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A Preliminary Study on Non-Destructive Gold Authentication Using Ultrasonic Waves

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ABSTRACT

The authentication of gold is crucial in the industries of jewellery, banking and finance, precious metal trading, as well as manufacturing and industrial use. Conventional methods such as chemical assays and visual inspections are invasive, time-consuming, and prone to errors and fraud. Consequently, there is a growing need for a reliable, non-destructive, and accurate authentication system. Recent advancements in ultrasound imaging provide a promising solution to these challenges. Ultrasound imaging reveals internal structures by analysing acoustic properties, allowing for precise assessment of gold purity and composition. This research aims to introduce a conceptual model of an authentication system that leverages ultrasound technology to enhance accuracy, reliability, and non-destructive testing capabilities for gold. The research focuses on creating a comprehensive theoretical model integrating ultrasonic principles for the authentication of gold by designing an authentication system and performing simulations using COMSOL Multiphysics software to predict system performance. This innovative approach is expected to provide substantial benefits to the jewellery industry and financial markets by ensuring the authenticity of precious materials.

Keywords: Gold Authentication, Non-destructive Testing (NDT), Ultrasonic Sensor

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1. INTRODUCTION

The authentication of gold plays a pivotal role in various industries. As the market for precious materials continues to grow, so does the risk of counterfeit products, thus ensuring their authenticity becomes more crucial [1]. Widespread practice for gold authentication, such as chemical assays (e.g., fire assay, gravimetry, potentiometric titration) and visual inspections, often involve invasive, time-consuming, and susceptible to human errors [2], [3], [4]. Furthermore, these methods are unable to provide the necessary internal or compositional details to conclusively verify the authenticity of gold [5]. Consequently, there is a growing need for more reliable, non-destructive, and efficient techniques that can offer a comprehensive assessment of both the internal and external properties of these valuable materials.

Recent advancements in ultrasound imaging present an innovative approach to address the limitations of conventional authentication methods [6], [7]. Ultrasound imaging is well-regarded for its ability to penetrate materials and reveal internal structures based on acoustic properties such as sound speed and acoustic impedance [8]. This capability makes ultrasound a powerful tool for detecting internal flaws and distinguishing material compositions [9], [10], providing valuable insights into the material's authenticity.

This research aims to develop a conceptual model of an authentication system for gold based on ultrasound technology. By leveraging the strengths of ultrasound imaging, this system seeks to improve the accuracy, reliability, and non-destructive capabilities of gold authentication processes. The research focuses on creating a theoretical model that integrates ultrasonic principles, designing and simulating an authentication system using COMSOL Multiphysics software. The anticipated outcome of this research is a novel, efficient approach to gold authentication that will benefit various industries, from jewellery to finance, by providing a reliable means of ensuring the authenticity of gold and mitigating the risks of counterfeiting.

2. LITERATURE REVIEW

Gold is one of the most valuable commodities in the world and is widely regards as a safe investment asset. For pawnbroker and jewellers, being able to accurately determine its purity is crucial [11], as it helps them give fair prices and avoid being tricked by fake or low-quality gold items.

Over the past century, the market has experienced a rise in counterfeit gold bars, many of which are merely gold-plated or contain hidden cores made of other metal. This deceptive practice is known as gold bar adulteration [1]. Driven by gold's stable value and potential to generate profit and prevent loss, fraudsters often substitute part of the gold cheaper metals such as tungsten, silver or copper. This significantly reduces production cost while allowing them to sell the adulterated bars at full market price [4]. Tungsten is the most commonly used metal for this purpose because its density (19.25g/cm^3) closely matches that of pure gold (19.3g/cm^3), making it difficult to detect adulteration through weight measurement alone [5], [12], [13], [14].

In Malaysia, the Yayasan Pembangunan Ekonomi Islam Malaysia (YaPEIM) reported over a total of 500 cases of gold scam attempts, including tungsten-adulterated gold bar [15]. To address the growing incident of gold adulteration, various methods have been developed to authenticate gold and assess its purity. These techniques can be broadly classified into destructive and non-destructive testing methods

Destructive methods such as fire assay, acid testing and gravimetric analysis required physical alteration of the sample to determine its composition. Fire assay and gravimetric analysis, though considered the gold standard in terms of accuracy, is unsuitable for retail or pawned items [16], [17]. Acid testing is more practical and widely used in pawnshops for on-the-spot assessment, but it may not be reliable for items that are gold-plated or items that contained internal adulteration (e.g., tungsten core) [18].

Conversely, non-destructive testing methods offer a better means of analysis, where the methods do not damage the gold samples, items can be tested multiple times without any loss in appearance or weight and being able to provide faster results compared to most destructive methods. Examples of non-destructive testing methods include density measurements, X-Ray Fluorescence (XRF) and ultrasonic testing [1], [19], [20].

Density measurement is limited in its ability to detect tungsten-adulterated gold. Since tungsten's density is nearly the same as that of gold, making the two indistinguishable by this method alone [5], [21]. XRF method is only able to analyse the surface layer of the item and may not detect internal adulteration, especially if a metal was adequately covered with gold layer. Moreover, XRF method required costly equipment, special procedures and standard testing facilities [4], [11].

Ultrasonic testing on the other hand, can overcome the limitations of both density measurement and XRF by detecting hidden materials or internal consistencies. It works by sending high-frequency sound waves through the gold item and measuring the time it takes for the waves to pass through. Each metal has a unique sound velocity, gold at 3240m/s and tungsten at 5180 m/s, making it possible to distinguish between them based on how sound travels through the object [1], [5], [20]. Because of its ability to detect such internal discrepancies, ultrasonic testing has become widely recognized as one of the most reliable non-destructive methods for identifying counterfeit gold bars.

3. METHODS

This research employed ultrasonic system, a non-intrusive technique capable of detecting foreign materials in gold, to accurately determine its authenticity. An ultrasonic authentication system was designed, and preliminary simulations were conducted using COMSOL Multiphysics software to predict its performance.

The simulation model was illustrated as in
Figure ***1***. It was governed by a generalized acoustic wave equation, that accounts for acoustic propagation in a heterogenous medium [22], [23]. The Equation 1 is used.

$$\frac{1}{\rho c^2}\frac{\partial^2 p_t}{\partial t^2} + \nabla \cdot \left(-\frac{1}{\rho}(\nabla p_t - \boldsymbol{q}_d)\right) = Q_m \tag{1}$$

In this expression, p_t is the total acoustic pressure, defined as the sum of the acoustic pressure fluctuations p and background pressure p_b. The variables ρ and c represent the medium's density and speed of sound, respectively. The term $\boldsymbol{q}_d$ denotes dipole-like source effects, such as those arising from local flow or scattering features, while Q_m accounts for monopole sources, including volumetric thermal expansion or other local energy additions. This formulation allows for an accurate representation of acoustic wave behaviour, including propagation, reflection, scattering and absorption due to internal heterogeneities in the material.

To implement the model, the simulation was carried out using the Pressure Acoustics, Transient interface in COMSOL Multiphysics. The geometry consisted of a two-dimensional rectangular domain representing the gold specimen. A foreign inclusion was embedded within the block, modelled as a square region with contrasting acoustic properties to simulate a potential counterfeit or impurity. The material properties for gold were defined based on standard values, with a density of approximately 19,300 kg/m^3 and a speed of sound around 3,240 m/s. The inclusion was assigned material parameters representing the metal of tungsten (W) to produce a clear acoustic impedance mismatch.

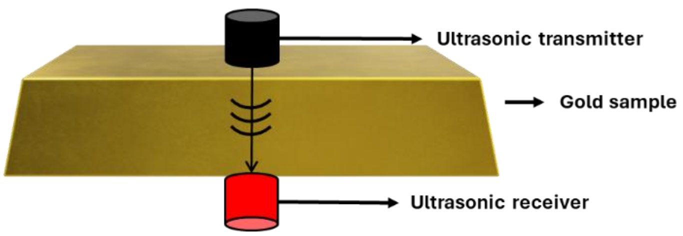

Figure 1. Ultrasonic authentication system for gold

4. RESULTS AND DISCUSSION

The simulation results in Figure 2 show a clear difference between the acoustic signals in pure gold and in impure gold (tungsten-adulterated gold). In the case of the pure gold sample (Figure 2 (a)), the received ultrasonic signal closely matches the transmitted one. The wave travels smoothly through the material without any major reflections or disturbances. This indicates that the material is uniform and free of internal defects or foreign objects. The gradual decrease in the signal's strength over time is expected and simply shows normal energy loss as the wave moves through the gold.

However, when a tungsten inclusion is introduced into the gold bar, the received signal changes noticeably (Figure 2 (b)). Although the transmitted pulse remains the same, the received wave becomes distorted. This distortion is caused by the wave bouncing off the tungsten, which has very different physical properties compared to gold. Some of the energy is reflected back toward the source, and this creates echoes or delayed signals that weren't present in the pure gold case. The signal may also lose strength or shift in shape due to scattering at the inclusion.

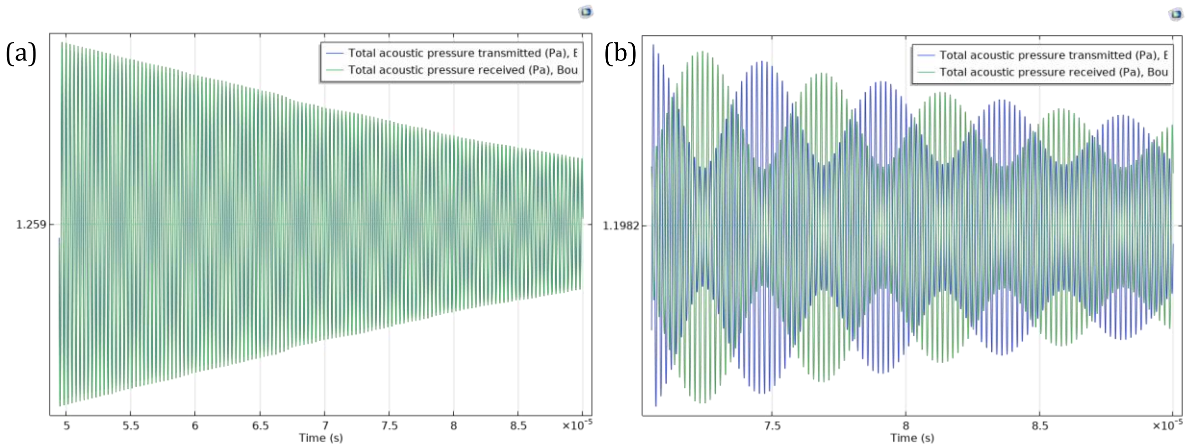

Figure 2. Simulation result from COMSOL Multiphysics Software: (a) Pure gold sample, (b) Impure gold sample.

To support this observation, a statistical dot plot (Figure 3) was generated comparing the data distributions for both pure and impure gold samples. The plot shows that the values from the pure gold cluster around a much higher range, while the impure gold (with tungsten) consistently shows lower amplitude values. This indicates that the presence of tungsten significantly affects the pressure wave behaviour inside the material. The shift in data distribution not only reinforces the visual differences in waveforms but also confirms the effectiveness of ultrasonic tomography in detecting even subtle internal changes.

CONCLUSION

As a conclusion, this proposed research successfully demonstrated the use of ultrasonic tomography as a non-intrusive and reliable technique for verifying the authenticity of gold and detecting hidden foreign materials. Using COMSOL Multiphysics, simulations were conducted on both pure gold and gold embedded with a tungsten inclusion. The results revealed that pure gold produced a clean, undistorted acoustic signal, while the presence of tungsten caused clear disruptions in the received waveform due to reflections and scattering effects.

These differences were further confirmed through statistical analysis, where the data distribution of pure gold showed consistently higher-pressure values compared to the impure sample. Together, the waveform behaviours and dot plot analysis clearly validate the method's sensitivity to internal defects or foreign bodies. Overall, ultrasonic tomography proves to be an effective approach for quality control and counterfeit detection in high-value materials like gold.

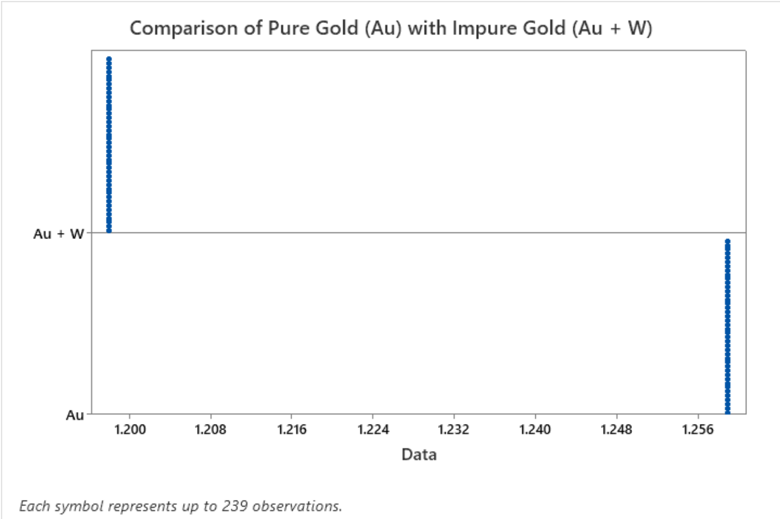

Figure 3. Dot plot of pure and impure gold sample.

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