Ultrasonic inspection of fake gold jewelry

Mohamad Pauzi Ismail1, a) Suhairy Sani1, Faris Syazwan bin Mohd Shofri2, Mohd. Harun3 and Norlaili Binti Omar4

1Agensi Nuklear Malaysia, Bangi
2Universiti Putra Malaysia
3Pensioner, Bandar Baru Bangi
4Institut Penyelidikan dan Perundingan YaPEIM (INPUT), Kuala Lumpur.

a) pauzi2010@gmail.com

Abstract. Hollow jewelry made from combination of gold and other material was found in the market. At the outside it is made of gold and the inside layer is made of other material. X-ray fluorescent method cannot detect the inside material that was covered by gold. This paper explained the experimental result of ultrasonic inspection of fake gold used for jewelry. The ultrasonic pulse echo contact method was used to measure longitudinal wave velocity in the gold jewelry. The results of measurements are explained and discussed.

1. Introduction
X-ray fluorescence (XRF) testing is one of the common methods to detect fake gold. It is however applicable to surface and near surface detection. If the metal is covered with adequate thickness of gold layer then the X-ray fluorescence cannot detect the main metal behind the gold. In other cases, fake gold bar is produced by replicating gold bar with dimensions and weight, and with enough gold plating to fool X-ray fluorescence testing using tungsten. Tungsten is very nearly the same density as gold and it can be used as a core for counterfeit bars and coins that can be made to appear identical to the real item, and also keep the correct weight. However there is one physical property that cannot be confused between tungsten and gold and that is the speed at which sound travels through metal. The sound velocity for gold is 3240 m/s and for tungsten it is 5180 m/s. The velocity of sound for any particular metal can be measured by applying ultrasonic pulses and measuring how much time it takes for the pulses to travel through the metal. This is why ultrasonic testing has become known as the best method to detect fake gold bullion bars and coins (1).

It is not difficult to detect fake gold bar and coins using ultrasonic but for complicated geometry like jewelry the technique becomes more challenging.

2. Technical background
In ultrasonic testing sound energy is transmitted through a solid material by a series of small displacement within the materials. There are three basic types of mode of sound propagation in materials, i.e. longitudinal, transverse and surface) wave. A longitudinal wave is a wave formed by individual particles oscillating in the direction of propagation. This mode of transmission is the one most often used in ultrasonic testing. This wave is the most easily generated and detected. Almost all
of-the sound energy used in ultrasonic testing originates as longitudinal sound and then may be converted to the other modes for special applications.

The velocity of sound propagation varies from one material to another. It depends on the elastic property and density of the material. It is given by,

\[ c = \sqrt{\frac{E}{\rho}} \]  \hspace{1cm} (1)

where \( c \) is the wave velocity, \( E \) elastic modulus and \( \rho \) density. Sound velocity in various materials is given in Table 1.

When the ultrasonic waves passing through a material reach the interface between that material and a material with different acoustic properties, part of the ultrasonic waves are partly passed through it and the other partly reflected at the interface. There are many kinds of interface material or boundary involved in ultrasonic testing, for example, the interface between the transducer and the test surface in a contact test, that between water and the test surface in an immersion test and that between flaws or discontinuities and the test material.

When the ultrasonic wave or sound beam strikes a plane separating two materials, some of the wave is transmitted forward and the remainder reflected backward (as shown in Figure 1). The relative amounts of reflected and transmitted beam intensities are expressed by the reflection and transmission coefficients, defined as follows,

Transmission coefficient,

\[ T = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2} \]  \hspace{1cm} (2)

where \( Z_1 \) and \( Z_2 \) are the acoustic impedance of the two materials. \( Z \) is a multiplication of density and velocity of sound in materials.

Reflection coefficient, \( R = 1 - T \)

![Figure 1. Reflection and Transmission at a plane surface, normal incidence](image)

The coefficient may be expressed either as percentages or as decreases in the number of decibels. The equation shows that the transmission coefficient approaches unity and the reflection coefficient tend to zero when \( Z_1 \) and \( Z_2 \) have approximately similar value. The materials are then said to be well matched or coupled. On the other hand, when the two materials have substantially dissimilar characteristic impedance, e.g. for a solid or liquid in contact with a gas, the transmission and reflection coefficients tend to zero and 100 per cent, respectively. The materials are then said to be mismatched or poorly coupled.
Figure 2 illustrates the principle of ultrasonic flaw detection.

![Figure 2. Principle of ultrasonic flaw detection](image)

3. Experimental Method
The fake gold jewellery received from YaPIEM are as in figure 3. The measurements were made by immersion method using 5 MHz focused probe and SIUI CTS-9009 Plus Ultrasonic Flaw Detector (figure 4). Engine oil was used as a couplant between probe and specimen.
Figure 3. Fake gold jewelleries
Figure 4. Typical ultrasonic signals from bracelet and necklace

4. Results and discussion
Figure 4 shows typical ultrasonic signals from the fake gold jewelleries. The echo signal from bracelet and pendant are quite clear and easy to interpret. However the echo from necklace is not clear and difficult to interpret due to complex geometry of the sample.

Experimental results are tabulated in table 1. The measured sound velocities showed that the values are much different from actual sound velocity in pure gold, i.e. 3240m/s.
Table 1. Results of ultrasonic measurement as compared to XRF (2) and SEM (2)

| Sample identification | Contents | Density (g/cc) | XRF Sound velocity (m/s) | SEM-EDX (% weight) | Measured sound velocity (m/s) |
|-----------------------|----------|----------------|--------------------------|---------------------|-------------------------------|
| GLG1                  | Fe       | 6.95-7.86      | 3500-6000                | 0                   | 4023                          |
|                       | Co       | 3931           |                          |                     |                               |
|                       | Ni       | 3740           | 5300-5900                | 0                   |                               |
|                       | Cu       | 4443           | 3500-4700                | 1.737               |                               |
|                       | Zn       | 4327           | 0                        |                     |                               |
|                       | Ru       | 4592           | 0                        |                     |                               |
|                       | Rh       | 0              | 0                        |                     |                               |
|                       | Pd       | 1.143          | 0                        |                     |                               |
|                       | Ag       | 3600-4760      | 63.849                   | 3.52                | 6.26                          |
|                       | Os       | 0.015          | 0                        |                     |                               |
|                       | Ir       | 0              | 0                        |                     |                               |
|                       | Pt       | 0.215          | 0                        |                     |                               |
|                       | Au       | 19.3           | 3240                     | 33.04               | 93.8                          |
|                       |          |                |                          |                     | 89.08                         |
| GLG2                  | Fe       | 6.95-7.86      | 3500-6000                | 0                   | 4023                          |
|                       | Co       | 3931           | 0                        |                     |                               |
|                       | Ni       | 3740           | 5300-5900                | 0                   |                               |
|                       | Cu       | 3852           | 3500-4700                | 0                   |                               |
|                       | Zn       | 3961           | 0                        |                     |                               |
|                       | Ru       | 3736           | 0                        |                     |                               |
|                       | Rh       | 0              | 0                        |                     |                               |
|                       | Pd       | 0              | 0                        |                     |                               |
|                       | Ag       | 3600-4760      | 1.882                    | 3.57                | 3.93                          |
|                       | Os       | 0              | 0                        |                     |                               |
|                       | Ir       | 0              | 0                        |                     |                               |
|                       | Pt       | 0.488          | 0                        |                     |                               |
|                       | Au       | 19.3           | 3240                     | 97.63               | 96.43                         |
|                       |          |                |                          |                     | 96.07                         |
| RL6                   | Fe       | 6.95-7.86      | 3500-6000                | 0.122               | 4223                          |
|                       | Co       | 4400           | 0                        |                     |                               |
|                       | Ni       | 4059           | 5300-5900                | 47.746              | 7.77                          |
|                       | Cu       | 94.97          | 3500-4700                | 49.033              | 0.76                          |
|                       | Zn       | 4912           | 0                        | 2.9                 |                               |
|                       | Ru       | 0.053          | 0                        |                     |                               |
|                       | Rh       | 0              | 0                        |                     |                               |
|                       | Pd       | 0.194          | 0                        |                     |                               |
|                       | Ag       | 3600-4760      | 0.471                    | 5.03                |                               |
|                       | Os       | 0.012          | 0                        |                     |                               |
|                       | Ir       | 0              | 0                        |                     |                               |
|                       | Pt       | 0              | 0                        |                     |                               |
|                       | Au       | 19.3           | 3240                     | 91.47               | 78.01                         |
|                       |          |                |                          |                     |                               |
| RL3                   | Fe       | 6.95-7.86      | 3500-6000                | 0.137               | 3097                          |
|                       | Co       | 3331           | 0                        |                     |                               |
|                       | Ni       | 3448           | 5300-5900                | 47.346              | 7.77                          |
|                       | Cu       | 3600-4700      | 84.224                   | 14.71               | 24.7                          |
|                       | Zn       | 4912           | 1.463                    | 4.7                 |                               |
|                       | Ru       | 0.004          | 0                        |                     |                               |
|                       | Rh       | 0              | 0                        |                     |                               |
|                       | Pd       | 0              | 0                        |                     |                               |
|                       | Ag       | 3600-4760      | 0.236                    | 5.03                |                               |
|                       | Os       | 0.09           | 0                        |                     |                               |
|                       | Ir       | 0              | 0                        |                     |                               |
|                       | Pt       | 0.027          | 0                        |                     |                               |
|                       | Au       | 19.3           | 3240                     | 85.29               | 75.3                          |
|                       |          |                |                          |                     |                               |
| Ear ring              | Fe       | 6.95-7.86      | 3500-6000                | 0.137               | 7014                          |
|                       | Co       | 6300           | 0                        |                     |                               |
|                       | Ni       | 3448           | 5300-5900                | 47.346              | 7.77                          |
|                       | Cu       | 6.03           | 3500-4700                | 6.081               | 3.16                          |
|                       | Zn       | 6.03           | 0                        | 6.03                |                               |
|                       | Ru       | 0.004          | 0                        |                     |                               |
|                       | Rh       | 0              | 0                        |                     |                               |
|                       | Pd       | 0              | 0                        |                     |                               |
|                       | Ag       | 3600-4760      | 2.019                    | 1.11                | 3.56                          |
|                       | Os       | 0.09           | 0                        |                     |                               |
|                       | Ir       | 0              | 0                        |                     |                               |
|                       | Pt       | 0.027          | 0                        |                     |                               |
|                       | Au       | 19.3           | 3240                     | 91.9                | 95.73                         |
|                       |          |                |                          |                     | 90.41                         |

Measurement is also compared with 916 gold pendant which give sound velocity values of 3304 – 3454 m/s.
5. Conclusion
Ultrasonic testing can be used as an additional NDT method for checking fake gold. It is quite reliable for gold bar or coin. For jewelry with complicated shape and thin material, XRF and SEM are adequate but sound velocity measurement can be used as a complementary method.

6. References
[1] The Application of Ultrasonic Testing for Silver Bars, Bullion and Coins (5 June 2017). https://www.scribd.com/document/267911050/The-Application-of-Ultrasonic-Testing-for-Silver-Bars
[2] M. Harun, M. P. Ismail, A. A. Abas and S. Sani, 2013, Teknologi ultrasonik dalam pengujian ketulihan fizikal barang kemas berongga, Seminar Mineral Berharga: Pengaruh Pasaran Dan Penawarannya di Dunia, Hotel Grand Season, Kuala Lumpur, 13-14 Mei 2013.

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