

#### INVESTIGATION OF EFFECTS OF TUNGSTEN ON ACOUSTIC IMPEDANCE BY CALCULATING SOUND VELOCITIES FROM ELASTIC MODULUS APPROACH

ELASTİK MODÜL YAKLAŞIMI İLE SES HIZLARININ HESAPLANARAK TUNGSTENİN AKUSTİK EMPEDANS ÜZERİNDEKİ ETKİLERİNİN ARAŞTIRILMASI

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# ÖZET

Tungsten gibi bazı metal dolgu tozları, ultrasonik dönüştürücülerin gövdelerinde destek malzemeleri olarak kullanılmaktadır. Destek malzemeleri, esas olarak sertleştirici ve yapıştırıcı olmak üzere iki tip epoksi malzemeden ve dolgu tozlarından oluşmaktadır. Bu dolgu tozlarının epoksi malzemelere dahil edilmesinin nedenlerinden biri, ultrasonik problarda yüksek akustik empedans elde etme arzusudur. Bu bağlamda, ölçüm için 1, 2, 5 ve 10 gram miktarlarda tungsten tozu ilave edilen farklı epoksi karıştırma oranlarına sahip örnekler hazırlanmış ve akustik empedansın hesaplanmasında kullanılan ses hızları; mekanik olarak ölçülen elastik modül ve yoğunluklar üzerinden hesaplanmıştır. Böylece bu çalışmada, destek malzemesinde kullanılan tungstenin ultrason cihazlarının problarındaki etkileri araştırılmıştır. Sonuç olarak, mekanik yöntemle yapılan hesaplamalar ile de tungstenin akustik empedans üzerindeki artan etkisi belirlenmiştir.

Anahtar Kelimeler: Akustik Empedans, Tungsten, Ultrasonik Dönüştürücü/Prop, Elastik Modülü, Ses Hızı Ölçümü

# ABSTRACT

Some metal filler powders, such as tungsten, are available as support materials in the bodies of ultrasonic transducers. The backing materials consist of two types of epoxy material, mainly hardener and adhesive, and filler powders. One of the reasons why these filler powders are incorporated into epoxy materials is the desire to achieve high acoustic impedance in ultrasonic probes. In this context, samples with different epoxy mixing ratios of tungsten added in amounts of 1, 2, 5 and 10 grams were prepared for the measurement, and the sound velocities used in the calculation of acoustic impedance were calculated over elastic modulus and densities measured by mechanical method. Thus, the effects of tungsten used in the support material in the probes of ultrasound devices were investigated. As a result, the increasing effect of tungsten on acoustic impedance was also determined with the calculations made by mechanical method.

Keywords: Acoustic Impedance, Tungsten, Ultrasonic Transducer/Probe, Elastic Modulus, Sound Velocity Measurement



# **1. INTRODUCTION**

Reinforcing materials located within ultrasonic transducers are widely utilised in many transducer applications in the field of clinical/biomedical, non-destructive testing, underwater acoustics, etc. These reinforcing materials, which are generally composed of epoxy mixtures, have a structure supporting the piezoelectric element. These reinforcing materials are called as "backing materials". Metallic filling powders such as tungsten are utilised in reinforcing materials in order to obtain maximum acoustic impedance. In many kinds of transducers (such as underwater acoustics and ultrasonic non-destructive inspection probes), epoxies combined with suitable additives are made used of as supporting material. Reinforcement materials are used for the following purposes; supporting the active element in one direction, absorbing/dissipating the power radiated on the back part of the active element, obtaining as much power as possible from the transducer, preventing/reducing/controlling the oscillation of the transducer, to accomplish a more precision resolution, to supply powerful ultrasonic wave attraction as well as suitable acoustic impedance, and finally it is also used for purposes such as working at high pressures under difficult operating conditions (K. B. Kim, 2005) (Jones, 1984) (Jain, 1998) (Ultrasonic Sensor, 2019).

In this article, sound velocities were determined using elastic modulus, a mechanical approach rather than an acoustic method. Sound velocities and densities of mixtures containing various quantities of tungsten were found separately in the investigation, and so acoustic impedance values were calculated.

In this study, the effect of tungsten powder on the acoustic impedance values of the prepared mixtures was searched. Investigation of additives except for tungsten material in the development of ultrasonic transducers by the method described herein will also provide an innovative contribution to the scientific literature.

The organization of the paper will be as follows. In the second part, information about materials forming the epoxy mixture, prepared samples with weight ratios, prepared samples with tungsten additive by weight ratio, sound velocity calculated over elastic modulus, density measurement method and calculation of acoustic impedance will be given. In the third part, elastic modulus measurements, density measurements, sound velocity measurements of the mixtures without tungsten additive, sound velocity measurements of the mixtures with different amounts of tungsten additive and acoustic impedance calculation results will be shared. In the final section, the studies made and the results obtained will be summarized and some suggestions will be given.

# 2. METHODOLOGY

# **2.1. Materials Forming the Epoxy Mixture**

Backing material is mainly prepared with two kinds of epoxy material and tungsten powder. Epoxy materials; the thickening material consists of HARDENER HV 953 U BD and epoxy resin ARALDITE AW 106. These two different chemical materials were mixed in predetermined proportions and then various amounts of tungsten (also known as Wolfram) powder were added to this mixture.

# 2.2. Prepared Samples with Weight Ratio

The epoxy backing materials with weight ratio have been prepared from ARALDITE AW 106 and HARDENER HV 953 U BD as per predetermined weight ratios such as 80/20, 85/15, 87.5/12.5 and 90/10. In the ratios, for example 80/20 ratio, the first one (80) represents ARALDITE AW 106 and the last one (20) shows the HARDENER HV 953 U BD.

# 2.3. Prepared Samples with Tungsten Additive by Weight Ratio

Subsequently, new mixtures were produced by adding 1, 2, 5 and 10 grams of tungsten powder to the epoxy mixtures prepared by weight ratio. The twenty samples prepared for the investigation study can be seen in Figure 1 below.





Fig 1. Prepered samples with different weight ratio

#### 2.4. Sound Velocity Calculated Over Elastic Modulus

The elastic deformation that occurs when force is applied to the material enables us to find the "Elasticity Module", also known as the "Elastic Modulus". The elastic modulus is indicated by "E". It is obtained by the ratio of the stress applied to the material to the unit deformation caused by the applied stress. The higher the elastic modulus of a material, the higher the strength that a material can withstand without permanent deformation, or the lower the elastic elongation rate ( $E = \sigma / \epsilon$ ). The E constant in the relation is called the "Elastic Modulus".

Elastic modulus; differs from material to material. In addition, elastic modulus can show differences due to the external factors such as chemical structure of materials, ambient temperature and so on. For example; as the temperature increases, the elastic modulus decreases as more deformation occurs with less force. However, the force modulus applied to the material will generally give the same elastic modulus, whether it is pressure or pulling force, but differences may be seen in some materials.

The speed of sound waves emitted in an environment depends on two factors. These are the compressibility or flexibility of the media and the inertia. Speed of mechanical waves is given by the following equation;

$$c = \sqrt{\frac{E}{d}} \tag{1}$$

Where E is the Elastic modulus in the equation, which characterizes the flexibility of the environment, d is the density and c is the velocity or speed of sound (Wegst, 2006) (Bucciarelli, 2019) (Elastisite Modülü(Young Modülü) ve Hooke Kanunu, 2019) (Durmuş, 2019) (Dolgin, 2021).

#### 2.5. Density Measurement Method

Density is the ratio of the mass of a body to its volume. The volume and mass of each sample was measured and then densities were calculated by the following formula (Density, 2021).

$$d = \frac{m}{V} \tag{2}$$

Here, "m" represents the mass and "V" represents the volume.



#### **2.6.** Calculation of Acoustic Impedance

The acoustic impedance, Z, is calculated by the following formula. In the formula "d" shows the density and "c" represents the speed of sound (Chi-Man Wong, 2021).

 $\mathbf{Z} = \mathbf{d} \cdot \mathbf{c} \tag{3}$ 

#### **3. MEASUREMENT RESULTS**

#### **3.1. Elastic Modulus Measurements**

Elastic modulus measurements were made with Zwick brand device in the TUBITAK UME Force Laboratory. The pressing force was applied to the prepared samples with a sample with a flat bottom of 8 mm as shown in Figure 2. Elastic module values were determined from the slope of the  $\sigma$  -  $\epsilon$  curve taken from the device (Aydemir, 2019) (ASTM E 111, 2017) (Lord, 2010). The elastic modulus measurements carried out can be seen in the following tables (from Table 1 to Table 5).



Fig. 2. The elastic modulus measurement device

Tungsten-free Mixtures	Elastic Modulus (MPa)	Standard Deviation (%)
80/20	891.2	2.2
85/15	772.1	1.7
87.5/12.5	501.4	1.7
90/10	169.9	2.7

 Table 1. Elastic Modulus of tungsten free mixtures

Table 2.	Elastic	Modulus	of 80/20	Weight	Ratio	Mixtures	with	tungsten
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80/20 Weight Ratio Mixtures with	Elastic Modulus	Standard Deviation
tungsten	(MPa)	(%)
80/20 + 1 g tungsten	893.9	6.0
80/20 + 2 g tungsten	899.4	4.0
80/20 + 5 g tungsten	1127.9	5.1
80/20+10 g tungsten	1344.0	7.2



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85/15 Weight Ratio Mixtures with	Elastic Modulus	Standard
tungsten	(MPa)	Deviation (%)
85/15 + 1 g tungsten	921.0	2.3
85/15 + 2 g tungsten	865.7	5,1
85/15 + 5 g tungsten	892.4	2.9
85/15 + 10 g tungsten	961.3	6.3

**Table 3.** Elastic Modulus of 85/15 Weight Ratio Mixtures with tungsten

Table 4. Elastic Modulus of 87.5/12.5 Weight Ratio Mixtures with tungsten

87.5/12.5 Weight Ratio Mixtures	Elastic Modulus	Standard
with tungsten	(MPa)	Deviation (%)
87.5/12.5 + 1 g tungsten	1273.7	7.3
87.5/12.5 + 2 g tungsten	881.5	5.6
87.5/12.5 + 5 g tungsten	1021.4	5.1
87.5/12.5 + 10 g tungsten	977.9	3.2

Table 5. Elastic Modulus of 90/10 Weight Ratio Mixtures with tungsten

90/10 Weight Ratio	Elastic Modulus	Standard
Mixtures with tungsten	(MPa)	Deviation (%)
90/10 + 1 g tungsten	851.8	3.4
90/10 + 2 g tungsten	617.3	7.6
90/10 + 5 g tungsten	649.4	5.7
90/10 + 10 g tungsten	848.4	3.9

#### **3.2. Density Measurements**

Densities of different epoxy mixtures without tungsten and added with different amounts of tungsten can be seen in Tables below (from Table 6 to Table 10).

Mixtures	Density	Standard
without tungsten	$(kg/m^3)$	Deviation (%)
80/20	1279.1	1.2
85/15	1154.8	1.5
87.5/12.5	1253.0	0.9
90/10	1240.7	1.6

Table 6. Densities of Mixtures without tungsten

Table 7. Densities of 80/20 Mixtures with tungsten

80/20 Mixtures	Density	Standard
with tungsten	$(kg/m^3)$	Deviation (%)
80/20 + 1 g tungsten	1036.1	0.8
80/20 + 2 g tungsten	1053.8	2.0
80/20 + 5 g tungsten	1330.5	0.2
80/20+10 g tungsten	1325.0	0.3

85/15 Mixtures	Density	Standard
with tungsten	$(kg/m^3)$	Deviation (%)
85/15 + 1 g tungsten	1105.6	1.5
85/15 + 2 g tungsten	1159.9	2.2
85/15 + 5 g tungsten	1254.3	0.9
85/15 + 10 g tungsten	1363.2	2.3

Table 8. Densities of 85/15 Mixtures with tungsten

Table 9. Densities of 87.5/12.5 Mixtures with tungsten

87.5/12.5 Mixtures with tungsten	Density (kg/m <sup>3</sup> )	Standard Deviation (%)
87.5/12.5 + 1 g tungsten	1121.5	1.6
87.5/12.5 + 2 g tungsten	1182.0	1.6
87.5/12.5 + 5 g tungsten	1329.1	1.8
87.5/12.5 + 10 g tungsten	1268.2	1.5

Table 10. Densities of 90/10 Mixtures with tungsten

90/10 Mixtures	Density	Standard
with tungsten	$(kg/m^3)$	Deviation (%)
90/10 + 1 g tungsten	1208.	2.0
90/10 + 2 g tungsten	1295.4	0.5
90/10 + 5 g tungsten	1202.2	1.7
90/10 + 10 g tungsten	1238.8	1.5

# **3.3. Sound Velocity Measurments of the Mixtures Without Tungsten Additive**

Sound velocities of different tungsten-free epoxy mixtures can be viewed in Figure 3. As can be understand from the figure, the velocity of sound decreases as the amount of epoxy increases. The sound velocity of the 80/20 mixture has the highest value.



**Different Mixing Ratios** 

Fig 3. Sound velocities of different tungsten-free epoxy mixtures



#### 3.4. Sound Velocity Measurements of Mixtures With Different Amounts of Tungsten Additive

Calculated sound velocity measurements of different tungsten and tungsten-free epoxy mixtures for 80/20, 85/15, 87.5/12.5 and 90/10 weight ratios can be seen in the following figures (from Figure 4 to Figure 7).



Fig 4. Sound velocities of different tungsten and tungsten-free epoxy mixtures for 80/20 weight ratio



Fig 5. Sound velocities of different tungsten and tungsten-free epoxy mixtures for 85/15 weight ratio





Fig 6. Sound velocities of different tungsten and tungsten-free epoxy mixtures for 87.5/12.5 weight ratio





Fig 7. Sound velocities of different tungsten and tungsten-free epoxy mixtures for 90/10 weight ratio

When we evaluate the sound velocities of tungsten mixtures as average among themselves, we see in Figure 8 that the sound velocities increase with increasing amount of adhesive, or in other words, with decreasing the amount of hardener, the sound velocities decrease.



Average Sound Velocity (m/s)

Fig 8. Sound velocities of tungsten mixtures as average among themselves

#### 3.5. Results of Acoustic Impedance

The calculated average acoustic impedances of different epoxy mixtures with the different amounts of tungsten additions were also found as shown in Figure 9 below. As can be viewed from the figure, the calculated acoustic impedance values of epoxy mixtures raise as tungsten amounts increase.



Fig 9. Average acoustic impedance values according to different amounts of tungsten.



Again, if we evaluate average acoustic impedances of different epoxy mixtures with different amounts of tungsten additions, we see in Figure 10 below that the best acoustic impedance is in epoxy mixtures having with the 80/20 ratio.



# Fig 10. Average acoustic impedances of different epoxy mixtures having with different amounts of tungsten additions

# 4. CONCLUSION

In this paper, it was investigated the most appropriate mixture of the backing material over elastic modulus approach and the best acoustic impedance mixtures by the weight ratios were determined. Tungsten powder in different amounts (1 g, 2 g, 5 g and 10 g) was added to the epoxy mixtures prepared by the weight ratio and the final acoustic impedance values were calculated.

As a result, this research study can be summarized as follows.

- It was found that tungsten additives (even 1 gram of tungsten) significantly increase the sound velocities.

- The best sound velocity and hence the acoustic impedance values have been achieved in mixtures with 80/20 tungsten additives.

- The amounts of hardener have an important role in the measurement of sound velocities in epoxy mixtures.

- The uncertainties in some measurements are considered to be high due to manual mixing process. And this has increased the bubble formation. Therefore, this bubble formations have been adversely affected the measurements.

- The results of the hardness measurements in our previous article (Durmuş, 2019), and the results of the elastic modulus measurements made in this study gave the same results in terms of tungsten's effect and the best mixing ratios, hence acoustic impedance results.

- Mechanical properties such as hardness and elasticity have been found to be complementary elements in the measurement of sound velocities.

It concluded that acoustic impedance values increase as tungsten quantities increase in the epoxy mixtures. This adds up to that acoustic harmonization also raises. This situation clearly endorses the literature information about the tungsten. Therefore, it can be proposed that this study can also be extended towards to the different additive metals other than tungsten, and much more similar research studies with elastic modulus approach can be carried out in the future.

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