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ACOUSTIC PROPERTIES OF PISTACHIO SHELL ADDITIVE POLYESTER RESIN

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BY

TESNIM SAFADI ERDEMLI

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Supervisor

Prof. Dr. Eser OLĞAR

By

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September 2023

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct. I have fully cited and referenced all material and results that are not original to this work.

Tesnim SAFADI ERDEMLI

ABSTRACT

ACOUSTIC PROPERTIES OF PISTACHIO SHELL ADDITIVE POLYESTER RESIN

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The discovery and production of numerous new environmentally friendly materials have been made possible by the technology's quickening pace of development. This prompts research into the use of polymer composites in the sector, which stands out for its benefits and keeps growing daily. When it comes to environmental protection, polymers made from recycled PET are a key component of these composites.In this context, the polymer composition enriched with pistachio shells will hold a significant place in the area. The mechanical and acoustical properties of polymers obtained by adding pistachio shell powder in specific ratios were examined. Sound absorbing, Tensile, bending and Izod-Charpy Impact strength tests were conducted sequentially on moulded composite specimens. Additional to the mechanical and acoustical test, SEM analyses were conducted to produce complex, high- magnification images of the surface topography of all samples prepared. The outcomes demonstrated that the prepared composite offered effective mid-frequency sound absorption, which can be used as membrane absorbers. Additionally, the mechanical properties of the pistachio shell filling are improved, lengthening the lifespan of the composite panel.

Keywords: Polyester Resin, Pistachio Shells, Mechanical Properties, Acoustic Properties

ÖZET

ANTEP FISTIĞI KABUĞU KATKILI POLYESTER REÇİNENİN AKUSTİK ÖZELLİKLERİ

SAFADİ ERDEMLİ, Tesnim
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Danışman: Prof. Dr. Eser OLĞAR
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Teknolojinin gelişmesinin hızla artması birçok yeni çevre dostu malzemenin geliştirilmesine ve üretilmesine yol açmıştır. Bu durum avantajlarıyla ön plana çıkan polimer kompozitlerin endüstride kullanımının her geçen gün artarak devam ettiği yönündeki çalışmalara yol açmaktadır. Bu kompozitler arasında geri dönüştürülmüş PET'ten elde edilen polimerler çevrenin korunmasında önemli rol oynamaktadır. Bu bağlamda fıstık kabukları ile zenginleştirilmiş polimer bileşimi bölgede önemli bir yer tutacaktır. Antep fıstığı kabuğu tozunun belirli oranlarda ilave edilmesiyle elde edilen polimerlerin mekanik ve akustik özellikleri incelenmiştir. Kalıplanmış kompozit numuneler üzerinde sırasıyla Ses Emme, Çekme, Eğilme ve Izod-Charpy Darbe Dayanımı testleri yapılmıştır. Mekanik ve akustik teste ek olarak, hazırlanan tüm numunelerin yüzey topografyasının karmaşık, yüksek büyütmeli görüntülerini üretmek için SEM analizleri yapıldı. Sonuçlar, hazırlanan kompozitin orta frekanslarda iyi bir ses emilimi sağladığını ve membran yutucu olarak kullanılabileceğini gösterdi. Ayrıca fıstık kabuğu dolgusu mekanik özelliklerini artırarak kompozit panelin ömrünü uzatır.

Anahtar Kelimeler: Polyester Reçine, Fıstık Kabuğu, Mekanik Özellikler, Akustik Özellikler.

"Dedicated to my Isaac".

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LIST OF SYMBOLS

g	Gram
s	Second
J	Joule
m	Meter
K	Kilo
°C	Degrees Celsius
h	Hour
MPa	Mega pascal
Is	Sample current
M	Magnification
f	Frequency
Hz	Hertz
P	Pressure
α	Sound Absorption Coefficient
min	Minutes
N	Newton
V	Volt
λ	Wavelength
ρ	Density
E	Young's modulus
c	Speed of sound
τ	Transmission Coefficient
E_i	Incident energy
E_r	Reflected energy
E_a	Absorbed energy.
E_t	Transmitted energy.

LIST OF ABBREVIATIONS

PS	Pistachio shell
PSP	Pistachio shell powder
Wt. %	Percentage of the weight
SEM	Scanning Electron Microscopy
PET	Polyethylene terephthalate
mid	Medium
P-PS	Polyester Pistachio Shells
PET	Polyethylene terephthalate
MEKP	Methyl Ethyl Ketone Peroxide
ISO	International Organization for Standardization
ASTM	American Society for Testing Materials
DIN	German Institute for Standardisation
WD	Working distance
Fig	Figure
Max	Maximum

CHAPTER 1

INTRODUCTION

1.1 Background

To date, the utilization of solid waste in composite polymer manufacturing has been constrained by the lack of a cost-effective additive. However, there is a growing interest in incorporating natural materials that offer eco-friendly, abundant, and renewable properties. Agricultural residues such as peanut shells, jute, rice husk, nutshells, and sugarcane have been commonly employed as rigid fillers in polymer composites, effectively enhancing their physical and mechanical characteristics while also reducing production expenses. In the midst of these agricultural remnants, pistachio shells (PS) hold significant potential due to their abundant availability in Turkey. Every year, substantial quantities of pistachio shells are generated, with many being either incinerated after harvest or left abandoned in the fields. This underutilization of pistachio shells presents a valuable opportunity to explore their incorporation as a filler material in composite polymer manufacturing, thereby contributing to waste reduction while potentially enhancing the composite's overall performance.

In the southeastern region of Turkey, including Gaziantep, Urfa, and Siirt, pistachio cultivation is widespread due to unique weather conditions and specific land needs [1]. However, the potential of utilizing agricultural residues as raw materials in polymer composite industries has not received adequate attention. The incorporation of Polystyrene as an additive material in polymer composites offers significant economic and environmental benefits. Despite its common usage as a medium for orchids, fire starters, pet food, and additives for wood products, its potential in polymer composites remains largely untapped [2].

Moreover, PS particles exhibit remarkable mechanical properties, making them highly suitable for various engineering applications. While numerous researchers have investigated the mechanical and acoustical properties of polymer composites filled with industrial and agricultural residues, there is a notable gap in research concerning the tensile, bending, absorption coefficient, and impact properties of PS-filled polyester composites.

This study explores the feasibility of incorporating PS in the manufacturing process of polymer composites while analysing its acoustical and mechanical properties. The objective is to investigate PS particles as a potential additive material derived from waste for recycled polyester resins. The study involves a comprehensive evaluation of the sound absorption coefficient, tensile strength, bending properties, and Izod-Charpy impact behaviour of Polyester Resin with PS additives [3].

To conduct the research, composite specimens with varying filler contents (0%, 10%, 20%, 30%, 40%, and 50% by weight) are prepared using the hand lay-up method. The distribution of micro-PS particles within the polyester matrix is also observed through the use of Scanning Electron Microscopy (SEM). Through this investigation, the thesis aims to contribute to the understanding of the potential applications and performance characteristics of PS-filled polyester composites.

1.1 Object of the Thesis

Natural polymers without any reinforcing elements have been used for industrial purposes for many years. Due to processing problems and insufficient physical and mechanical properties of the products natural polymers have been modified with various additives over time, and semi-synthetic polymers have emerged.

The utilization of polymer materials solely as sound absorbers in the acoustic field yields unsatisfactory results due to their inherently low sound absorption coefficient, making them less suitable for acoustic applications [3].

However, the favourable attributes of polyester resin, such as cost-effectiveness, ease of moulding, corrosion resistance, and low water absorption, have motivated efforts to enhance its acoustic performance [4].

Techniques to enhance the quality of life have been explored by researchers like Iwan [5] acoustical behaviour of polyester resin. One approach involved creating a series of holes and configurations on the acoustic panel surface, thereby investigating the resultant changes in acoustic behaviour.

Various methodologies have been developed to improve the acoustic properties of polymers. Moreover, the field of textiles has also seen works focused on producing fabrics and carpets with sound-absorbing characteristics.

In the pursuit of enhancing the properties of polymer materials while reducing costs, numerous products serve as reinforcement elements. These elements play a pivotal role in augmenting the overall performance of polymer materials, making them more versatile for diverse applications.

This investigation, in order to increase the acoustic performance of polyester resin with its properties, is planned to produce composites by mixing different shells of pistachios into powder (flour) in a laboratory environment and blending them with polyester resin. It aimed to improve the material and acoustic properties of the blend obtained with polyester resin and pistachio powder. Acoustic tests will be carried out along with abrasion, tensile, compression, Izod, or Charpy impact tests of the obtained composite. As it can be understood from the tests to be made, the mechanical properties of the material will be examined as well as increasing the acoustic performance. As a result, the material to be used in industry is expected to have advantageous properties in every aspect. In addition, contributing to the protection of the environment within the scope of recycling by using polyester resin is among the aims of this study.

1.2 Literature Review

Essentially this section discusses the previous studies that are related to this thesis and explains the advantages or disadvantages side of these works as well as introduces the concepts, tools, and techniques that will be used to implement this work. The analysis of acoustical and mechanical studies of polyester resin additive by a green composite (natural materials) that are eco-friendly, sustainable, and similar to the way that the shells of peanuts, corn husks, nutshells, and sugarcane are typically used as hardened fillers to produce a polymer composite in order to enhance its mechanical and physical characteristics and reduce costs of manufacture. Standards set by ISO and ASTM are followed for evaluating this research.

The acoustical and non-acoustical properties of composites were investigated employing corn husk fibre (CHF) as well as unsaturated polyester as the sound-absorbing materials. Other studies examined the acoustical properties of polyester resin additive by a green composite, corn husk fiber-polyester composites were analysed as a sound absorber. Experimental research was done to determine how the volume proportion of CHF affected acoustic performance. Additionally, analyses of the non-acoustical characteristics of composites, such as their porosity, airflow resistance, and mechanical qualities [3,6, 28].

One more study investigate the acoustic properties of a sound absorber made from modified polyester resin with sodium bicarbonate as a filler. The research explores the possibility of utilizing sodium bicarbonate as an additive material to enhance the acoustic performance of the sound absorber manufactured from polyester resin. By incorporating sodium bicarbonate as a filler, the study seeks to improve the sound absorption coefficient and overall acoustic behaviour of the polyester-based sound absorber [7 ,34].

Some papers examined the mechanical properties of Polyester resin additive by pistachio shells like, the application of pistachio shells as a substitute filler in a conveyor belt compound made of natural rubber and styrene-butadiene rubber. To accomplish that, compounds were prepared in laboratory tests two-roll mills using pistachio shells to replace some of the carbon black. The research looks into the mechanical, thermal, morphological, and abrasion resistance properties of the resulting vulcanizates that contain pistachio shells. Furthermore, it looks into cure characteristics [8, 30, 31].

Pistachio Shell Powder, for example, is made from natural fibres. To create a composite material, these natural fibres are mixed with polyester resin. The primary objective of this research is to investigate and evaluate the physical characteristics (Hardness, Compressive strength, and Impact strength) of the materials, and in this research, we investigated the mechanical behaviours of Acacia Nilotic as well as polyester resin enhanced with a plastic composite by which leads to the following findings. The manufacture of glass Fibre, the resin of polyester, and acacia Nilotic shown in this study [9].

The impact of microscale natural pistachio shell particle concentration on the physical properties of polyester composites with matrix structure was examined experimentally. On moulded composite samples, tensile, flexural, and Charpy impact tests were performed. SEM micrographs revealed that the pistachio shell particles were well dispersed in the polymer matrix. The greatest tensile strength, flexural strength, and strength of impact occurred at pistachio shell particle contents of 10%, 5%, and 5%, consequently [10, 35].

Yet, these works, on the other hand, investigate the influence of natural composite on polyester resin and its mechanical properties. Some of them investigated their impact on the acoustical qualities of the polymer. In this work, the impact of pistachio shell particles on the mechanical and acoustic properties of polyester resin will be investigate. SEM micrographs, tensile, flexural, impact effect, and abrasion of the composite material on the mechanical part will be examined.

In contrast, for the acoustic component, this study will use the impedance tube method to investigate the absorption coefficient of the produced material at varied PS particle ratios. Following that will compare it to an unfilled specimen to demonstrate the impact caused by PS particles on the acoustical and mechanical qualities, as well as the application of this material in our lives because it is cost-effective, environmentally friendly, and renewable. The PS particles ratios which will take up the material are 10, 20, 30, 40, and 50% by weight.

CHAPTER 2

THEORY AND METHODS

This chapter discusses the type of the materials that used, and the methodology of specimen's preparation before testing at different ratios and comparing them with the non-additive samples with PS-particles.

2.1 Definition of The Materials

The main materials used in this study was recycled polyester resin and waste of pistachio shell.

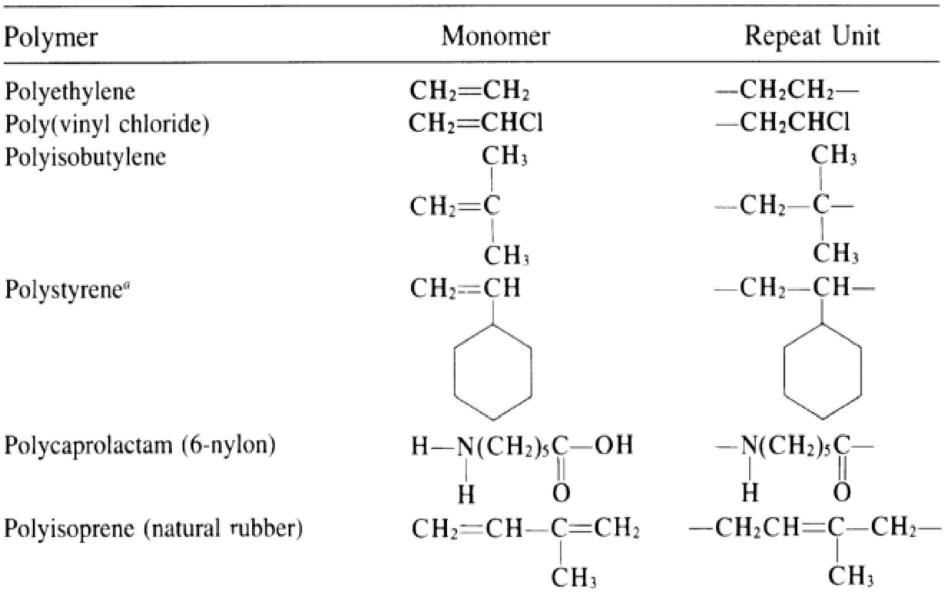
2.1.1 Polyester Resin

Recycled Polyester Resin with a density about 1.105 g/cm^3 was utilised as shown in Figure 2.1. The polymolecular structure formed by small (monomer) molecules by chemical bonding with each other by polymerization reaction under appropriate conditions is called a polymer. The resins made from polyester are synthetic materials that are created through the interaction of dibasic organic acids with polyhydric alcohols. Maleic anhydride is a common primary component in polyester resins that are unsaturated in diacid activity [11].

Figure 2.1 Polyester Resin (Polipol 3401-TAB).

In the field of chemistry, an ester is created when a carboxylic acid and an alcohol react, leading to the production of water as a byproduct. Polyesters are a type of polymer in which ester functionality is found throughout the main chain. These polymers are examples of step-growth polymerization, which occurs when a difunctional (or higher order) acid or acyl halide reacts with a difunctional (or higher order) alcohol. Polyesters can be produced commercially in both unsaturated and saturated resin formats. Polyethene terephthalate (PET), an example of a saturated polyester, is one of the most common and widely produced polyesters [12].

Table 2.1 Some linear high polymers, their monomers, and their repeat units [12].



Polymer	Monomer	Repeat Unit
Polyethylene	$CH_2{=}CH_2$	$-CH_2CH_2-$
Poly(vinyl chloride)	$CH_2{=}CHCl$	$-CH_2CHCl$
Polyisobutylene	$CH_2{=}\underset{CH_3}{\overset{CH_3}{C}}$	$-CH_2-\underset{CH_3}{\overset{CH_3}{C}}-$
Polystyrene[a]	$CH_2{=}CH$	$-CH_2-CH-$
Polycaprolactam (6-nylon)	$H-\underset{H}{N}(CH_2)_5\underset{\overset{\|}{O}}{C}-OH$	$-\underset{H}{N}(CH_2)_5\underset{\overset{\|}{O}}{C}-$
Polyisoprene (natural rubber)	$CH_2{=}CH-\underset{CH_3}{C}{=}CH_2$	$-CH_2CH{=}\underset{CH_3}{C}-CH_2-$

2.1.2 Pistachio shell

PS(pistācium) were thoroughly cleaned and subsequently ground into a fine powder form utilizing a jaw crusher as depicted in Figure 2.4. The grinding process took approximately 60 seconds to complete where particle size distribution of pistachio shell powder after grinding was between 1μm to 5μm. For reference, both the powder form and the raw pistachio shells can be observed in Figure 2.2. The chemical composition of the pistachio shell, as reported, consists of Cellulose (42%), Lignin (13.5%), extractable components (0.18%), and ash content (1.26%) the chemical structure of Cellulose is illustrated at Figure 2.3 [13]. Notably, the pistachio shells exhibit a highly fibrous structure, comprising a combination of amorphous and crystalline polymers [13].

Figure 2.2 The powder and raw PS

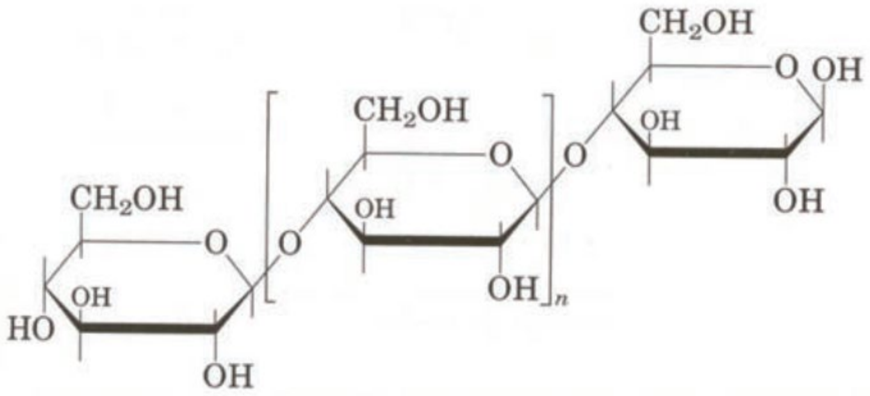
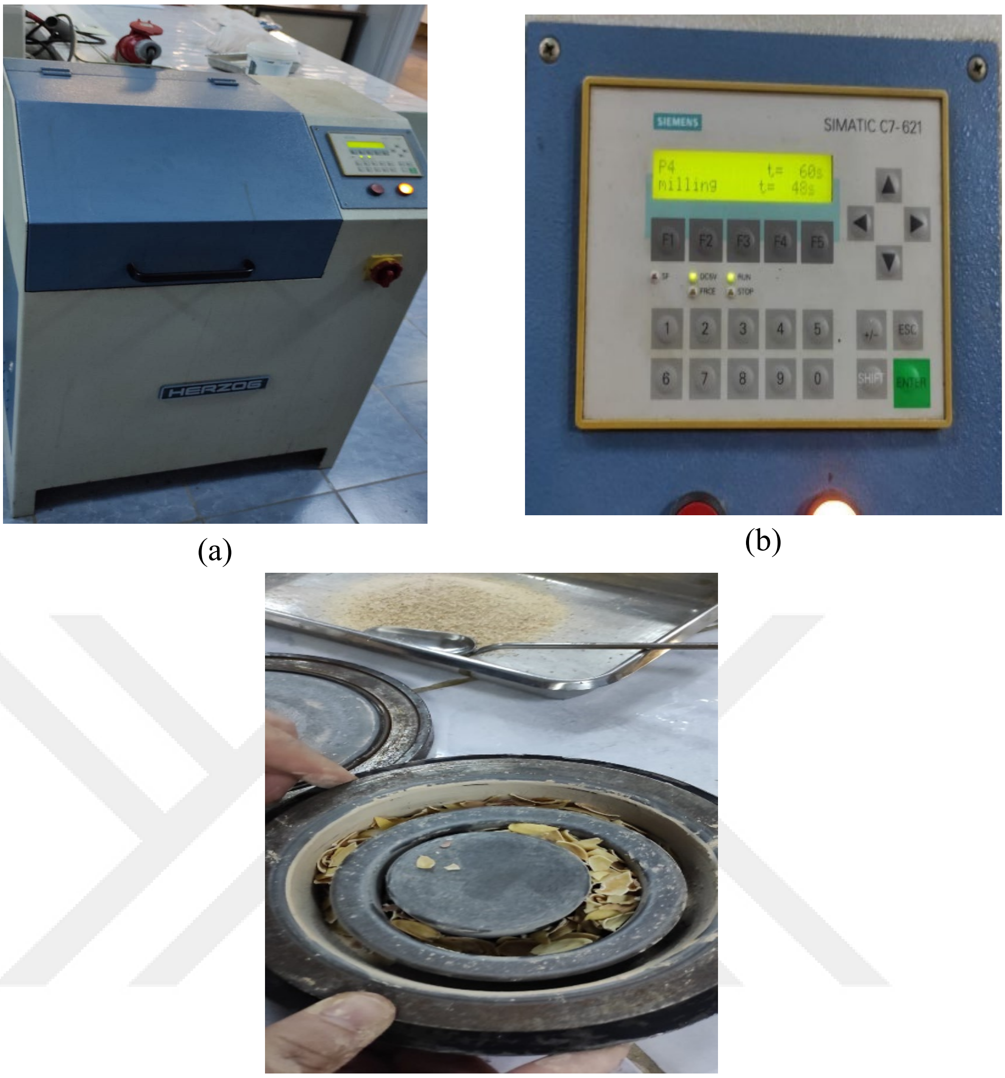


Figure 2.3 Cellulose, the group in brackets, is an individual glucose molecule [12]



(a) (b)

(c)

Figure 2.4 Jaw crusher (Herzog-Simatic C7-621)

2.1.3 Hardener

For the fabrication of the composites, a hardener known as Methyl Ethyl Ketone Peroxide (MEK-Peroxide) was employed, as depicted in Figure 2.5. Methyl ethyl ketone peroxide (MEKP) is categorized as an organic peroxide with the chemical formula $[(CH_3)\,(C2_2H_5)C(O_2H)]_2O_2$ where the chemical structure of MEKP is shown at Figure 2.6.

It presents itself as a colorless oily liquid and finds widespread usage in the vulcanization (crosslinking) of polymers. MEKP plays a crucial role as a chemical agent that governs and controls the transition of resins such as Polyester, Gelcoat, Adhesive Tix, and Vinyl ester from a liquid state to a solid state [14].

In the production process of all specimens, the hardener was incorporated, replacing 1.5 Wt. % of the polyester weight.

Figure 2.5 Hardener from KP Company

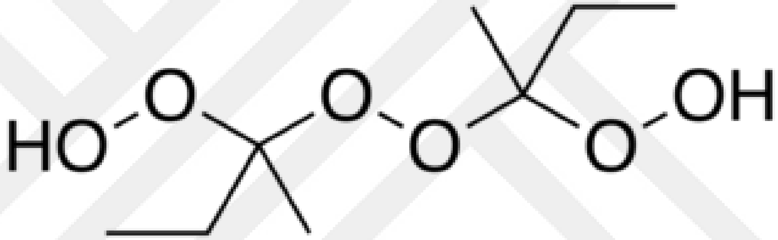


Figure 2.6 Methyl Ethyl Ketone Peroxide chemical structure [14].

2.2 Composite and Samples Preparation

Hand-mixing the mixture of PS and polyester resin at room temperature was the method employed to prepare every single specimen. To quickly harden the composite specimens, the hardener had been added to the mixture. The hardener replaced fifteen percent of the polyester weight in the production process of all the samples. Then, the mixture was poured into the mould which is shown in Figure 2.7. After waiting for these specimens to be post-cured at room temperature for almost 3 hours, they have a second post-cured at the oven (OF-105) from Ah-DAIHAN Scientific which is shown in Figure2.8 at 85°C for 2 hours before mechanical and acoustical testing.

Figure 2.7 Photograph of the mould

Next to smallest six samples were equipped for each examination and more than 12 one for each composite. Figure 2.10 shows the specimens with powder include of 0, 10, 20, 30, 40, and 50 Wt. % full polyester resin compound.

Figure 2.8 Ah-DAIHAN Scientific oven (OF-105)

Figure 2.9 shows the process and steps of preparing the samples, firstly by measuring the weight of the used cup for mixing every time before mixing, then weighting the Polyester resin measure the weight of the added pistachio particles according to the used ratio, the Pistachio particles ratios to the polyester resin are 0, 10, 20, 30, 40, 50 Wt. %. And a sample was prepared without any PSP to compared to the effect of the polyester.

Figure 2.9 The process of preparing the samples.

Figure 2.10 The specimens of polyester resin with filled PS powder

2.2.1 Composites of the samples

The sample composites are 0, 10, 20, 30, 40, 50 Wt. % of pistachio shell powder of the total weight of polyester resin, as shown in Table 2.2. The table illustrates that P-PS0% is the sample of polyester resin without any additive PS, then was started to fill the samples with the PSP starting with 0, 10, 20 ,30 ,40 ,50 Wt. % respectively. Figure 2.11 presents some of the samples that have been prepared.

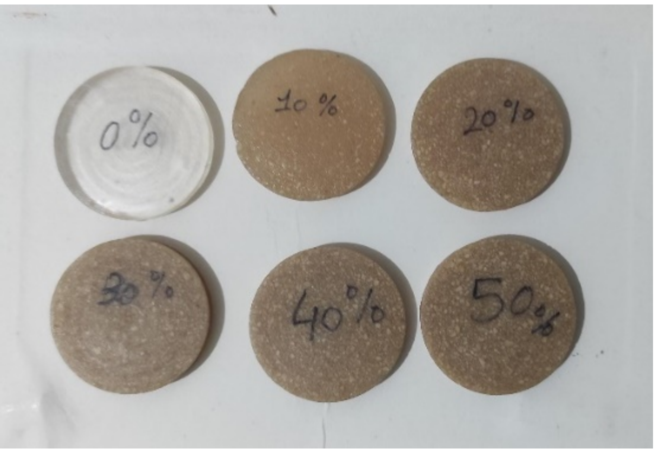


Figure 2.11 Some of the Prepared Samples

As mentioned before all the samples were post-cured in two steps: firstly, at room temperature for almost 3 h, then at oven at 85°C for 2 h before the mechanical and acoustical tests were started.

Table 2.2 Composites weights used for the samples.

Composite rate	**Filler weight**	**used cup**	**Polyester resin**	**Pistachio powder**	**hardener**
P-PS0%	0%	3.29 g	83.8 g	0 g	1.25g
P-PS10%	10%	1.6 g	127.23 g	12.7g	1.9 g
P-PS20%	20%	1.6 g	86.26 g	17 g	1.29 g
P-PS30%	30%	3.29 g	82.17 g	24.6 g	1.23 g
P-PS40%	40%	3.29 g	80.3 g	32.12 g	1.2 g
P-PS50%	50%	3.29 g	84.49 g	42 g	1.27 g

2.3 Tests Definition

2.3.1 Definition of Scanning Electron Microscopy Test

SEM is a testing technique that employs a focused beam of electrons to scan a sample, generating highly magnified images for analysis. This imaging method is precious for evaluating various materials, enabling the examination of surface fractures, defects, contaminants, and corrosion with exceptional resolution. SEM analysis serves as a powerful investigation tool, allowing the generation of complex images at high magnification, revealing the detailed surface topography of the sample. The test relies on the principle of secondary emission of electrons [18].

Image magnification in SEM achieved by maintaining the specimen's x- and y-scan distances significantly smaller than the size of the displayed image. The magnification factor (M) is mathematically expressed as the ratio between the scan distance in the image and the scan distance on the specimen, as indicated in the equation:

$$M = \frac{scan\ distance\ in\ the\ image}{scan\ distance\ on\ the\ specimen} \tag{2.1}$$

To maintain a fixed-size image that fits the display screen, increasing magnification involves reducing the x- and y-scan currents proportionally to avoid image distortion. One notable advantage of SEM is that specimen preparation does not necessarily require thinning. Special preparation is not necessary before conducting examinations in SEM. However, when dealing with samples of insulating materials, there may be challenges due to the absence of a current path to the ground for the sample's current (Is). As a result, the specimen can acquire an electrostatic charge when exposed to the electronic probe, leading to the occurrence of positive or negative local charges. The presence of a negative charge may cause image intensity distortion, presenting a potential drawback in SEM analysis. A SEM image generated from the intensity of the backscattered electrons and the location of the beam may show the distribution of the various elements in the sample. The heavier sample elements and reflect more electrons will appear brighter in the image so that back-scattered electrons may show contrasts in chemical composition [19].

2.3.2 Definition of Tensile Test

A tensile test determines the specimen's capability to withstand tensile stress. This is a basic type of mechanical examination performed by engineers and materials scientists in manufacturing as well as academic establishments all around worldwide [20]. It is one of the most important measured properties of materials used in structural applications. A tensile test applies force per unit area equal to the tensile strength (Mpa) to a specimen of the material to determine its tensile response. The tensile strength of the material is Tensile strength is the highest level of stress that a material can withstand. It is the boundary that divides the plasticity region and the breakage region and has played a significant part in distinguishing resistance in order from elasticity.

The standard test method for tensile Properties of plastics is ASTM D638. This test method determines the tensile properties of reinforced plastics in where the tested specimens are in dumbbell shaped as shown in Figure 2.12.

Figure 2.12 Standard dumbbell -shape specimens in tensile test

Furthermore, the tensile test is the most popular and one of many procedures for measuring Young's modulus (E) which is a property of the material that tells us how easily it can stretch and deform and is defined as the ratio of tensile stress (σ) to tensile strain (ε). Where stress is the amount of force (F) applied per unit area (A):

$$\sigma = F/A \tag{2.2}$$

and strain is extension (dl) per unit length (l).

$$\varepsilon = dl/l \tag{2.3}$$

so, it quantifies the material's stiffness and its ability to return to its original shape after deformation. Also, it determines the elasticity of rigid or solid materials, which is the connection between the strength required to deform a material and its deformation. Young's modulus is expressed in Pa, a pressure unit.

The relationship between strain and stress is a fundamental concept in the field of materials science and mechanical engineering. It is described by Hooke's Law, which states that the strain in a material is directly proportional to the stress applied to it, if the material remains within its elastic limit(Young’s modulus). This relationship can be expressed as:

$$\sigma = E\varepsilon \tag{2.2}$$

This relationship helps to understand how materials respond to external forces and how they deform under stress. Beyond the elastic limit, materials may exhibit plastic deformation or even rupture, and Hooke's Law no longer accurately describes the behaviour of the material.

Figure 2.13 Tension test machine and specimen

According to ISO 527, the elongation at break (fracture strain) can be determined by the tensile test. Elongation at break is the elongation that a material can support before it breaks. And it expresses the capability of the material to resist changes of shape without breaking. In tensile test, the standard specimen with 153mm x 11mm x 30 mm is placed in the ZWICK/Z010 test machine which shown at Figure 2.13, where they are taken to each end and pulled in an axial direction. After that a force is applied on the specimen starting from zero and increasing gradually until breaking with a fractious head speed equal to 5 mm/min., so the force essential to pull the sample away from each other is measured and how much the model stretches previously breaking [22].

2.3.3 Definition of Izod-Charpy Test

Izod impact tests are a standard method used by ASTM D4812, ISO180 to determine impact energy. An unnotched sample is usually used to determine the impact energy that the test is named after the English engineer Edwin Gilbert Izod, who described it in his 1903. Impact is a very important factor in order to govern a structure's life. Impact is a very important phenomenon in governing the life of a structure. For example, in the case of an aircraft take-off and landing the aircraft may be struck by debris present on the runway [23].

In the machine shows in Figure 2.14, an arm maintained at a specific height with a constant potential energy is released. The arm hits the sample and breaks it. The energy absorbed by the sample is used to determine the impact energy. Where the used pendulum energy in the experiment was 5.4 J. Impact tests are used to investigate the strength of the material. The toughness of a material is a factor in its capacity to absorb energy during plastic strain [24].

Figure 2.14 Izod-Charpy test machine

2.3.4 Definition of Three Point Bending Test

A Three-Point Bending Test, also known as a 3-point bend test or flexural test, is a mechanical testing procedure used to evaluate the bending or flexural properties of materials, particularly those that are used in engineering and construction. This test assesses a material's ability to withstand bending forces and deformation.

Bending strength is described as a material's capacity to resist stress deformation. The flexural strength of a material indicates the maximum stress experienced by the material at the time of fracture [25]. For materials like metals, plastics, ceramics and composites it is common for them to perform Three Point Bending Tests in order to understand how they respond to bent loads. When designing and evaluating the performance of components and structures which are subjected to bending forces such as beams, bridge columns or other load bearing elements, results from this test shall be important for engineers and material scientists. It is calculated using stress. The test provides insights into how materials behave when subjected to flexural stress, which is important for material selection and structural design.

A three-point bending test is commonly used to measure a specimen's flexural strength and bending toughness. When the sample is bent, it undergoes a variety of stresses throughout its depth. The stress will be at its highest compressive value near the sample's concave edge. The stress will be at its highest tensile value on the specimen's opposite face (the convex face). The 3-point bending test machine is seen in Figure 2.15 [26].

Figure 2.15 The 3-point bending test machine

The majority of compounds breakdown under tensile stress before breaking under compression stress, hence the flexural strength is the greatest tensile stress value that can be sustained before breaking the sample. If the material were homogenous, the flexural strength might be the identical as the tensile strength.

2.3.5 Abrasion Test

Abrasion occurs when a hard particle or protrusion on the surface of a body interacts with the surface of the component, tool, or machine. The abrasion test technique (ISO 4649 / DIN 53516) is straightforward. Moving a test piece of rubber across the surface of an abrasive sheet placed on a revolving drum measures abrasion resistance. The Abrasion test machine is seen in Figure 2.16.

Figure 2.16 Image of the Abrasion Test Machine

A key point to remember when looking at abrasion test values is that a larger score signifies a greater loss of surface, implying a low resistance to abrasion. Conversely, the lower the abrasion number, the higher the wear resistance. The percentage of loss between weight 'A' and weight 'B' of the test sample should be represented as a percentage of the test sample's initial weight. This value should be reported as follows [26]:

$$\text{Abrasion ratio} = \frac{A-B}{B}\ x100 \qquad (2.2)$$

At this test, the used distance was at 40 m and applied force is 10 N.

2.3.6 Impedance Tube Test

According to ISO 10534-2 and ASTM E-1050-19 standards, the acoustic characteristics of the material created from polymer composites of polyester resin added by PS content were tested using a two-microphone transfer-function technique. As indicated in Figure 2.17, the testing instrument was part of a full acoustic material testing system, Bruel-Kjaer 1406 [28].

Figure 2.17 Two microphones impedance tube (Type Bruel-Kjaer 1406).

A tiny tube set was utilised to evaluate various acoustical characteristics from 100Hz to 6.4 kHz. A loudspeaker was installed at one end of the tube to function as a sound source, and the test sample was placed at the other end to assess sound absorption capabilities. Two acoustic microphones were placed in front of the sample to record both the event and the the sound reflected from the speakers. To get the absorption coefficient of the sample under test, the recorded signals in the analyser in terms of the transfer function between the two microphones were processed using Bruel-Kjaer material testing software [29] as shown in Figure 2.18.

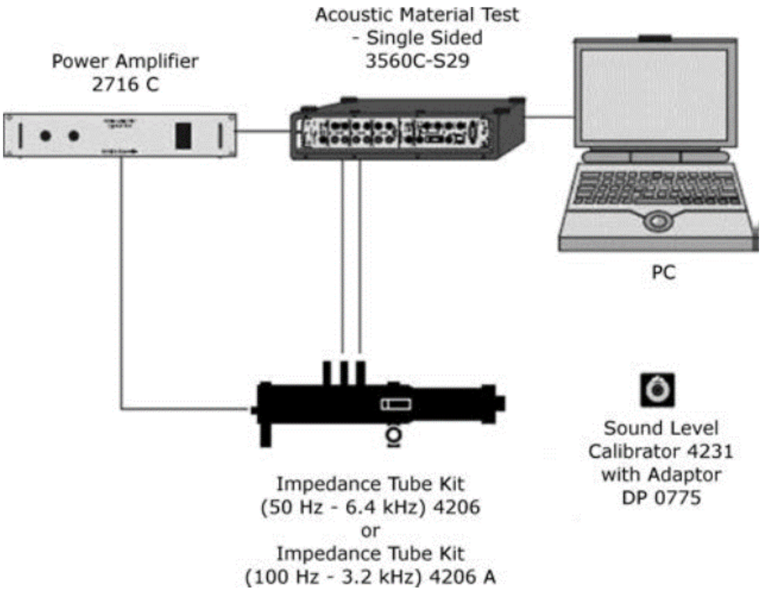


Figure 2.18 Measurement tester of acoustic properties [30]

CHAPTER 3

MECHNICAL TESTS ANALAYSIS AND ITS RESULTS

The results of various experimental methods used to evaluate the mechanical and wear properties of the composite materials are discussed. SEM was used to observe the microstructure and fracture morphology of the samples after different tests. The Tensile test was performed to measure the ultimate tensile strength, yield strength, and elongation at break of the samples. The 3-point bending test was conducted to determine the flexural strength and modulus of the samples. The Izod-Charpy Impact test was applied to assess the impact resistance and energy absorption of the samples under different notch configurations. The Abrasion test was carried out to evaluate the wear rate and coefficient of friction of the samples under different loads and sliding distances. The results of these tests are presented and analysed in detail in the following sections.

3.1 Scanning Electron Microscopy Test

One of the main advantages of this test occurs at the case of specimen preparation does not have to be made thin. So, there is no need to have a special preparation before examination. As a solution of the negative charge that may results a distortion in image intensity, and this charge occurs when the electronic charge exposed to the electronic probe, where this charge [19]. Therefore, the surface of the specimen has been coated with a thin film of metal or conducting carbon. Figure 3.1 shows the coating machine and samples of 30 and 40 Wt. % PS particles content after coating.

SEM can create images based on the intensity of backscattered electrons and the position of the electron beam. This feature allows for the visualization of the distribution of different elements within the sample. Heavier elements that reflect more electrons will appear brighter in the SEM image, enabling the observation of contrasts in the chemical composition of the sample. In this study, SEM was utilized to examine the morphology of polyester resin composites with the addition of PS particles.

The SEM images for various PS particle contents below are illustrated in Figures 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7, respectively. Notably, a favourable distribution of pistachio particles was observed in the SEM images for PS particle contents of 10Wt. % and 20Wt. % by weight. These proportions resulted in well-dispersed and homogeneously distributed PS particles within the polyester resin composites.

Figure 3.1 The coating machine and Samples of after coating

In addition, particle combination occurs at content above 10 Wt. % of pistachio particles, resulting a reduce in strength comparing with 0% of pistachio shells particles. Figure 3.2 shows SEM photo for raw polyester resin at two different magnifications, at 5 kilo scale and 10 kilo scale, at voltage of 10 KV, and its working distance (WD) between the specimens the lens is 6.4 mm and 6.5, respectively.

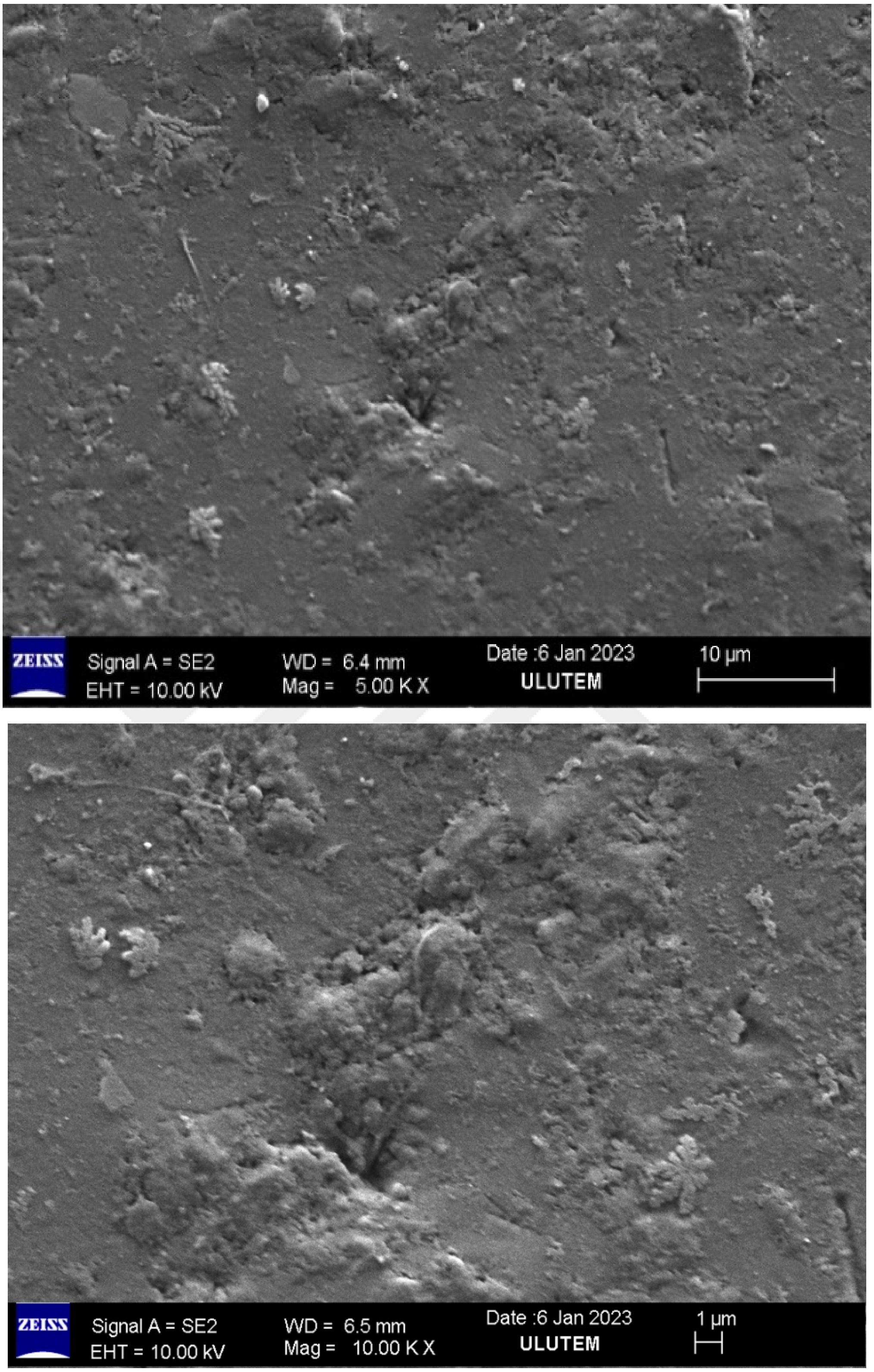


Figure 3.2 SEM micrographs of the P-PS 0% samples at 5 and 10 KX

SEM photos of P-PS 10% at 5 kilo and 10 kilo magnification, at voltage of 10 KV, and its WD is 8.1 mm and 7.9 mm, respectively moderated in Figure 3.3.

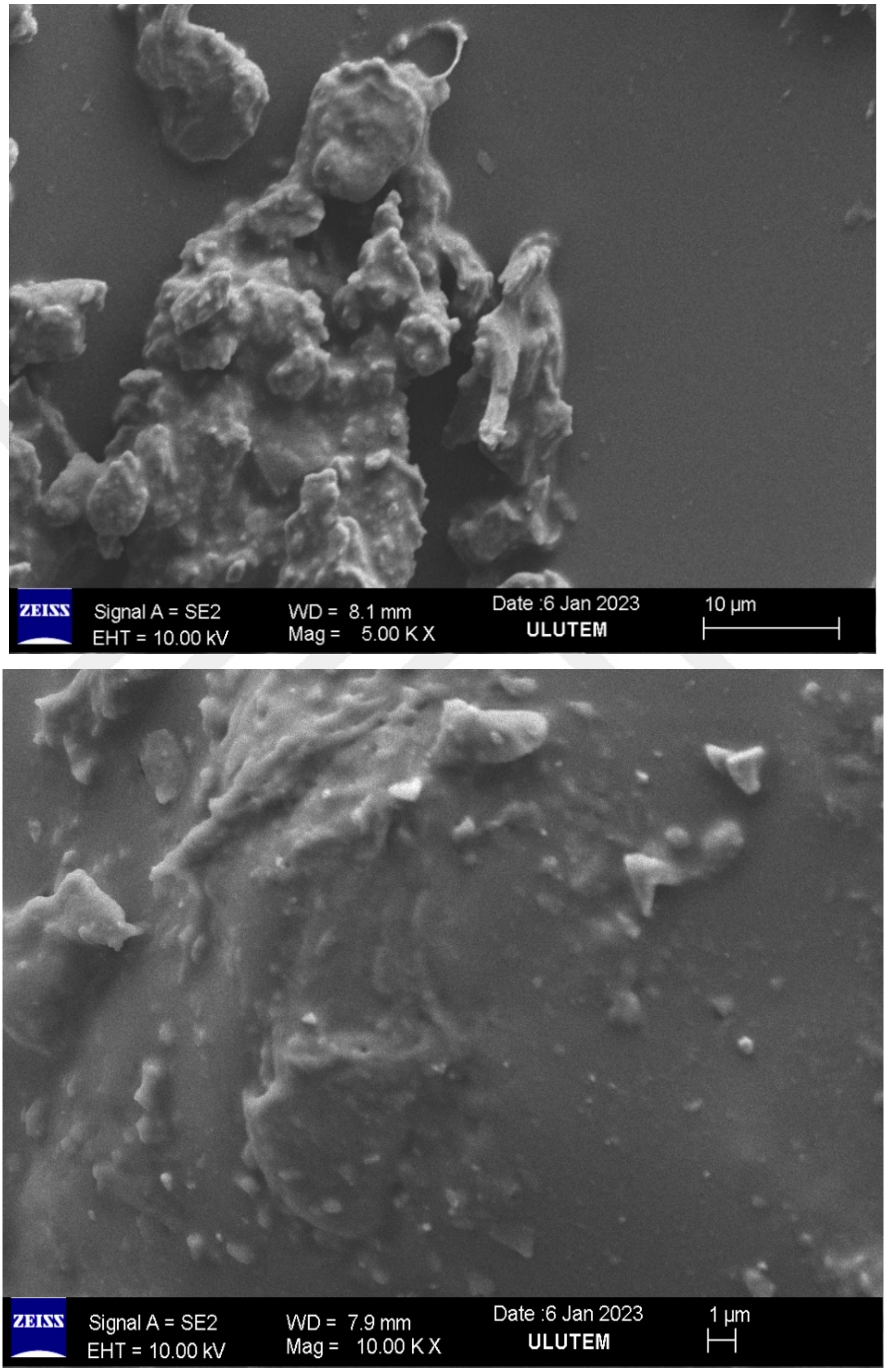


Figure 3.3 SEM micrographs of the P-PS 10% samples at 5 and 10 KX

Figure 3.4 presents P-PS 20% SEMs' photos at magnification scale of 5, and 10 KX at 10 KV voltage and WD equal at 8.8 and 9.1 mm, respectively.

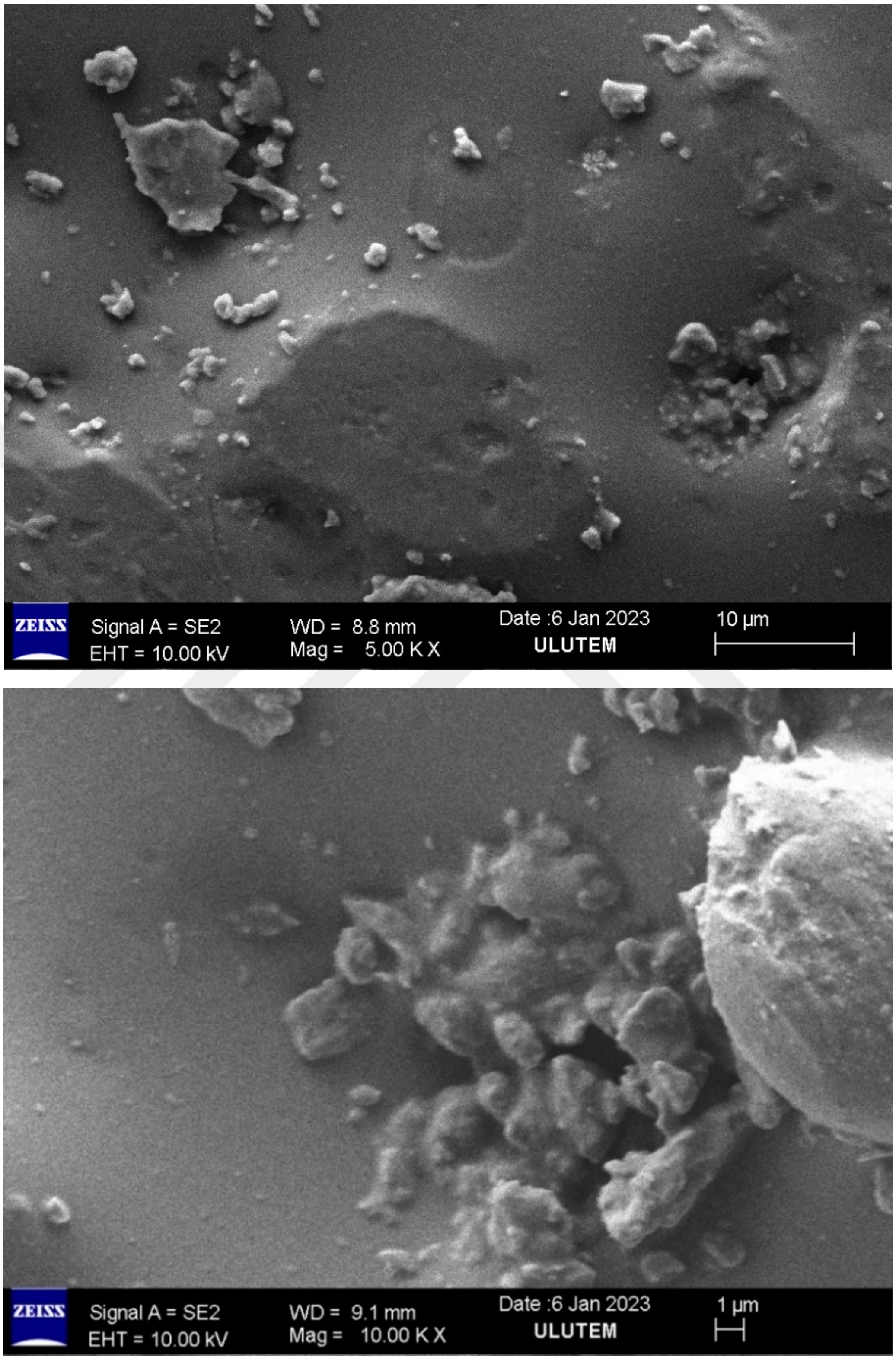


Figure 3.4 SEM micrographs of the P-PS 20% samples at 5 and10 KX

In Figure 3.5, P-PS 30% SEMs' photos at magnification scale of 500, and 10 KX at 10 KV voltage and WD equal at 6.5 mm are presented.

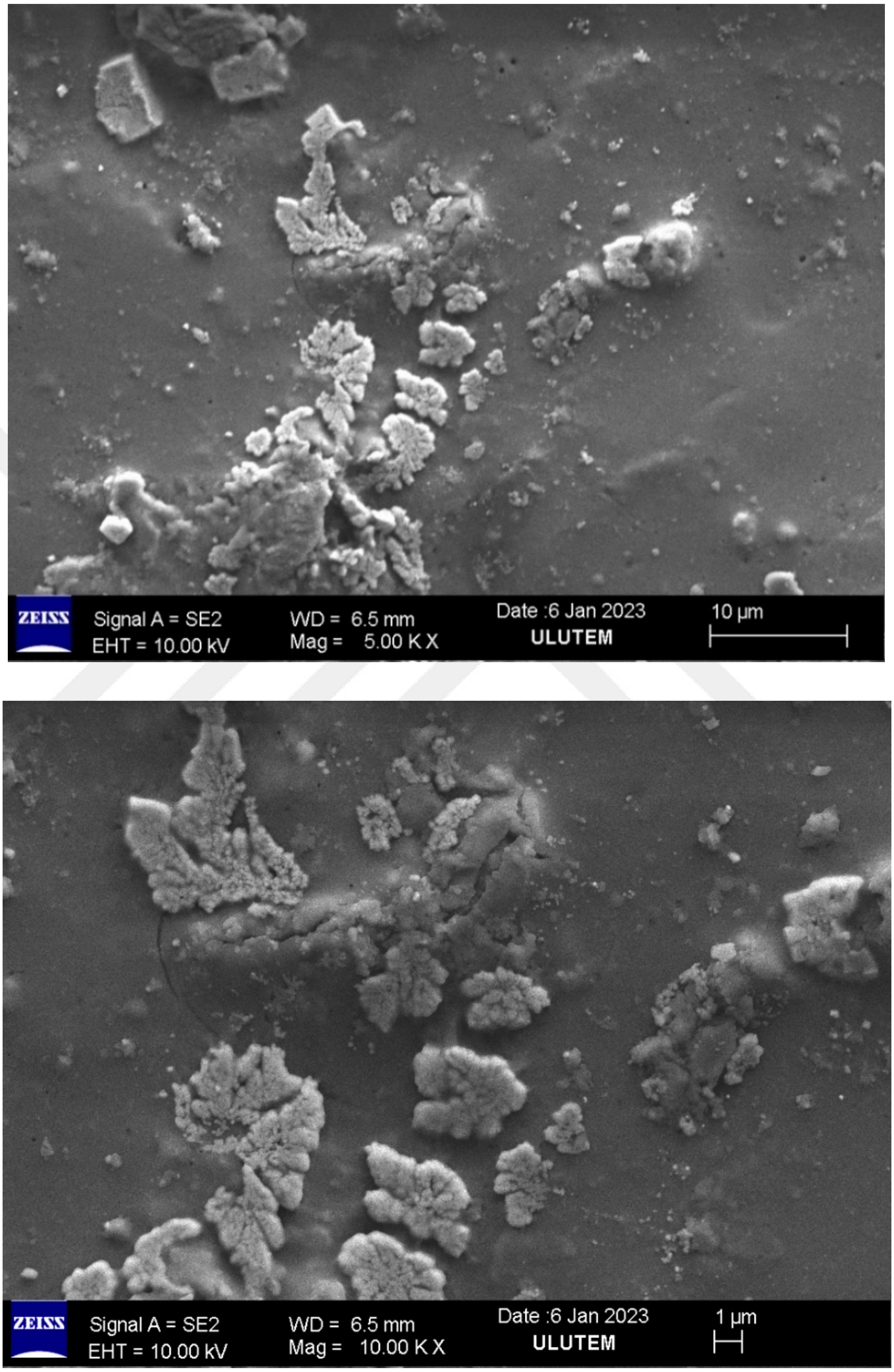


Figure 3.5 SEM micrographs of the P-PS 30% samples at 5 and, 10 KX

Figure 3.6 illustrates P-PS 40% SEMs' photos at magnification scale of 5, and 10 KX at 10 KV voltage and WD equal at 7.4 mm.

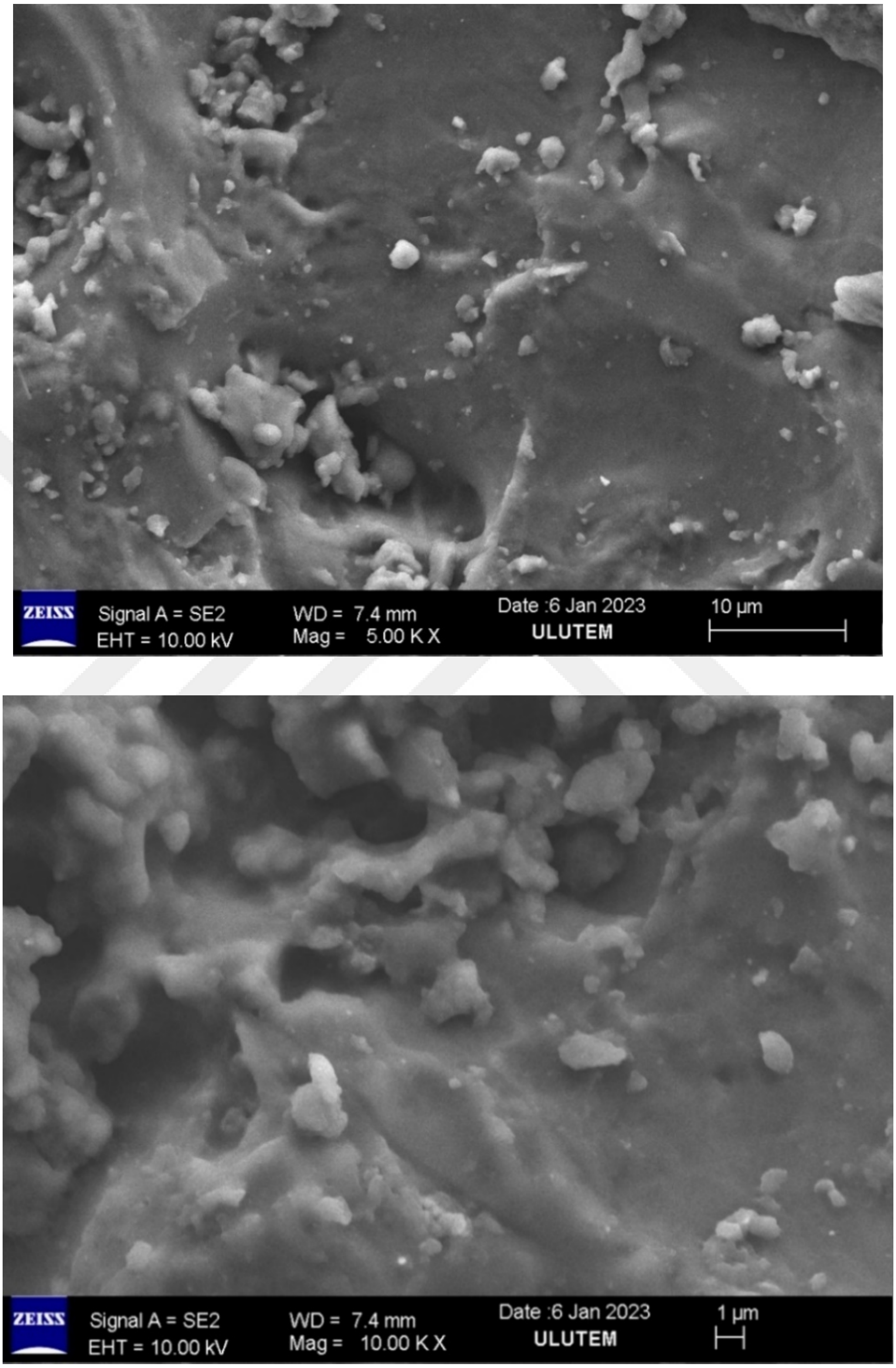


Figure 3.6 SEM micrographs of the P-PS 40% samples at 5 and 10 KX

Figure 3.7 also shows SEM photo of P-PS 50% at 5,00 kilo and 10,000 kilo magnification, at voltage of 10 KV, and its WD is 8.5 mm.

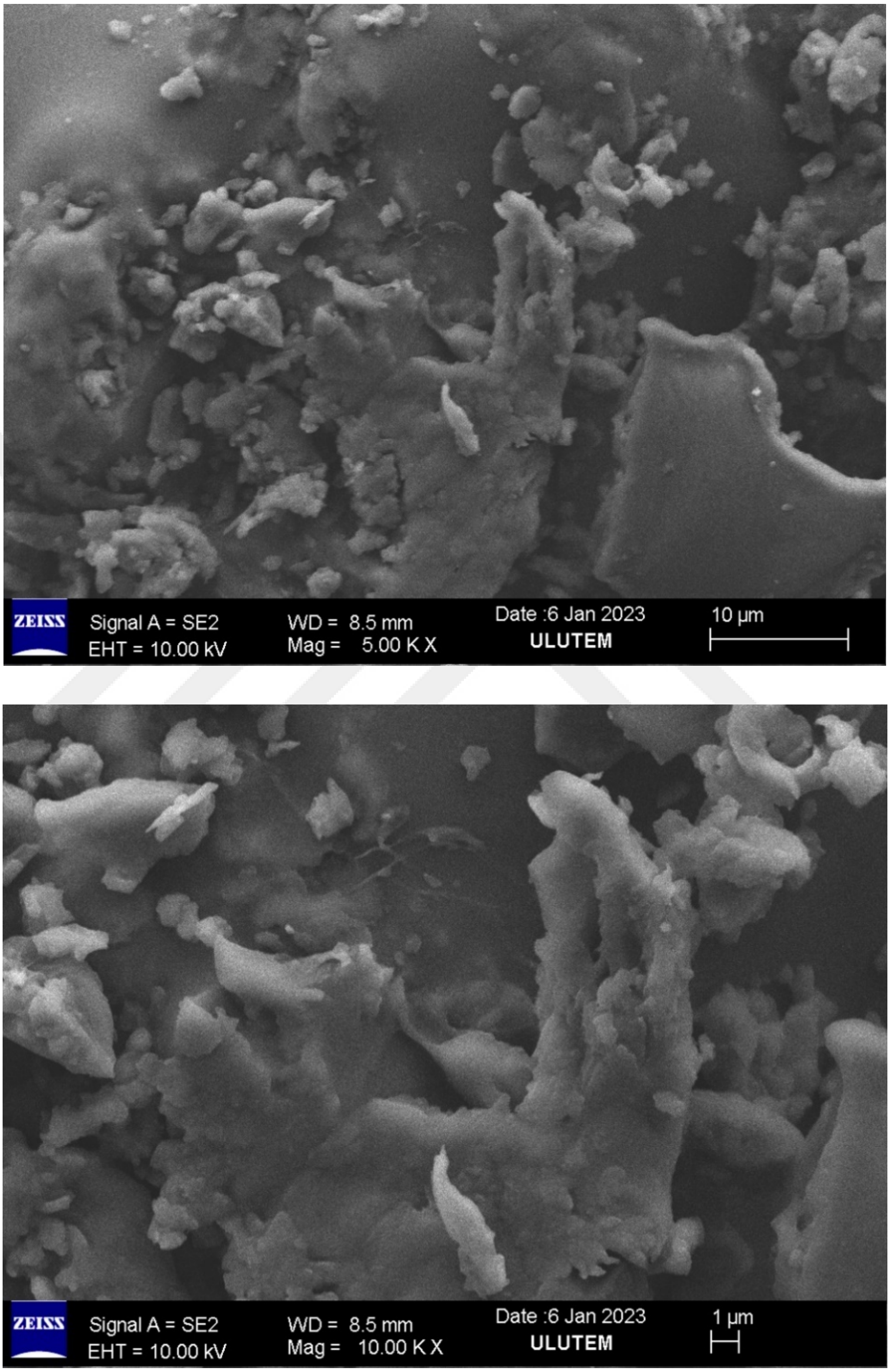


Figure 3.7 SEM micrographs of the P-PS 50% samples at 5 and 10 KX

3.2 Tensile Test

Tensile test is one of the most important measured properties of materials used in structural applications, and it a method determines the tensile properties of reinforced plastics. As explained before at Section 2.3.2, the tensile test is a method also to test the Young's modulus and the elongation at break. The average readings for tensile strength, Young's modulus, and elongation break for the specimens with its standard deviation are tabulated in Table 3.3.

Table 3.3 Tensile testing readings of the samples with its standard deviation

COMPOSITE RATE	FILLER WEIGHT	TENSILE STRENGTH (MPA)	YOUNG'S MODULUS E (MPA)	ELONGATION AT BREAK (%)
P-PS 0%	0%	38 ± 3.33	1846 ± 89.13	4.2 ± 1
P-PS 10%	10%	36 ±3.06	3240 ± 308.06	0.62 ± 0.06
P-PS 20%	20%	28 ± 3.32	3100 ±159.48	0.59 ± 0.22
P-PS 30%	30%	26 ± 3.43	2700 ± 515.58	0.75 ± 0.05
P-PS 40%	40%	25 ± 4.36	2605 ± 1003.3	0.73 ± 0.11
P-PS 50%	50%	22 ± 2	2510 ± 181.48	0.69 ± 0.1

The tensile strength, Young's modulus, and elongation break are compared for the recycled polymer resin and filled PS- powder as shown in Figures 3.26, 3.27, 3.28, respectively. Figure 3.8 shows the higher tensile strength is for the sample which filled with 10 Wt. % of PS, and then it starts to decrease. Where the tensile strength of the unfilled polyester resin was the highest, then it starts to decrease with the increment of the particle of pistachio shells in the specimen. And this effect was expected since the composition of materials plays a role in affecting their tensile strength. Also, the tensile strength affects with its molecular structure. if the molecular structure changes, then the tensile strength would get affected.

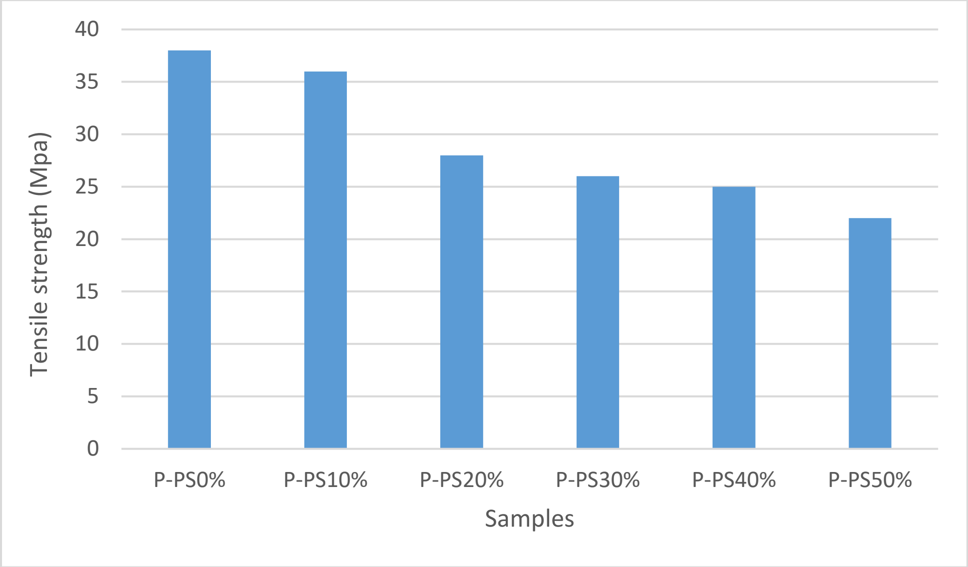


Figure 3.8 Tensile strength of each sample

Figure 3.9 shows the sample which filled with 10 Wt. % of pistachio shells also has the higher Young's modulus. And comparing with the raw polyester resin samples, the Young's modulus is much higher when the samples has been filled with PSP. That refers to the increasing of the elasticity of the sample when it filled with PSP. But as illustrated in Fig 3.9, the Young's modulus starts to increase when adding the PS particle at 10 Wt. %, then re-decreased stably at 20, 30, 40, 50 Wt. %.

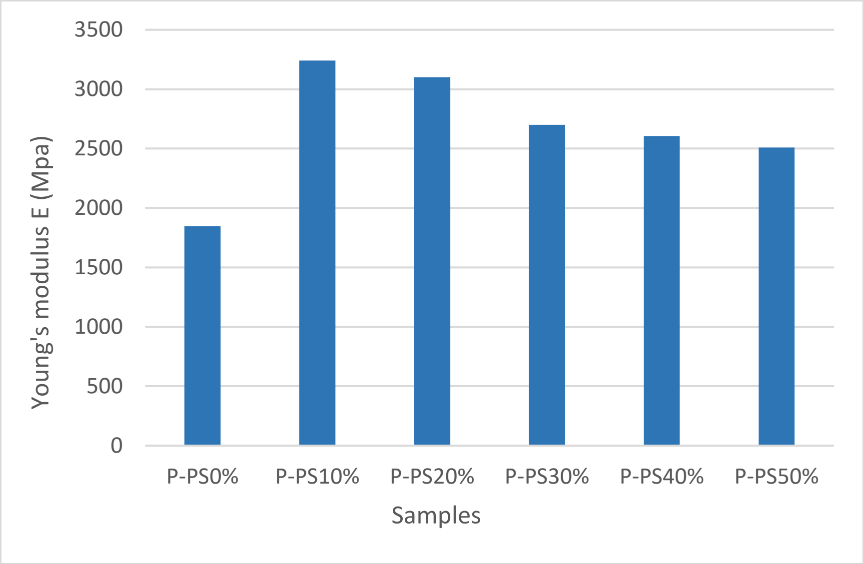


Figure 3.9 Young's modulus of each sample

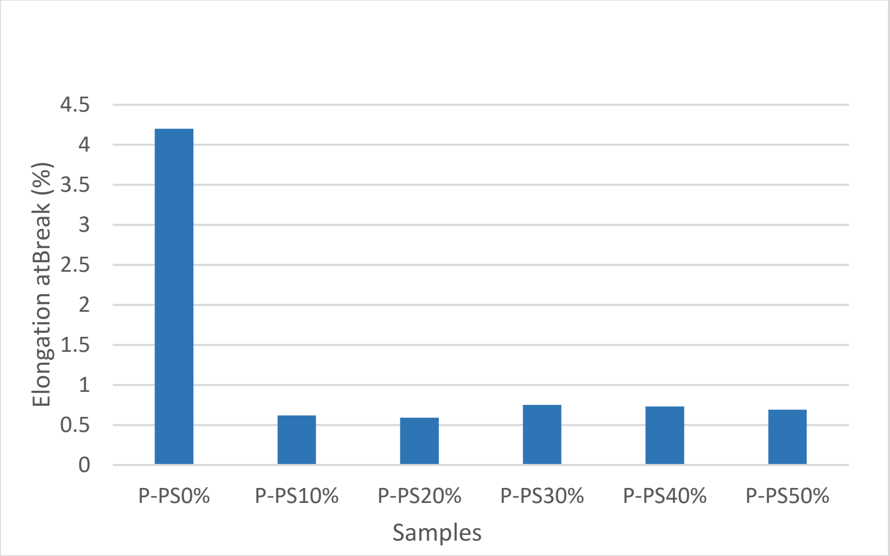


Figure 3.10 Elongation at break VS samples

Figure 3.10 shows the samples versus strain at break of the PS/polyester composites. The tensile strength good at the sample of 10 Wt. % PSP, and then start to decrease. However, when the tensile strength increases then elongation at break decreases, and vice-versa. A higher strength means a harder and less deformable material, means that it is hard to deform and break at low strain.

Conversely, a more elastic or plastic material is less strong, but breaks at higher deformation. So that the elongation at break starts to increase by increasing the PSP at the same time in the specimens. The relation between the strength and the strain at break is illustrated at Figure 3.11. In addition, the PSP samples at 10, 20, 30, 40, 50 Wt. % are brittle materials since the elongation at break is less 5%.

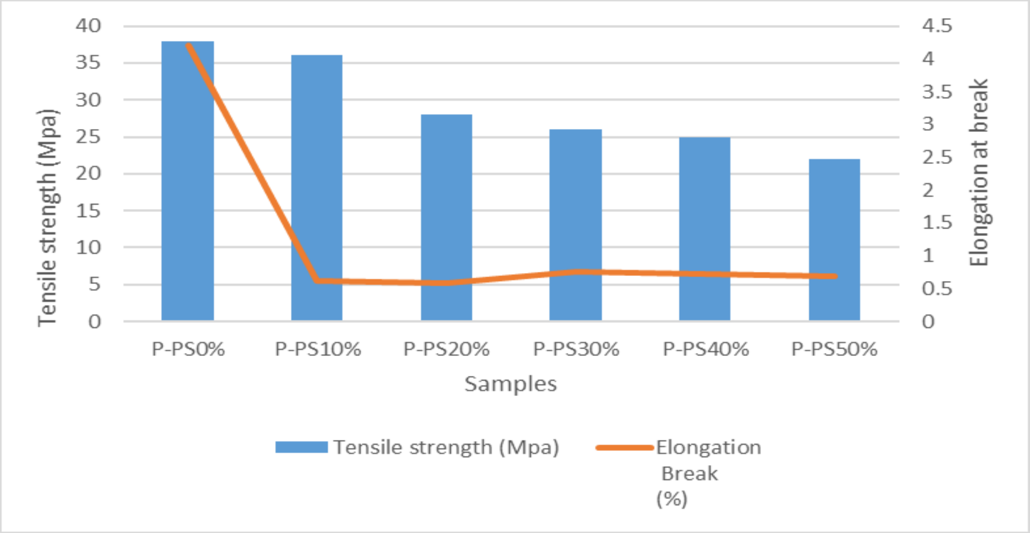


Figure 3.11 Samples contain PSP versus tensile strength and strain at break.

3.3 Izod-Charpy Test

At Izod impact tests, the used pendulum energy in the experiment was 5.4 J. As mentioned at Section 2.3.3, this test is used to investigate the strength of the material. The toughness of a material is a factor in its capacity to absorb energy during plastic strain [22]. Table 3.4 illustrates the varies of impact strength with the percentage of PSP added to the specimens.

Table 3.4 Readings of Impact strength of the samples

	P-P S0%	**P-PS 10%**	**P-PS 20%**	**P-PS 30%**	**P-PS 40%**	**P-PS 50%**
Impact strength (KJ/m^2)	1.8±2.28	2.0±3.54	2.4±0.68	2.4±0.62	2.6±0.68	2.5±0.51

The lower toughness in the material mean that it is Brittle materials, that is as a result of the small amount of plastic deformation that they can support. The impact value of a material can also changes with temperature and the size of the specimen. usually, in the case of low temperature, the impact strength of a material is decreased. In the other hand, the size of the specimen may also affect the value of the Izod impact test, where the bigger size the lower the impact energy. Figure 3.12 presents the Impact strength versus PS content in the specimens. The impact strength starts to increase at pistachio shell particle content of 10 Wt. % and keep increasing with increasing the weight of the PS particle content.

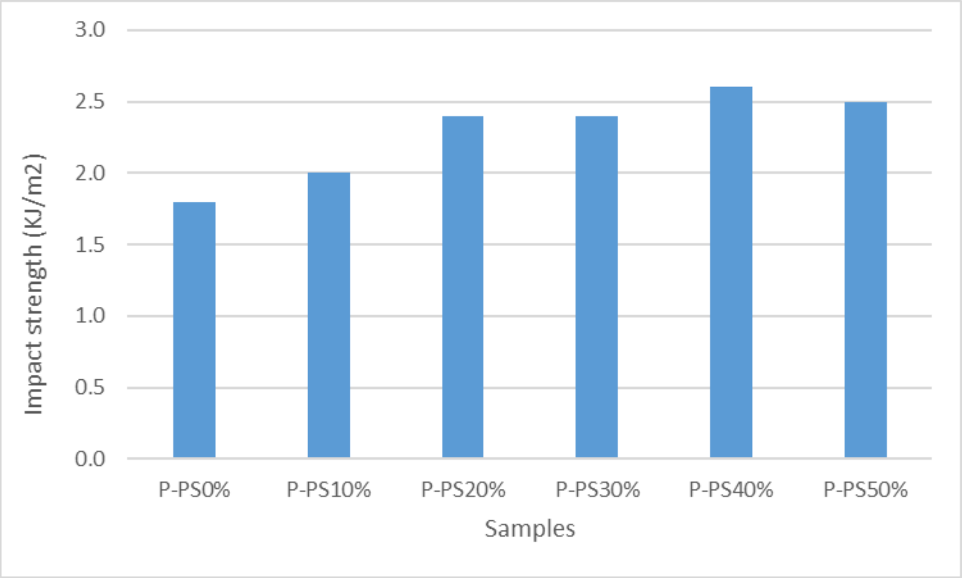


Figure 3.12 Impact strength versus PS content in the specimens

The highest impact strength was 2.6 kJ/m^2 at PS particle content is 40 Wt. %, while the unfilled polyester resin (P-PS 0%) was 1.8 kJ/m^2corresponding to an increment of between the impact strength of unfilled specimen to the highest impact strength is 44%. This indicates that the pistachio shell particles have the potential to significantly improve impact strength.

3.4 Three Point Bending Test

According to ASTM D790 and ISO178 the bending test measures the flexural strength of the specimen to find out if the used material is a good choice for the intended end use. Table 3.5 presents the average of readings for the test and also illustrated the data's standard deviation. Flexural strength measures the force require to break the specimen. When this value is exceeded, the tested specimen breaks. So, the higher the value, the greater impacting forces the material can resist [25].

Table 3.5 The readings and its standard deviation of three-point bending test.

	Flexure strength (Mpa)	Flexure modulus (Mpa)	strain at Break (%)
P-P S0%	84 ± 10.32	2510 ± 583.89	11 ± 3.38
P-PS 10%	80 ± 13.55	2450 ± 173.21	2 ± 0.32
P-PS 20%	79 ± 11.36	5100 ± 485	1.5 ± 0.25
P-PS 30%	64 ± 5.48	4720 ± 1077	1.8 ± 0.12
P-PS 40%	60 ± 5	3560 ± 1042	1.7 ± 0.15
P-PS 50%	57 ± 5.69	2780 ± 687	1.4 ± 0.26

As shown in Figure 3.13, the flexural strength isn't so much affected by the addition of PS particles. The flexural strength slightly decreased by about 5.0% at 10 Wt. % PS particles and decreased stably at higher contents. As discussed before this is because of the agglomeration in the PS particles and this leads to decrease in the stiffness of the composite.

However, the agglomeration of particles does not affect the bending modules (Flexural modulus). The modulus was significantly enhanced by adding PS particles in the polymer as seen in Figure 3.14, at the highest value at the sample of 20 Wt. % of PS particles content. It is increased by 51% comparing with the raw sample (0 Wt. % PS particles content), this is due to the rigid particles have much higher stiffness than the polyester resin.

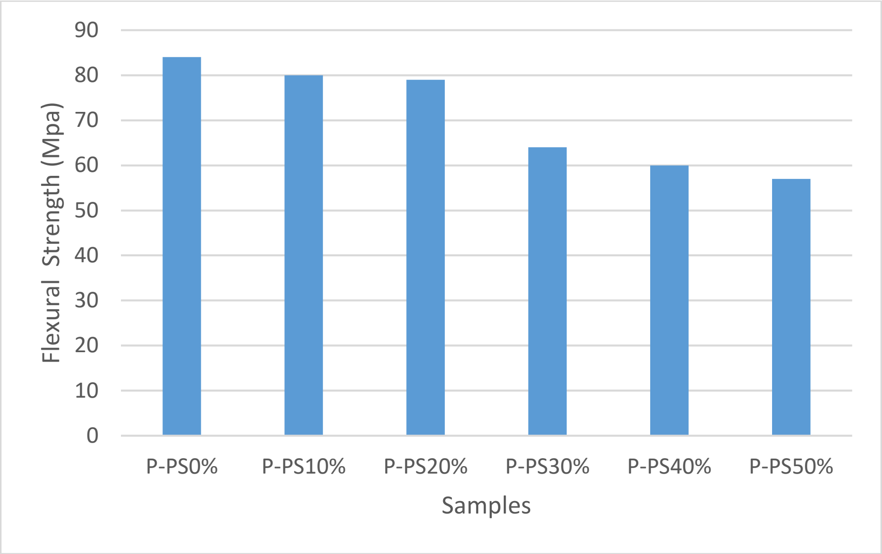


Figure 3.13 Flexural strength versus PS content in the specimens

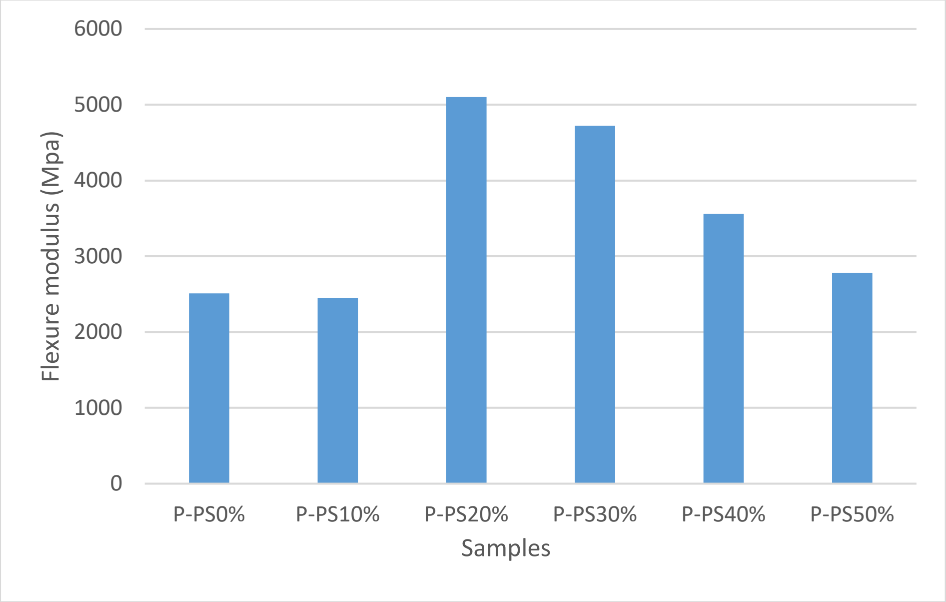


Figure 3.14 Flexural modulus VS PS content in the specimens

Figure 3.15 illustrates the Flexural stress at break (%) when the specimen breaks during the bend test. The value of the break at stress decreases by increasing the PS particles in the sample. It decreases by 55% where the highest value after adding the PS particles is at 10 Wt. % PSP content sample. On the other hand, Figure 3.16 shows also the relation between the flexural strength and strain at break, the curve represents an almost linear behaviour up to the flexural strength where a sudden break, that is to say brittle occurred. Consequently, the tested samples are brittle as discussed before.

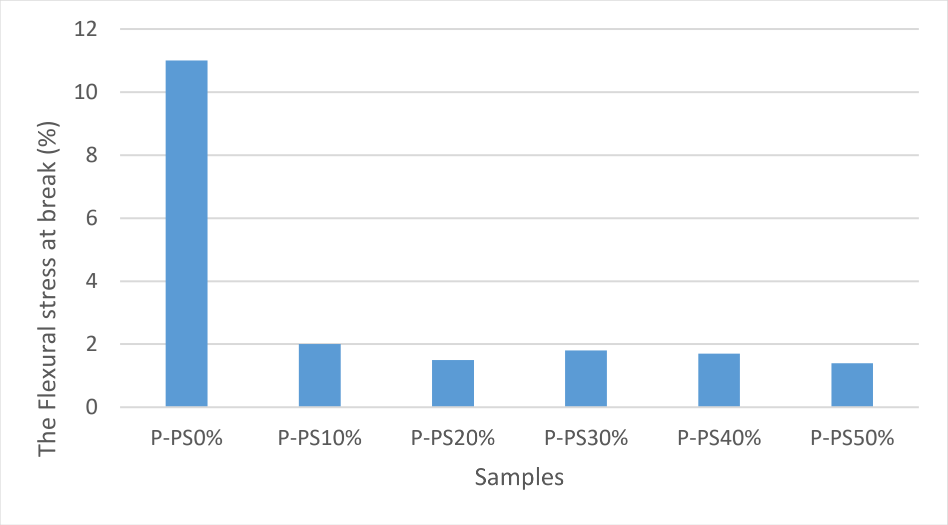


Figure 3.15 Flexural stress at break VS PS content in the specimens

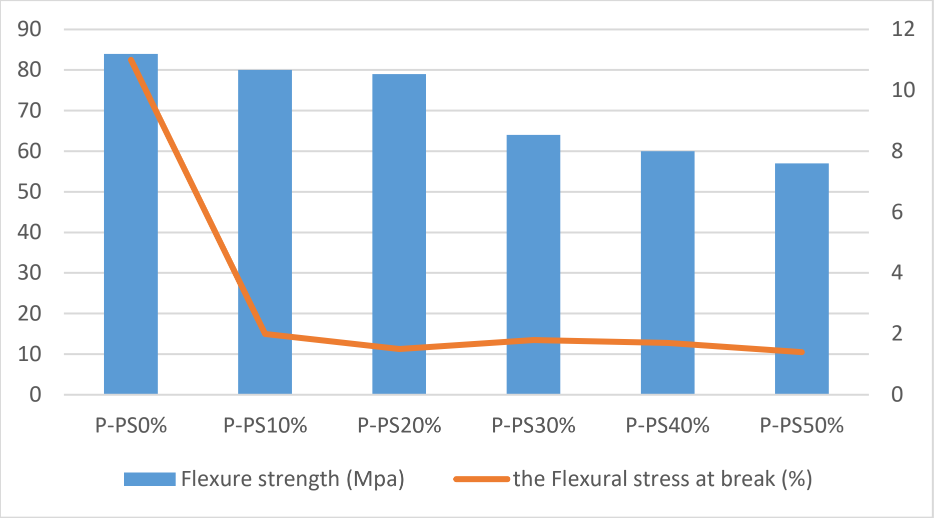


Figure 3.16 Flexural stress–strain curve of the samples

3.5 Abrasion Test

At Section 2.3.5 the abrasion test was explained, and it have been mentioned that at this test readings value is that higher value represents a greater loss of surface, so that a low resistance to abrasion and vice versa. Table 3.6 shows the readings values of the abrasion at 40 m and applied force is 10 N.

Table 3.6 The readings values of the abrasion resistance vs the samples

composite rate	Filler weight	Density (g/cm^3)	Abrasion ratio (Nm/cm^3)
P-PS 0%	0%	1.2211	0.0004728
P-PS 10%	10%	1.2403	0.0005572
P-PS 20%	20%	1.2439	0.0002912
P-PS 30%	30%	1.2638	0.0003232
P-PS 40%	40%	1.2745	0.0003117
P-PS 50%	50%	1.2746	0.0003358

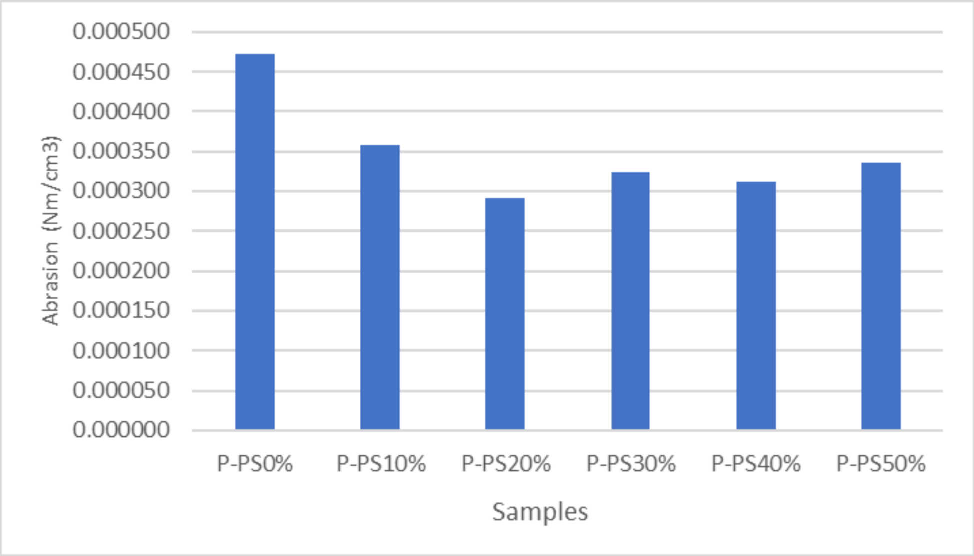


Figure 3.17 Abrasion VS the PS content samples.

Figure 3.17, illustrating the decreasing of the Abrasion resistance with increasing the PS particle inside the sample, which, means that the PS particle improved the wear resistance. The best value of abrasion is at the sample of 20 Wt. % PS content and compared to the non-additive sample the abrasion improved by 38%.

CHAPTER 4

ACOUSTICAL TESTS AND ITS PROPERTIES

In this section, the definition of sound, its behaviour, and the Impedance tube test to calculate the sound absorption and sound transmission of the prepared specimens are discussed.

4.1 Fundamental of the Sound

Sound can be defined as a wave motion in air or other elastic media or as that excitation of the hearing mechanism that results in the perception of sound (sensation) [15]. The sound wave propagates when an air particle is displaced from and to its original position by the elastic forces of the air. But the inertia of the particle, it greater than the resting position, to have elastic forces in the opposite direction. And this movement of the particles in the medium produce the sound wave. However, this movement has pressure fluctuation is called sound pressure P and a velocity of motion of the particles of the medium v. The number of fluctuations in 1 s is called the frequency f, its unit is hertz (Hz). However, the speed is the distance travelled by the sound wave profile by unit time (m/s). The value is reported as,

$$c = \lambda f \tag{4.3}$$

where λ is the wavelength, its unit is m .

Sound wave can travel through any kind of matter, but not through a vacuum. The speed of sound is different when the materials differ. In the case of speed of the sound in solids, depend on the density of the material ρ, and young's modulus E, as the following equation:

$$c = \sqrt{\frac{E}{\rho}} \tag{4.4}$$

Also, the speed of the sound depends on temperature. But it is generally the slowest in gases, faster in liquids, and the fastest in solids.

4.2 Sound Behaviours

When a sound wave is generated in an enclosed space, it behaves in different ways it is may reflected, absorbed, refracted, diffused, diffracted, or transmitted at different speeds dependent on the types of the structure. Especially when the sound hits a wall, its energy will divide into three parts as present in the following equation:

$$E_i = E_r + E_a + E_t \tag{4.5}$$

where; E_i is the energy of the incident sound on the wall, E_r is the reflected energy on the wall, E_a is the absorbed energy by the wall, and E_t is the transmitted energy.

All these behaviours will be defined respectively below.

4.2.1 Reflection

Sound wave is reflected when the size of obstruction is greater than the wavelength of the sounds. Sound wave acts similarly to light rays according to these conditions, so once sound waves contact the flat surface of a barrier, the reflected wave is split at the exact same angles as the original ray, according to the theory of reflection. This indicates that the point of occurrence angle equals the reflection angle, The amount of reflected waves is determined by the materials' smoothness, size, and softness. Smooth and broad surfaces, as well as soft materials, tend to create more noticeable sound wave reflections. Sound waves continuously impact the walls or borders of an enclosed area, resulting in repeated reflections. These reflections persist until the sound energy diminishes, resulting in a reduction in sound intensity and, finally, a minimal amount of sound energy to be about zero [16].

4.2.2 Absorption

Whenever high-frequency sound waves collide with an object, they are reflected as well as absorbed. While some of the sound waves are reflected off the item's surface, others are absorbed by it. The measure of absorption is defined by a constant called absorption coefficient and is donated by α. The sound absorption coefficient of a barrier is the percentage of sound energy absorbed by the material during contact.

Depending on the characteristics of the material, the level of sound absorption varies. The ratio of the absorbed sound energy to the incident sound energy is the mathematical definition of the sound absorption coefficient. This number, which ranges from 0 to 1, indicates how much sound energy has been absorbed. Porous and supple materials typically have larger absorption values, which means they can absorb a greater part of the sound energy that is incident on them. Hard and solid materials, on the other hand, have lower absorption coefficients,

$$\alpha = \frac{E_i - E_r}{E_i} = \frac{E_a + E_t}{E_i} \tag{4.6}$$

which means that when they come into touch with sound, they absorb less of its energy [16].

The efficacy of a surface or material in absorbing sound is measured by the sound coefficient, which is determined empirically. A perfect sound absorber is one in which the incident sound is completely absorbed by the absorber ($\alpha = 1$); in contrast, a perfect reflecting surface has $\alpha = 0$. In conclusion, a material will absorb sound if the absorption coefficient is high and will reflect sound if it is low.

4.2.3 Refraction

While a sound wave enters another medium at an angle, this phenomenon happens. Due to the different sound wave speeds in the two media, the sound ray bends [16].

4.2.4 Diffusion

When a sound wave emanates from a surface, it scatters or redistributes randomly. It happens when the wavelength of the sound is in close proximity to the surface depths of hard surface materials. The audience in the room will perceive sound coming from all directions at the same level when a satisfactory diffusion is achieved in an enclosed space [16].

4.2.5 Diffraction

Diffraction of sound is a phenomenon in which sound waves move and change direction as they pass through obstacles or openings. The behaviour is like a diffraction of the light, but it occurs with sound waves instead. It is possible to observe it in different situations such as when sound waves are passing through door cracks, at corners of buildings or even into your heads while you hear sounds coming from a source that's out of sight. It is an essential factor in wave behaviour and has the responsibility for how sound can be heard when a line of sight to its source is blocked. [16].

4.2.6 Transmission

The ensuing sound wave's energy is partially transmitted to solid obstructions. The molecules of the solid barrier vibrate as a result of the transmitted energy, producing sound. Structure-borne sound is the term used to describe this type of sound transmission. It is known as affect sound when it is produced mechanically. Airborne sound is referred to as sound that travels through the air [16]. The volume of sound that travels within the material is known as the transmission coefficient and is defined as follows:

$$\tau = \frac{E_t}{E_i} \tag{4.7}$$

As a result, the equation's statement that more sound energy permeates a material when the transmission coefficient is larger, and the opposite is true when the transmission coefficient is small indicates that the material reflects sound. Therefore, it helps to describe the sound insulation when is equal to 1 denotes a complete gearbox.

4.3 Sound Absorption Coefficient Calculations

An indicator of how well a surface or substance absorbs sound is called the absorption coefficient. For instance, the absorption coefficient is 0.55 if it absorbs 55% of the input sound energy [15].

As expressed before the sound absorption coefficient is determined experimentally. In case of $\alpha = 1$, the incident sound was absorbed 100 % by the absorber and it is called a perfect sound absorber, on the other hand; a perfectly reflected surface has $\alpha = 0$. As a conclusion, the large value of absorption coefficient, the material will absorb the sound. After recording the signal by the analyser and obtain the absorption coefficient reading data. Table 4.7 shows the reading absorption coefficient at 1/3 octave band.

Table 4.7 Readings data at 1/3 frequency octave band for all P-PS samples.

f (Hz)	0%	10%	20%	30%	40%	50%
16	0.35	0.81	0.19	0.26	0.24	0.08
20	0.98	0.99	0.91	0.03	0.98	0.96
25	0.36	0.40	0.40	0.38	0.39	0.39
31.5	0.14	0.16	0.19	0.17	0.18	0.17
40	0.02	0.00	0.03	0.01	0.02	0.01
50	0.02	0.03	0.01	0.02	0.02	0.02
63	0.01	0.02	0.02	0.01	0.01	0.01
80	0.04	0.04	0.04	0.04	0.05	0.04
100	0.01	0.02	0.02	0.02	0.02	0.02
160	0.00	-0.01	0.00	0.00	0.00	0.00
125	0.01	0.01	0.00	0.00	0.00	0.01
200	0.01	0.01	0.01	0.01	0.01	0.01
250	0.02	0.02	0.02	0.02	0.02	0.02
315	0.02	0.02	0.02	0.02	0.02	0.02
400	0.02	0.02	0.02	0.02	0.02	0.02
500	0.02	0.02	0.02	0.02	0.02	0.02
630	0.03	0.03	0.03	0.03	0.03	0.03
800	0.04	0.04	0.04	0.04	0.04	0.04
1000	0.03	0.03	0.03	0.03	0.03	0.03
1250	0.04	0.05	0.04	0.04	0.04	0.04
1600	0.05	0.08	0.05	0.07	0.07	0.06
2000	0.09	0.18	0.09	0.16	0.13	0.12
2500	0.26	0.29	0.16	0.29	0.23	0.22
3150	0.61	0.18	0.26	0.23	0.21	0.22
4000	0.24	0.15	0.28	0.20	0.21	0.22
5000	0.11	0.10	0.14	0.12	0.12	0.13
6300	0.11	0.11	0.13	0.12	0.12	0.13

The variation of the sound absorption coefficient with respect to frequency for the sample of P-PS 0% helps us to conclude the reading data in Table 4.7.It can be seen that the maximum value of absorption coefficient is 0.66 at frequency range between 3816 Hz and 3832 Hz as shown in Figure 4.1.

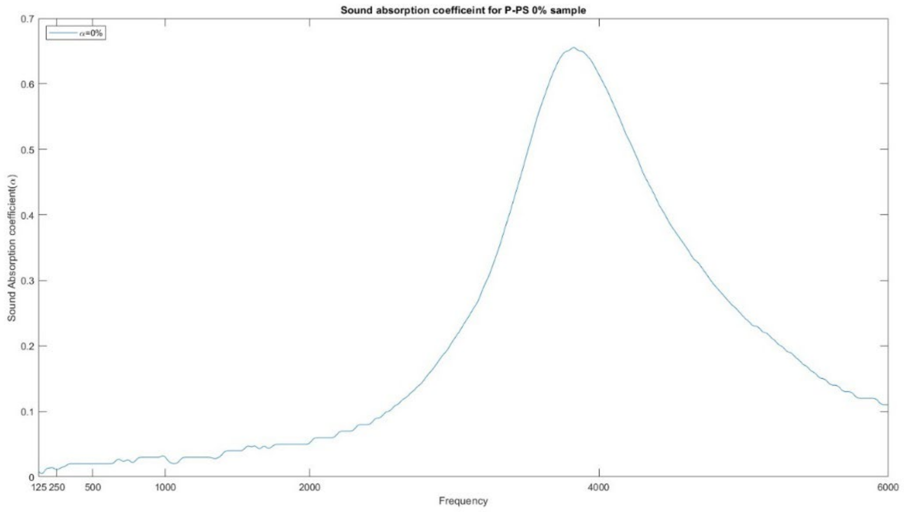


Figure 4.1 Sound absorption coefficient for P-PS 0% sample VS. frequency

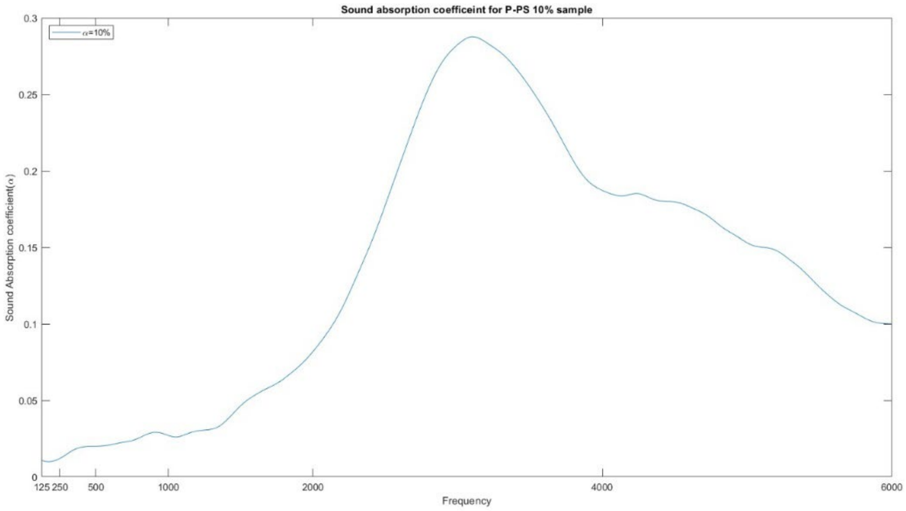


Figure 4.2 Sound absorption coefficient for P-PS 10% sample VS frequency

Figure 4.2 illustrates the absorption coefficient between 0 up to 0.29 versus frequency in range of 104 to 5704 Hz for the sample of P-PS 10%. The α_{max} was 0.29 at frequency range between 3023 Hz and 3192 Hz.

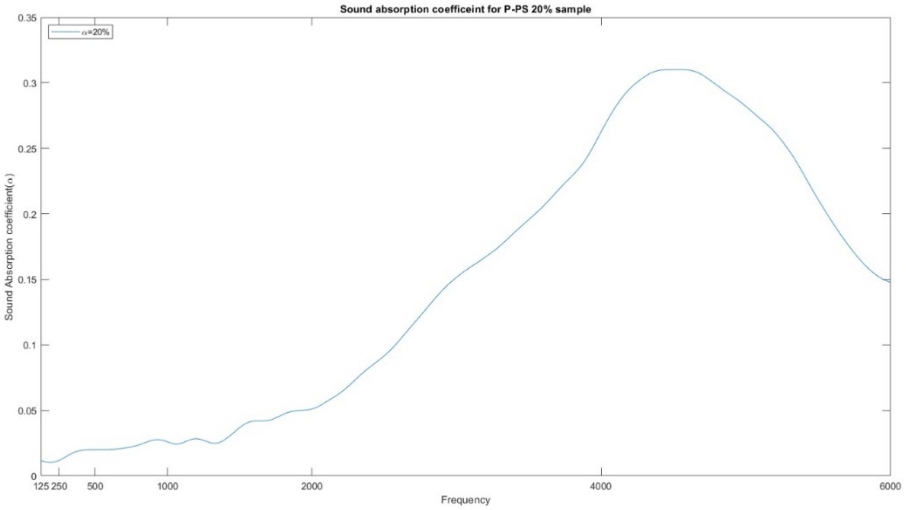


Figure 4.3 Sound absorption coefficient for P-PS 20% sample VS frequency

In Figure 4.3, absorption coefficient VS. frequency at the range for the sample P-PS 20% between 0 to 0.31 and 104 to 5704 Hz respectively. where the maximum absorption coefficient is 0.31 at frequency range between 4304 Hz and 4712 Hz is presented.

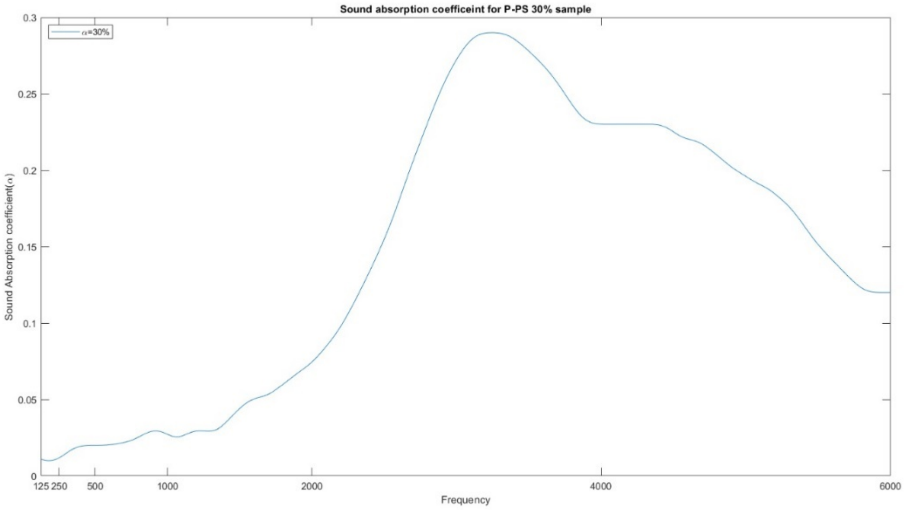


Figure 4.4 Sound absorption coefficient for P-PS 30% sample VS frequency

Figure 4.4 shows the results of frequency at range of 104 to 5704 Hz versus absorption coefficient at range from 0 to 0.29 for the P-PS 30% sample. While the results give that α_{max} was 0.29 at frequency range between 3080 Hz and 3416 Hz.

On the other hand, Figure 4.5 presents absorption coefficient readings data for the P-PS 40% from 0 to 0.24 VS. frequency at range from 104 to 5704 Hz, as a result the $\alpha_{\max}$ was 0.24 at frequency range between 3216 Hz and 3336 Hz.

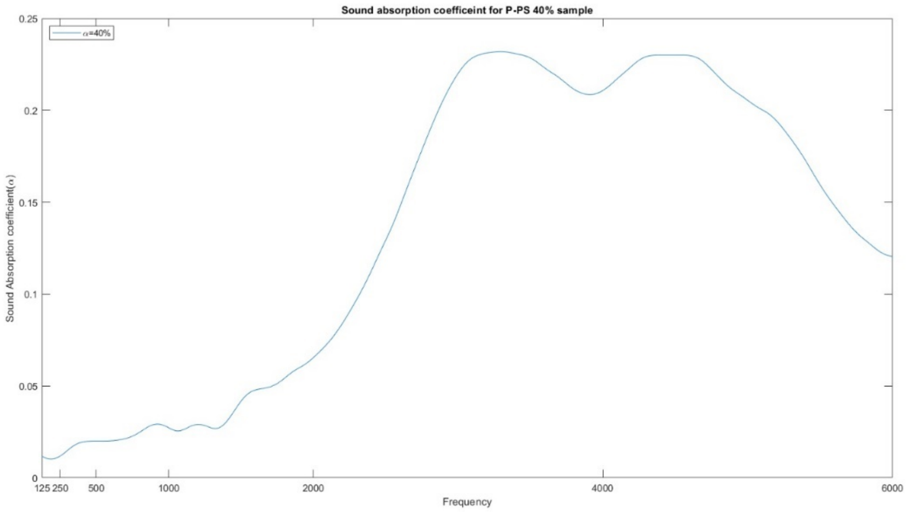


Figure 4.5 Sound absorption coefficient for P-PS 40% sample VS frequency

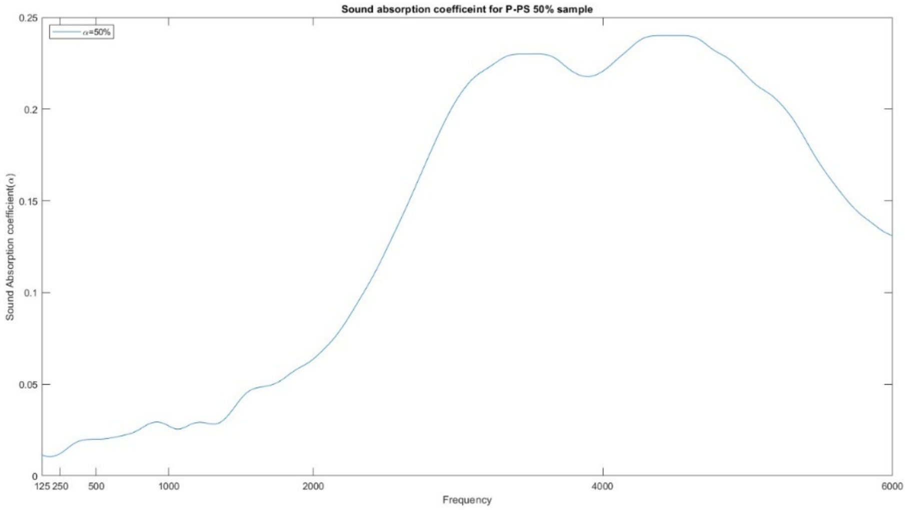


Figure 4.6 Sound absorption coefficient for P-PS 50% sample VS frequency

Finally, the Figure 4.6 presents the results of absorption coefficient at each frequency at a range from 104 to 5704 Hz for sample P-PS 50%. while α_{av} is 0.24 at frequency range between 4216 Hz and 4712 Hz.

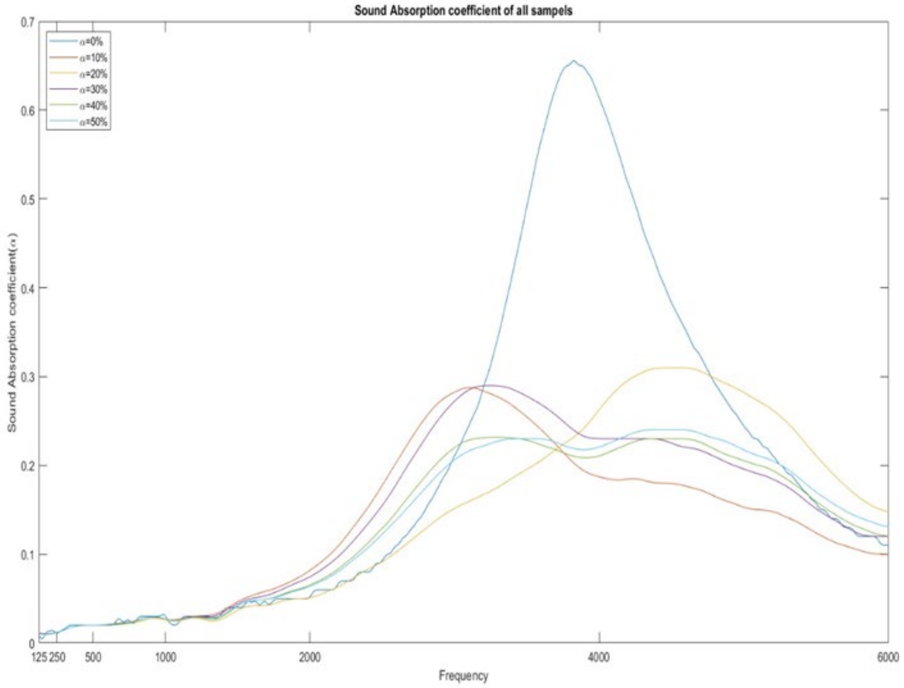


Figure 4.7 Sound Absorption coefficient of the samples.

Figure 4.7 shows absorption coefficient of the samples and its frequency range, where α is equal to 0.31 was the highest at P-PS 20%.

4.4 Noise Reduction Coefficient Calculation

In some situations, it's useful to have a single numerical rating that facilitates the comparison of how different materials absorb sound. However, access to a spectrum of values, which shows how surface absorption varies with frequency, is generally more beneficial for design purposes. To provide a rough idea of a material's acoustic absorption qualities, the Noise Reduction Coefficient (NRC) can be employed. The NRC is calculated as the average of the surface absorption coefficients within the octave bands of 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz. It's worth noting that NRC values are conventionally rounded to the nearest 0.05 for reporting purposes.

$$\text{NRC} = \left(\frac{1}{4}\right)*(\alpha_{250}+\alpha_{500}+\alpha_{1000}+\alpha_{2000}) \tag{4.8}$$

Table 4.8 tabulate the reading absorption coefficient 250, 500, 1000, 2000 Hz.

Table 4.8 Readings data at frequency octave band for all P-PS samples.

f (Hz)	0%	10%	20%	30%	40%	50%
250	0.02	0.02	0.02	0.02	0.02	0.02
500	0.02	0.02	0.02	0.02	0.02	0.02
1000	0.03	0.03	0.03	0.03	0.03	0.03
2000	0.09	0.18	0.09	0.16	0.13	0.12

After calculating the NRC using the equation 4.8, the results tabulated at Table 4.9.

Table 4.9 Readings data at 1/3 frequency octave band for all P-PS samples

	0%	10%	20%	30%	40%	50%
NRC	0.041794	0.062085	0.039457	0.056262	0.049298	0.047526

The NRC gives the rough measure of the effectiveness of the material at sound absorption. Moreover, there is no indication that the material is more effective for high-frequency sound than for low frequency-sound.

4.5 Results and Discussion

The results of the sound absorption measurement of all tested samples are graphically depicted in Figure 4.34 based on the measurement findings mentioned above. It is amply demonstrated that the highest sound absorption for the sample containing 20 Wt. % PS particles occurs between 3800 and 5200 Hz. However, when the sound absorption of the 20 Wt. % additive sample and the non-additive samples containing PS particles are compared, we can see that the 0 Wt. % sample has a peak at 0.66.

When PS filler is included in polyester resin, the sound absorption ability is significantly improved at medium frequencies for the purpose of making a suitable membrane absorber. The cells can be made of organic or inorganic materials, be homogeneous or heterogeneous, symmetrical, or asymmetrical, porous, or dense, electrically neutral or charged, and exhibit isotropic or anisotropic properties. Membranes are an interphase that restricts the passage of different components in a specific mode and over a wide range of particle sizes and molecular weights. The utilisation of PS-polymer composites results in materials that function exceptionally well as organic membrane absorbers at medium frequencies.

CHAPTER 5

CONCLUSION

This chapter summarizes the main findings and contributions of this thesis, which aimed to investigate the effects of different methods on the performance of a certain task. The chapter also discusses the limitations of the current work and suggests some directions for future research. The methods that were used to obtain the results and recommendations are briefly reviewed and evaluated in terms of their strengths and weaknesses.

5.1 Conclusion and Recommendations:

In this thesis, the pistachio shell powder is additive into polyester resin composites. All the specimens were prepared by hand-mixing method at different ratios 10, 20, 30, 40, 50 Wt. % and have two steps post-curing: firstly, at the room temperature for 3 h, then at oven at 85°C for 2 h. The Impedance tube, Tensile, Three-Point bending, Abrasion and Izod-Charpy impact tests, also SEM analysis were applied on the composite samples. On the other hand, these tests help on assessing both mechanical and acoustical behaviour of the prepared specimens.

According to the analysis of all results, the following conclusion were obtained:

- Tensile, and flexural tests present effect of adding of PSP on the mechanical properties of the composites where the results shows that the prepared material from polyester resin after additive it by 10 Wt. % PSP has the best tensile and flexural strength, and the material is brittle. This indicates that the PSP particles act as reinforcement agents that improve the stiffness and resistance to deformation of the polyester matrix. However, the brittleness also implies that the material has low ductility and toughness, which means it can fracture easily under high stress or impact. The optimal percentage of PSP for enhancing the mechanical properties of the polyester resin may vary depending on the application and design requirements of the composite material.

- Charpy impact test shows the highest impact strength was 2.6 kJ/m^2 at P-PS is 40 Wt. %, this illustrates that the PS-P have the potential to markedly improve impact strength. The Charpy impact test is a standardized method to measure the energy absorbed by a material during fracture under an impact load. The higher the impact strength, the more resistant the material is to be cracking or breaking under stress. The optimal value of 40 Wt. % in P-PS indicates that this composition has the best balance between toughness and stiffness among the tested samples.
- Abrasion test of the additive PS-polyester resin samples presents a decreasing at the Abrasion resistance with increasing the PS particle inside the sample, which, means that the PS particle improved the wear resistance.
- The SEM analysis at 5 Kx, and 10 Kx magnification a good distribution of pistachio particles was obtained for PS particle content of 10 and 20 Wt. %. In addition, particle combination occurs at content above 10 Wt. % of pistachio particles.
- Impedance tube test presents another feature of the polyester resin specimens filled by PS particles where the sound absorption performance is greatly increased at the medium frequencies. Especially at the 20 Wt. % additive sample, the sound absorption coefficient reaches up to 0.31 at around 4 kHz, which is much higher than that of the pure polyester resin sample. This indicates that the PS particles act as micro-resonators that enhance the sound absorption of the composite material. The impedance tube test also shows that the sound absorption performance of the specimens decreases at higher frequencies, which is consistent with the theory of sound absorption by porous materials.

However, these tests lead to both improvements as well as deteriorations in the mechanical properties depending on the content of PS particles. In spite of the fact that significant losses in mechanical properties can be found at high particle content, fabricating environmentally friendly and low-price particulate polymer that can be used a good organic membrane absorber at studios, home theatres, offices, gaming rooms, and other locations with low and mid- frequencies.

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