TSSA Journal of Tomography System & Sensors Application Vol.5, Issue 1, 20222
www.tssa.com.my e-ISSN: 2636-9133

A Review on Determining Purity of Gold Using Sensor

Pok Wei Han[1], Raudahtusoufwah Ruzairi[2], Mohamed Shukri Abdul Manaf[1*], Anita Ahmad[1], Nasaruddin Ahmad[1], Abdul Khamim Ismail[2]

[1]School of Electrical Engineering, Faculty Engineering, Universiti Teknologi Malaysia
[2] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia

Corresponding author* email : mshukri@utm.my
Available online 29 December 2022

ABSTRACT

Gold determination is a very challenging task in gold industries especially using non-destructive method. Some of the common method to determine the purity of gold will destroy the gold bar, for example, fire assay and scratch method. Besides, these types of methods need professional to carry out because it is complex and require some used of chemical. In this study, some of the non- destructive methods to identify the different golds purity were research before implement in COMSOL Multiphysics software to simulate and validate the data from gold industries. The research on this method by other researchers will be discussed in this report.
Keywords: gold determination, non- destructive methods, golds purity

1. Introduction

There are several types of gold in the world, for example: 14K, 18K, 22K, 24K and many more. All these golds are categorized based on their purity or in the other word is how many parts of others metals are added into the pure gold. 24K gold is also known as 100 percent pure gold in which 24 over 24 part is gold and for sure it is more expensive compare to others types of gold due to its excellent purity. Also, in the market, we can see there are many different colors of golds such as rose gold, white gold, yellow gold and et-cetera. All these color golds are actually depending on the metals that added into it.

It is important to determine the purity of gold accurately because the price of the gold is depending on the purity of gold bar. The purer the gold is, the more expensive the price will be. There are two ways to determine the gold purity, which is destructive and non-destructive method [1]. Destructive method will destroy the gold sample such as fire assay method. Non-destructive method will not destroy the gold sample during the purity test. Some of the non-destructive technique use is density, XRF and Ultrasonic.

However, in real life, to perform determination or research on the gold bar is not applicable for all the industries due to the price of the gold in the market. To perform determination of gold 916, a large number of gold plate are needed and the problem is, not all the industries can afford it since it is too expensive. The price of the gold based on purity is different from time to time. For example, the price for gold 999, or 24K gold is RM 277.55 per gram and the price of gold 916, or 22K gold is RM 254.49 [2]. A simplest and easy way to solve this problem is by simulation. One of the biggest advantages by using simulation is, we can get the gold bar in any size without limitation. In this study, some researches were made to identify the purity of golds before implement it in COMSOL Multiphysics software to validate the data from gold industries.

2. Non-destructive method

2.1 Densimeter

Densimeter consist of an analytic balance and a container that 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 that obtains from the densimeter is 0.1 g/ml. Commonly, the standard liquid use in the densimeter is distilled water since it is pure water and has a density of 1 g/ml [3]. In this method, the different of the gold weight in air and in distilled water is measured and

Vol.5, Issue 1, 20222
e-ISSN: 2636-9133

calculation was done. After that, the results are compared with the density of pure gold, which is 19.3 g/ml to determine the purity. Different gold has different density and this can be seen in Table 1.

Equation to calculate the density of the gold:

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

Where:

ρ_{gold} : Density of gold (g/ml)
ρ_l : Density of liquid (g/ml)
m_a : Mass of metal in the air (g)
m_b : Mass of metal in liquid (g)

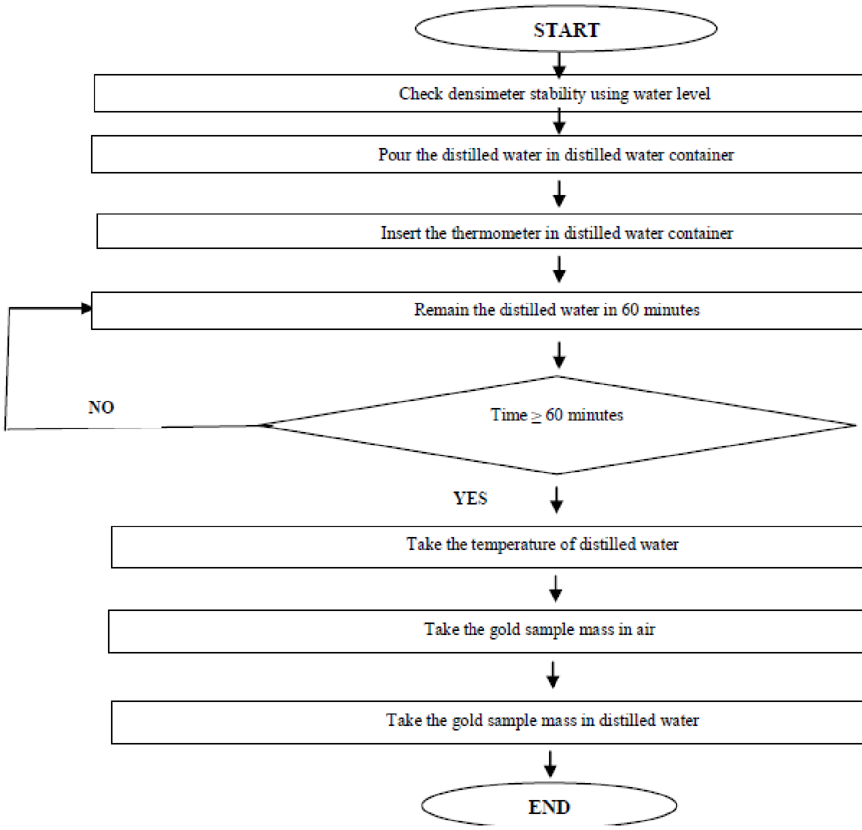
Table 1. Density for each type of gold

Gold	Content	Alloyed Metal			Density Range
		Copper	Copper & Silver	Silver	
K24	1000/1000		19.32		19.13~19.51
K22	916/1000	17.63	17.73	18.06	17.45~18.24
K20	834/1000	16.19	16.42	16.94	16.03~17.11
K18	750/1000	14.99	15.24	15.96	14.84~16.12
K14	584/1000	13.04	13.38	14.30	12.91~14.44
K10	417/1000	11.54	11.91	12.96	11.42~13.09

Adapted from METTLER TOLEDO-Jewelry density table.

By this method we can get the density of gold and from here we can differentiate the type of gold. Gold 916 has a density range of 17.45-18.25 g/ml, depending on the type of metals added. However, the present of the tungsten cannot determine by densimeter because the density of tungsten is very close to the pure gold [3] which is 19.3 g/ml. So, we cannot figure out the fake gold bar that contain tungsten by using densimeter.

Figure. 1. Figure show example of densimeter.



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

Figure. 2. Procedure to determine gold density using densimeter.

2.2 Hydrostatic Weighing System (HWS)

Hydrostatic Weighing System (HWS) use the principle of thermal expansion of the metals. It is a bit more complex compare to others. The volume of gold and tungsten can be determined without destroy the gold bar by using this method. To begin with, the gold sample will be weighed in air by using an analytical balance and jotted down as A_1. Then, immersed the sample in the distilled water which act as a standard liquid and jot down the weight again as A_2 [4]. The difference between A_1 and A_2 can be derived as the equation shown in equation below.

$$A_1 - A_2 = [m\,(1 - \frac{\rho_a}{\rho})] - [m\,(1 - \frac{\rho_l}{\rho})] \quad (1)$$

After that, the volume V_1 of the sample at temperature *t* was calculated.

$$V_1 = \frac{A_1 - A_2}{\rho_l - \rho_a} \quad (3)$$

Where:

A_1, A_2 : Balance reading (g)
m : Mass of sample (g)
ρ_a : Density of Air (g/ml)
ρ_l : Density of liquid (g/ml)
ρ : Density of sample (g/ml)
V_1 : Volume of the sample at temperature t

After that, 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 increase to T_2, the volume of the sample, V_1 will change and jotted as V_2. The difference in the temperature between T_1 and T_2 is stated as Δt [4]. Thermal expansion coefficient, β can be derived as shown in equation below.

$$\beta = \frac{V_2 - V_1}{V_1 \Delta t} \qquad (2)$$

Table 2 show the results obtain from the experiment.

Table 2. Volume thermal expansion coefficient of metal with uncertainty at K= 2

Material	Sample	β (°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 obtain from the HWS developed, the use of dilatometer is needed. Dilatometer was traceable to certified reference material from National Institute of Standards and Technology (NIST) [4]. In this case, E_n was calculated.

$$E_n = \frac{\beta_{HWS} - \beta_D}{\sqrt{U^2_{HWS}} + \sqrt{U^2_D}} \qquad (3)$$

Where:

β_{HWS} : Volume thermal expansion value determined by HWS
β_D : Volume thermal expansion value determined by Dilatometer
U_{HWS} : Expanded uncertainties of HWS
U_D : Expanded uncertainties of Dilatometer
$|E_n| \leq 1$: Indicates satisfaction in HWS performance
$|E_n| > 1$: Indicates unsatisfaction in HWS performance

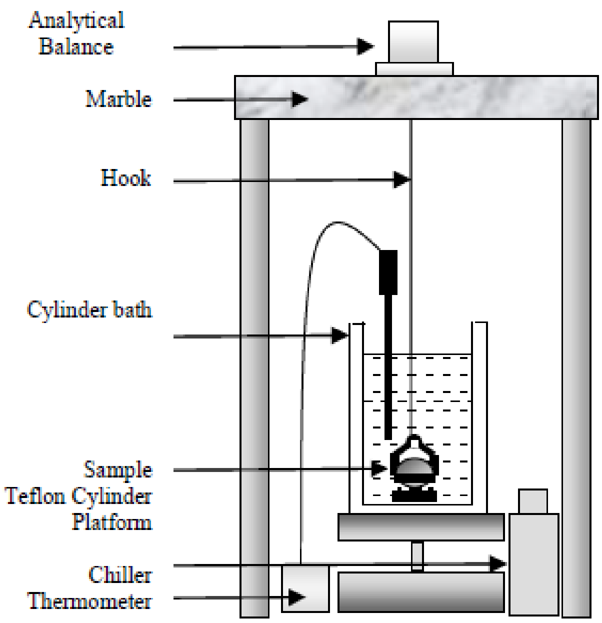


Figure. 3. Measurement setup for HWS system.

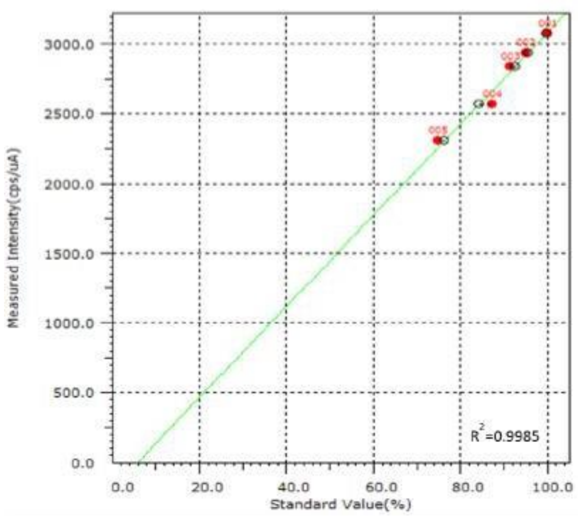
2.3 X-ray fluorescence

X-ray fluorescence, or also known XRF is a non-destructive chemical analysis that is widely use in determine the elemental composition of materials. XRF able to detect the elements in the Periodic Table start from sodium to uranium. When x-ray radiation penetrates a metal sample, the atom in the metal will be ionized and electrons of 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 broke the atomic bonds and electrons were ejected. At the same time, the electrons from higher states of shell will jump into the vacancy generated by the ejected electrons and causing energy loss. This energy loss or the emitted energy is called as the secondary x-ray radiation or the 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 monitor. This fluorescence can be analyzed to detect elements in the sample [5]. The intensity of gold can be easily determined by using XRF method and thus the purity of the gold can be determined and observed. However, XRF method can only penetrate 10 to 50 microns of the element, which is just on the surface and it is not able to detect the present of the tungsten in the middle of the gold bar [1]. Usually, to carry out gold analysis using XRF, a XRF spectrometer is use. Figure 4 and figure 5 shows some examples of XRF spectrometer.

Figure. 4. S1 TITAN Handheld XRF Spectrometer.

Figure. 5. iQ II XRF Spectrometer

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

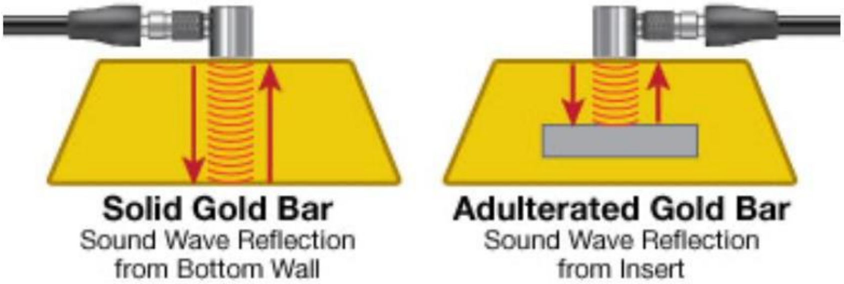


Adapted from GOLD JEWELRY ANALYSIS: XRF APPLICATIONS

Figure. 6. Calibration curve of gold standards.

2.4 Ultrasonic inspection

When ultrasonic waves pass through a medium, they are reflected back when they hit a boundary. Ultrasonic flaw detectors and phased array instruments will use small, hand-held transducers to generate high-frequency sound waves pulses. The sound energy is connected into the test piece and the instrument monitors to obtain the reflected echoes' pattern. From the sound wave result obtain, we can easily determine the present of other metals in the gold bar because the pattern will differ compare to the wave reflection coming from opposite of the gold bar. The sound velocity in pure gold is 3,240 m/S or 0.1275 in/uS. The harder gold alloys used in jewelry will typically be somewhat faster, but will similarly have a specific velocity associated with a given alloy. The content of the metal is modified if the sound velocity in a bar different from the expected value [6]. This is because when there is different materials presence in the gold bar, some of the ultrasonic wave will reflected at the interface and other partly pass through it [7].



Adapted from VM Vision: Ultrasonic testing of gold bars

Figure. 7. Figure illustrate different of wave reflection between pure gold bar and adulterate gold bar.

By using ultrasonic method, we can easily determine the gold bar that is plated with tungsten as shown in Figure 8.

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

Figure. 8. 100 g gold bar plated with tungsten.

Figure 9 below show the sound velocity of pure gold. The velocity of 916 gold pendant is between 3304 – 3454 m/s [7].

Material	Density kg/m^3	c trans m/s	c trans m/s	Z 10^3 Pa s/m
aluminium	2700	3130	6320	17 064
aluminium oxide	3600	5500	9000	32 400
bismuth	9800	1100	2180	21 364
brass	8100	2120	4430	35 883
cadmium	8600	1500	2780	23 908
cast iron	6900	2200	5300	24 150
concrete	2000	–	4600	9 200
copper	8900	2260	4700	41 830
glass	3600	2560	4260	15 336
glycerine	1300	–	1920	2 496
gold	19300	1200	3240	62 532
grey casting	7200	2650	4600	33 120
hard metal	11000	4000	6800	74 800
lead	11400	700	2160	24 624
magnesium	1700	3050	5770	9 809

Adapted from Ultrasonic Testing of Materials at Level 2.

Figure. 9. Densities, sound velocities and acoustic impedances of some common materials.

By using the mathematical expression, the velocity of the ultrasonic wave obtain in the output waveform in the materials can be obtain by using the equation below.

$$V = \lambda f \tag{4}$$

Where:

V : Velocity of sound wave (m/s)
λ : Wavelength
F : Frequency (Hz)

3. Conclusion

Gold is the most reasonable choice as a medium of exchange for goods and services. This metal is plentiful enough to make coins, but rare enough because only a few people able to make them. Gold does not corrode, making it a long-term store of value, and peoples are physically and mentally attracted to it [9]. So, we can't deny that gold had become a part of our daily life. Gold determination is important in some industries, such as gold or jewelries industries because the price of the gold is based on the purity. There are a few non-destructive methods such as densimeter, HWS, XRF and Ultrasonic inspection. All of these methods require the usage of specific apparatus and materials. Thus, a simplest way in determining the gold should be implemented. From the research made, we know that different gold has different density. For example, the density of gold 916 is 17.260 g/ml but for gold 998 is 19.222 g/ml. Besides, the sound velocity of the pure gold is 3240m/s but for gold 916 is in between 3304 – 3454 m/s. In this case, research on COMSOL Multiphysics software to perform simulation on determine gold can be done and validate with industrial result.

Determining of gold 916 using simulation of COMSOL Multiphysics software able to solve the problem for some small industries in purchasing of gold bar. The price of gold is unstable and keep changing from time to time. Besides, it is very expensive. So, it is very difficult to buy the gold bar at the minimum pricing. They can perform simulation to get the data needed instead from buying the real gold plate and perform identification manually. By using COMSOL software, it is hope that it able to decrease workloads and reduce the time in determining gold 916.

Acknowledgemet

This work has been supported by Universiti Teknologi Malaysia under UTM EncouraSPACE Quick Win Research Grant (Q.J130000.7751.4J551).

References

[1] Fazrul Mohd Nor, Abd Rahman Tamuri and Abd Khamim Ismail, "*Fake Gold: Gold Purity Measurement Using Non Destructive Method* " , International Journal of Engineering & Technology, 8 (1.1) (2019) 165-172.

[2] *Gold price Malaysia Today*. Gold Price Malaysia Today. (n.d.). Retrieved December 25, 2021, from https://goldrate.com/gold-price-malaysia/ .

[3] Fazrul Mohd Nor, Abd Rahman Tamuri , Abd Khamim Ismail and A.A.M.Mazuki, *"Verification of the hydrostatic weighing system with existing gold purity instruments, "* IOP Conf. Series: Materials Science and Engineering 824 (2020) 012007, doi:10.1088/1757-899X/824/1/012007.

[4] Fazrul Mohd Nor, Abd Rahman Tamuri and Abd Khamim Ismail, "*New Development of the Metal Volume Thermal Expansion,"*Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 53, Issue 1 (2019) 106-110.

[5] Roshasnorlyza Hazan, Wilfred Paulus and Nur Aqilah Sapiee, "*GOLD JEWELRY ANALYSIS: XRF APPLICATIONS*," Jurnal Sains Nuklear Malaysia, 2020, 32(1): 65 – 69

[6] VM Vision, "*Ultrasonic testing of gold bars,"* (n.d.). Retrieved November 20, 2021, from https://vmvision.eu/nl/toepassingen/edelemetalen1/.

[7] Mohamad Pauzi Ismail et al, "*Ultrasonic inspection of fake gold jewelry*", 2018 IOP Conf. Ser.: Mater. Sci. Eng. 298 012025, doi:10.1088/1757-899X/298/1/012025.

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, "*Ultrasonic Testing of Materials at Level 2 (Training Manual for Non-destructive Testing Techniques)",* TECDOC Series, 1988.

[9] Tardi, C. (2021, February 23). *"Why has gold always been valuable?"*, Investopedia. Retrieved November 20, 2021, from https://www.investopedia.com/articles/investing/071114/why-gold-has-always-had-value.asp .