017), "Vickers Hardness Test: What It Is and How it's Measured," http://www.engineeringclicks.com/vickers-hardness-test/ (accessed Aug. 26, 2021).

[14] Grimwade, M. (2009), *Introduction to Precious Metals*, Brynmorgen Press, Brunswick, Maine.

[15] Dawson, G., Grice, S., and Nyce, A. (2005), "Jewelry Alloy Hardening and Hardness Testing," *The Santa Fe Symposium on Jewelry Manufacturing Technology*, Met-Chem Research, Albuquerque, New Mexico, pp. 159–192, http://www.santafesymposium.org/2005-santa-fe-symposium-papers/2005-j metallurgy-part-v -and-hardness-testing (accessed Aug. 26, 2021).

[16] Whetstone, W.; Niklewicz, D., and Matula, L. (2010), *World Hallmarks*, Vol. 1, Hallmark Research Institute, San Francisco.

[17] *Glossary of Precious Metal Industry Terms* (1987), published jointly by the International Precious Metals Institute, Allentown, Pennsylvania, and Met-Chem Research Inc, Boulder, Colorado.

[18] Corti, C. (2018), "Jewellery-Is It Fit for Purpose? An Analysis Based on Examination of Customer Complaints," COReGOLD Technology Consultancy, Jewelry Technology Forum, Reading, UK, https://www.legor.com/en-us/jewellery-is-it-fit-for-purpose-an-analysis-based-on-examination-of-customer-complaints (accessed Aug. 14, 2023). Republished in *The Santa Fe Symposium on Jewelry Manufacturing Technology (2018)*, Met-Chem Research, Albuquerque, New Mexico, pp. 163–175.

[19] Corti, C. (2022), "Basic Metallurgy of the Precious Metals, Part IV: Deformation, Processing, Joining and Corrosion," *2022 Santa Fe Symposium Papers*, pp133-160. www.santafesymposium.org/2022-santa-fe-symposium-papers/2022-basic-metallurgy-of-the-precious-metals-part-iv-deformation-processing-joining-and-corrosion

[20] "Antique Jewelry University: Platinum" (n.d.), Lang Antiques, www,langantiques.com/university/platinum-2/ (Accessed Aug 26, 2021)

[21] "Make Platinum Memories: In Japan, Platinum's Unique Patina Is Revered as a Roadmap of Life's Journey" (n.d.), http://platinumjewelry.com/platinum-pulse/japan-platinums-unique-patina-revered-roadmap-lifes-journey/ (accessed March 12, 2019).

[22] Corti, C. (2022), "Basic Metallurgy of the Precious Metals, Part IV: Deformation, Processing, Joining and Corrosion," *2022 Santa Fe Symposium Papers*, pp133-160. www.santafesymposium.org/2022-santa-fe-symposium-papers/2022-basic-metallurgy-of-the-precious-metals-part-iv-deformation-processing-joining-and-corrosion

[23] Corti, C. (2019a), "Basic Metallurgy of the Precious Metals, Part III: Cracks and Other Defects–Their Causes and Prevention," *The Santa Fe Symposium on Jewelry Manufacturing Technology*, Met-Chem Research, Albuquerque, New Mexico, pp. 101–122, http://www.santafesymposium.org/2019-santa-fe-symposium/basic-metallurgy-of-the-precious-metals-part-iii-cracks-and-other-defectstheir-causes-and-prevention (accessed Aug. 26, 2021).

[24] If it is a hallmark, then the fineness mark is a guarantee.