Gold Purity Determination Using Ultrasonic Wave : A Review

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ABSTRACT

Gold purity is an important feature that has a direct impact on its market value as the purer the gold is, the more expensive the price will be. The method of verifying gold bar purity remains one of the most difficult in the gold industry. The objectives of this paper are to perform research on the principles used to identify the purity of gold, suggest and build a simulation model as an alternative way to determine the purity of gold and able to compare the results obtained. The review assesses the strengths, limits, and possible uses of technology, providing useful insights into its potential use in precious metal analysis. There are two common methods in determining the purity of the gold bar, which are the destructive and non-destructive methods. The destructive techniques, such as the fire assay method, will destroy the gold sample. During the purity test, the non-destructive procedure will not destroy the gold sample. This study dives into the principles and methodologies employed in several non-destructive techniques, such as density, XRF, and ultrasonic testing, to investigate their effectiveness in precisely analyzing gold purity The findings of this review contribute to a comprehensive understanding of non-destructive gold purity testing techniques and its implications for industry and research.
Keywords: Purity of gold, Hydrostatic Weighing System (HWS), X-ray fluorescence (XRF), Ultrasonic

1. Introduction

It is important to determine the purity of gold accurately because the price of the gold is depending on the purity of the gold bar. The purer the gold is, the more expensive the price will be. There are two ways to determine gold purity, which is the destructive and non-destructive method [6]. The destructive method will destroy the gold sample such as the fire assay method. The non-destructive method will not destroy the gold sample during the purity test. Some of the examples of non-destructive techniques used are density measurement, X-Ray Fluorescence (XRF) and Ultrasonic inspection.

Nowadays, there are so many fake gold bars in the market that are plated or insert some others metals inside the gold bar. This is known as gold bar adulteration. Tungsten was used because of its density which is very similar to the pure gold bar, 19300 kg/m^3 and cannot be detected using the density method, as shown in Figure 1. Ultrasonic testing was chosen to determine this kind of fake gold bar because when ultrasonic waves pass through a medium, they will reflect when they hit a boundary or obstacle. From the sound wave result obtained, it can easily determine the presence of other metals in the gold bar because the amplitude and wave pattern produced will differ compared to the wave reflection coming from opposite of the gold bar. There are several existing devices in the market to perform this ultrasonic detection, but all require the purchasing of a gold bar and also instruments needed which will cost a lot.

In conjunction to solve this problem, two sets of simulations were conducted using COMSOL Multiphysics® software [1] to determine the difference in the waveform for the gold bar with and without impurities. The results were then compared and further analyzed to prove that impurities in the gold bar can be determined by using simulation.

Figure 1. Fake gold bar that contains tungsten [12]

2. Determining the purity of gold

There are two common ways of determining the purity of the gold bar, which are the destructive and non-destructive methods. The destructive method for example uses a fire gas torch to burn the gold bar and identify the color changes. When the pure gold bar is exposed to the high-temperature flame, it will become brighter but for fake gold, it will become darker. This is the simplest way to determine the purity of a gold bar however, during the burning process, the gold bar will melt. So, this is not the best method in determine the purity of the gold bar. This paper will more focus on the non-destructive method. The non-destructive method will not destroy the gold bar and is more convenient. Examples of non-destructive methods are density measurement, X-Ray Fluorescence (XRF) and ultrasonic inspection.

2.1 Verification of the hydrostatic weighing system with existing gold purity instruments

The authors of this paper [8] carried out several measurements of density for gold bar and tungsten bar because they found out that the existing instruments have a limitation to determine the purity, which in turn have produced inaccurate gold purity measurement. For example, X-ray fluorescence (XRF) technique has a limitation to penetrate into the gold bar and it was only used to determine the surface purity. Two different methods are used by the authors to determine the gold purity, which is densimeter and Hydrostatic Weighing System (HWS). Figure 2 shows example of densimeter.

Densimeter consists of an analytic balance and a container that is filled with liquid to determine the density of the gold. The densimeter measurable range for type AlfaMirage: Model GK-300 is 5 g to 300 g. The density obtains from the densimeter is 0.1 g/ml. Commonly, the standard liquid used in the densimeter is distilled water since it is pure water and has a density of 1 g/ml [8]. In this method, the difference between the gold weight in air and distilled water is measured and calculation was done by using Equation (1).

The equation to calculate the density of the gold.

$$\rho_{gold} = \frac{m_a \rho_l}{m_a - m_b} \quad (1)$$

However, the presence of the tungsten cannot determine by densimeter because the density of tungsten is very close to that of pure gold which is 19.3 g/ml. So, we cannot figure out the fake gold bar that contains tungsten by using a densimeter.

Figure 2. Example of densimeter.

HWS has been set up and operates based on Archimedes' principle. In density measurement, the sample was weighed using an analytical balance in the air and noted as R_1. Then, the sample was immersed in standard distilled water and weighed again as R_2. The volume of the sample, V' will change due to temperature, Δt changes and the volume thermal expansion, γ of the sample. So, the volume of the sample, V' is calculated using Equation (2). To ensure accurate calculation, all factors affecting the gold purity such as density of distilled water (ρ_w), air density (ρ_a), mass in liquid and liquid temperature were considered. These parameters were also identified to evaluate the expanded uncertainty of measurement. Finally, the density of the sample, ρ_c can be determined using Equation (3)[8].

$$V' = \frac{R_1 - R_2}{\rho_w - \rho_a}(1 + \gamma\Delta t) \tag{2}$$

$$\rho_c = \frac{R_1}{V'} \tag{3}$$

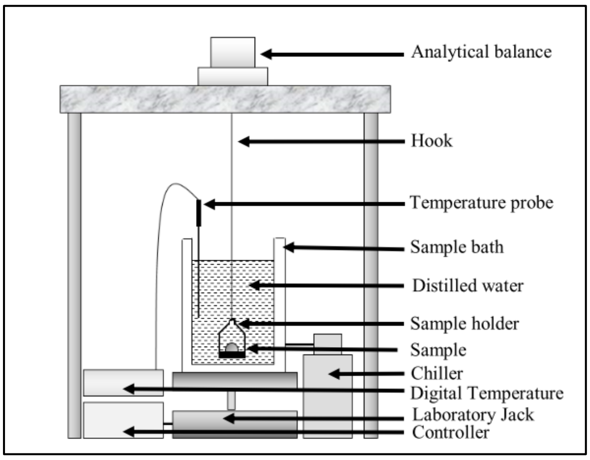

Figure 3. Experiment setup for HWS [8]

2.2 New Development of the Metal Volume Thermal Expansion

In this paper, the authors [7] state that the existing instruments such as the dilatometer cannot determine the volume thermal expansion of the material. Therefore, a new and precise system has been proposed to determine the volume thermal expansion. In the study, several samples such as gold and tungsten were used to determine their volume thermal expansion by using a custom-made hydrostatic weighing system (HWS) where the experimental results show that the HWS can determine the volume thermal expansion. This newly developed HWS has some advantages such as being able to measure any shape and size of the sample and better temperature stability since it was equipped with a temperature controller.

Hydrostatic Weighing System (HWS) can determine the volume of gold and tungsten can be determined without destroying the gold bar by using this method. To begin with, the gold sample will be weighed in the air by using an analytical balance and jotted down as B_1. Then, immersed the sample in the distilled water which acts as a standard liquid and jots down the weight again as B_2. The difference between B_1 and B_2 can be derived by using Equation (4).

$$B_1 - B_2 = \left[m\left(1 - \frac{\rho_a}{\rho}\right)\right] - \left[m\left(1 - \frac{\rho_l}{\rho}\right)\right] \tag{4}$$

After that, the volume V_1 of the sample at temperature t was calculated using Equation (5).

$$V_1 = \frac{B_1 - B_2}{\rho_l - \rho_a} \tag{5}$$

The temperature of the distilled water will increase or decrease based on the function of the chiller. The initial temperature of the distilled water is measured as T_1. When the temperature is increased to T_2, the volume of the sample, V_1 will change and be jotted as V_2. The difference in the temperature between T_1 and T_2 is stated as Δt [7]. The thermal expansion coefficient, β can be derived as shown in Equation (6).

$$\beta = \frac{V_2 - V_1}{V_1 \Delta t} \quad (6)$$

The results obtained from the experiment by the researcher can be shown in Table 1.

Table 1 Volume thermal expansion coefficient of metal with uncertainty at K= 2 [7]

Material	Sample	B (°C^{-1})	U (K=2)
Gold Rod	M1	0.00045	0.0003
Gold Bar	M2	0.00037	0.0003
Gold Bar	M3	0.00063	0.0003
Gold Bar	M4	0.00031	0.0003
Tungsten Rod	M5	0.00023	0.0003

Adapted from New Development of the Metal Volume Thermal Expansion.

However, to determine and verify the results obtained from the HWS developed, the use of a dilatometer is needed. Dilatometer was traceable to certified reference material from the National Institute of Standards and Technology (NIST). In this case, E_n was calculated by using Equation (7). If the value of E_n was lesser and equal to 1, it indicates satisfaction in HWS performance.

$$E_n = \frac{\beta_{HWS} - \beta_D}{\sqrt{U_{HWS}^2} + \sqrt{U_D^2}} \quad (7)$$

2.3 Gold Jewelry Analysis: XRF Application

In this paper, the authors [2] further explain the non-destructive technique because it was able to retain the original physical shape of the jewellery without destroying it. According to the authors, X-ray fluorescence, also known as XRF is a non-destructive chemical analysis that is widely used in determining the elemental composition of materials. XRF can detect the elements in the Periodic Table starting from sodium to uranium. When x-ray radiation penetrates a metal sample, the atom in the metal will be ionized and electrons of the inner shell will be ejected. This is because the high energy of incident x-ray radiation compared to the binding atom energy in the metal will break the atomic bonds and electrons were ejected. At the same time, the electrons from higher states of the shell will jump into the vacancy generated by the ejected electrons and causing energy loss. This energy loss or the emitted energy is called secondary x-ray radiation or fluorescence. A detector will detect the fluorescence produced and counts the radiation as dispersion. It will separate them into radiation of different elements presented and displayed on the monitor. This fluorescence can be analyzed to detect elements in the sample.

The intensity of gold can be easily determined by using the XRF method and thus the purity of the gold can be determined and observed. However, XRF method can However, XRF can only test on the surface of the jewellery up to 2 mm in depth [2]. Usually, to carry out gold analysis using XRF, an XRF spectrometer is used. Figure 4 and Figure 5 shows some examples of XRF spectrometer.

Figure 4. S1 TITAN Handheld XRF Spectrometer [11]

Figure 5. EDXRF Spectrometer

To perform a quantitative analysis of the result, a calibration curve was drawn. Figure 6 show the relationship between the gold target element and measured intensity. The composition of unknown gold can be determined. From the graph, we know that sample 003 is gold 916 because the percentage of the gold intensity is 91.53.

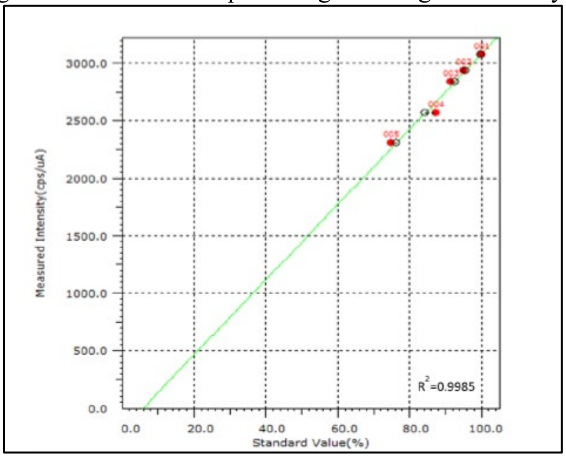

Figure 6. Calibration curve of gold standards [2] .

3. Fake Gold: Gold Purity Measurement Using Non-Destructive Method

The authors of this report method [6] present the limitation of the non-destructive method instruments such as densimeter, weighing balance, x-ray fluorescence (XRF) and ultrasonic in gold purity determination. This review has shown the difficulties to identify fake gold using a non-destructive. The results obtained are then tabulated as shown in Table 3.

Table 3 Limitations for non-destructive method instruments [6]

Instrument	Method	Unit	Limitation
XRF	Surface	%	Penetrate 10 to 50 microns
Weighing Balance	Whole	g/ml	Similar to tungsten density
Densimeter	Whole	g/ml	Similar to tungsten density
Ultrasonic	Whole	m/s	Similar to tungsten density

Adapted from Fake Gold: Gold Purity Measurement Using Non-Destructive Method

3.1 Ultrasonic inspection of fake gold jewelry

This paper [3] is focused on explaining the experimental result of ultrasonic inspection of fake gold used for jewelry. In this paper, the longitudinal wave velocity is measured to determine the presence of impurities inside gold jewelry. The velocity of sound for any particular metal can be measured by applying ultrasonic pulses and measuring the time taken for the pulses to travel through the material.

In ultrasonic testing, sound energy travels through a solid substance by a sequence of minute displacements. The three fundamental modes of sound propagation in materials are a surface wave, longitudinal wave, and transverse wave. A single particle oscillating along the direction of propagation creates a wave known as a longitudinal wave. Ultrasonic testing is most frequently used for this type of transmission since it is easily generated and detected. The sound energy used in ultrasonic testing originated as longitudinal sound and then may be converted to other modes for special applications. The velocity of sound propagation varies from one material to another. When the ultrasonic wave or sound beam strikes a plane separating two materials, some of the waves are transmitted forward and the remainder is reflected backward [3]. This is depending on the elastic property and density of the material and can be calculated by using Equation (2.8) which c is the wave velocity, E elastic modulus and ρ is density. Figure 7 is one of the results obtained from the experiment carried out by the authors.

$$c = \sqrt{\frac{E}{\rho}} \tag{2.8}$$

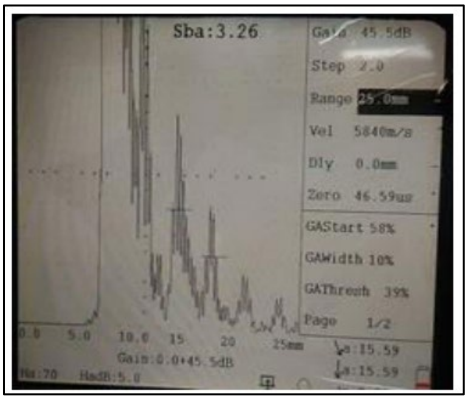

Figure 7. Ultrasonic signals from the fake gold jewelry [3]

3.2 Ultrasonic testing of gold bar

When ultrasonic waves pass through a medium, they are reflected when they hit a boundary. Ultrasonic flaw detectors and phased array instruments will use small, hand-held transducers to generate high-frequency sound wave pulses as shown in figure 8 The sound energy is connected to the test piece and the instrument monitors to obtain the reflected echoes' pattern. From the result obtains, we can easily determine the presence of other metals in the gold bar because the pattern will differ compared to the wave reflection coming from opposite of the gold bar. [10]. By using the ultrasonic method, we can easily determine the gold bar that is plated with tungsten as shown in Figure 9.

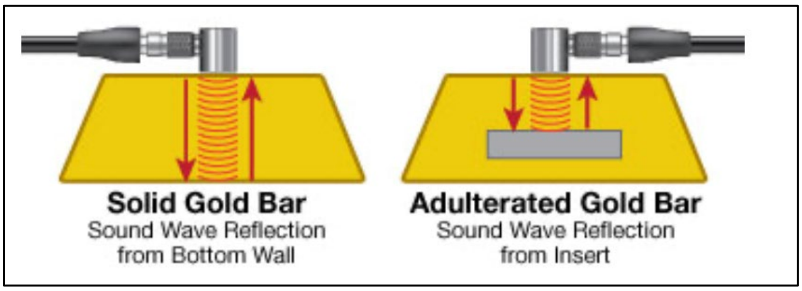

Figure 8 Different wave reflections between the pure gold bar and adulterate gold bar [10]

Figure 9. 100 g gold bar plated with tungsten [6]

Figure 10 show an example of the result carried out by the researcher using the ultrasonic method to determine the presence of tungsten in the gold bar.

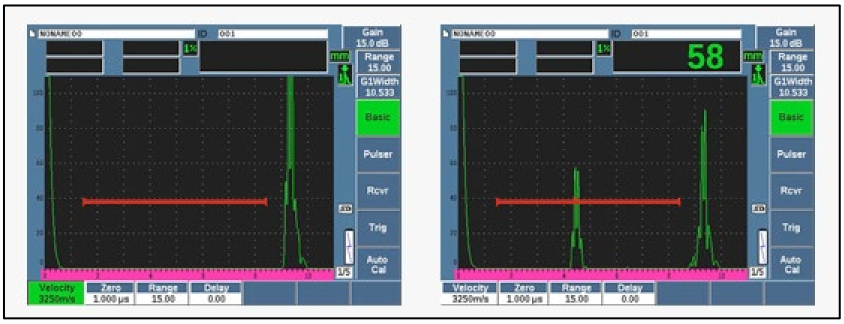

Figure 10. Waves obtain for the pure gold bar (left) and adulterate gold bar (right) [10]

4. Introduction to the Elastic Waves, Time Explicit Interface

Mads Herring Jensen [4], the author of this article briefly explains the usage of Elastic Waves, Time Explicit Interface in COMSOL Blog. In general, the Elastic Waves, Time Explicit interface is suited for modeling the propagation of elastic waves over large distances relative to the wavelength, such as ultrasound propagation like nondestructive testing (NDT) applications or seismic wave propagation in soil and rock. The interface exists in 2D and 3D, besides including absorbing layers that are used to set up effective non-reflecting boundary conditions. The user interface and boundary conditions mirror the features available in the Solid Mechanics interface when applicable to wave propagation problems [4]. The user interface for Elastic Wave, Time Explicit can be seen in Figure 11.

When meshing vibration problems, it is essential to spatially resolve the propagating waves in the structure. Since different waves will have different speeds when traveling in a different medium, the shear wave speed which has a slower velocity and shorter wavelength of the materials is needed. The default for the Elastic Waves interface is to use quartic shape functions or in other words fourth-order functions [4]. The maximum element size, x can be obtained by using Equation (2.9).

$$x = \frac{c_{min}}{1.5 f_0} \tag{9}$$

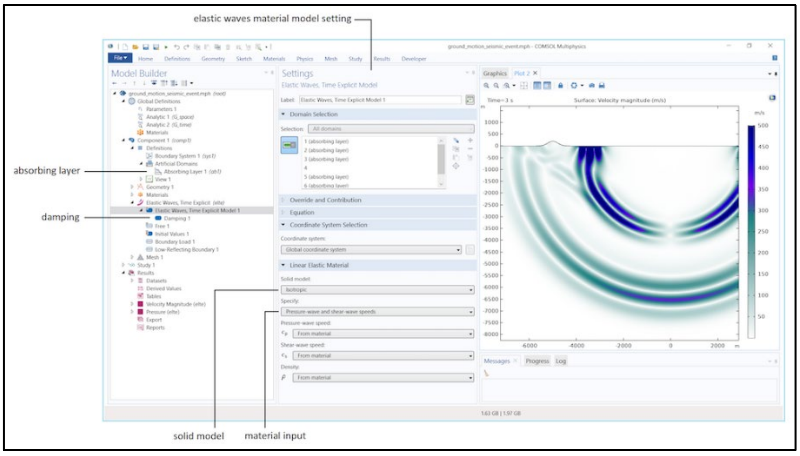

Figure 11. User interface for the Elastic Waves, Time Explicit interface [4]

5. Conclusion

Table 2.3 shows the summary of the research articles about gold purity determination. Table 2.4 shows application used in determining the purity of gold and their limitations.

Table 2.3 Overall summary of the research articles about gold purity determination

YEAR	TITLE & AUTHORS	REMARKS
2018	Ultrasonic inspection of fake gold jewellery [6]	The authors conducted an experiment utilizing ultrasonic waves to identify jewellery made of fake gold. The longitudinal wave velocity in the gold jewellery was

		measured using the ultrasonic pulse-echo contact technique. The paper then went on to discuss the outcomes.
2019	New Development of the Metal Volume Thermal Expansion [8]	This paper is about the investigation of HWS in the thermal expansion of metals. Gold and tungsten were used in the experiment.
2019	Fake Gold: Gold Purity Measurement Using Non-Destructive Method [7]	The limitation of non-destructive method instruments in determining the purity of gold by using densimeter, weighing balance, x-ray fluorescence (XRF) and ultrasonic is investigated by the authors and the results were compared and tabulated.
2020	Introduction to the Elastic Waves, Time Explicit Interface [4]	The author introduces Elastic Waves, Time Explicit Interface in COMSOL Multiphysics® software and some requirements that are needed to full field when using it.
2020	Gold Jewellery Analysis: XRF Application [2]	This paper focuses on the working principle of XRF in determining the purity of the gold bar. Besides, the author also explains the application and advantages of XRF in determining the purity of gold.
2021	Verification of the hydrostatic weighing system with existing gold purity instruments; [8]	This paper is about the development of an improved non-destructive method and precise technique to determine gold purity. The density of the gold bar was calculated using a custom-made hydrostatic weighing system (HWS).
2022	Ultrasonic testing of gold bar [10]	This article used ultrasonic waves to identify the purity of the gold bar. Comparison between the output waveform obtains able to show the difference between a gold bar with and without impurities.

Table 2.4 Overall summary of the application used in determining the purity of gold and their limitations.

No	Method	Summary	Limitation
1	Densimeter	Determine the gold bar by using the density measurement.	Cannot detect the presence of metals that have a density that is almost the same as the pure gold bar. For example, tungsten.
2	HWS	Determine the gold purity by using the thermal expansion method	It is very complicated to carry out since it requires many procedures and setups.
3	XRF	Can detect the composition of metals in the gold bar	Just able to detect the surface of the gold bar only. Besides, the apparatus used is very expensive.
4	Ultrasonic	Can determine the presence of different metals in a gold bar.	Require the needs of instruments and it is expensive.

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