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Determination of mechanical properties of fruit shell powders reinforced wood plastic composite (wpc) materials and case study for ı-type snap-fit model

Meyve kabuğu tozları takviyeli ahşap plastik kompozit (apk) malzemelerin mekanik özelliklerinin belirlenmesi ve i-tipi snap-fit modeli için örnek çalışma

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Determination of Mechanical Properties of Fruit Shell Powders Reinforced Wood Plastic Composite (WPC) Materials and Case Study for I-Type Snap-Fit Model

Önemli noktalar (Highlights)

- *Wood plastic composite materials production.*
- *Analysis of I-type snap-fit using the finite element method.*
- *Determination of mechanical properties of wood plastic composite materials.*

Grafik Özet (Graphical Abstract)

In the present work, 6 wt. % of shell powders consisting of walnut, almond, hazelnut, peanut, pistachio and apricot kernel shells at a rate of 1 wt. % is combined with ABS granules. The mechanical properties of the obtained composite material were determined and compared with pure ABS material.

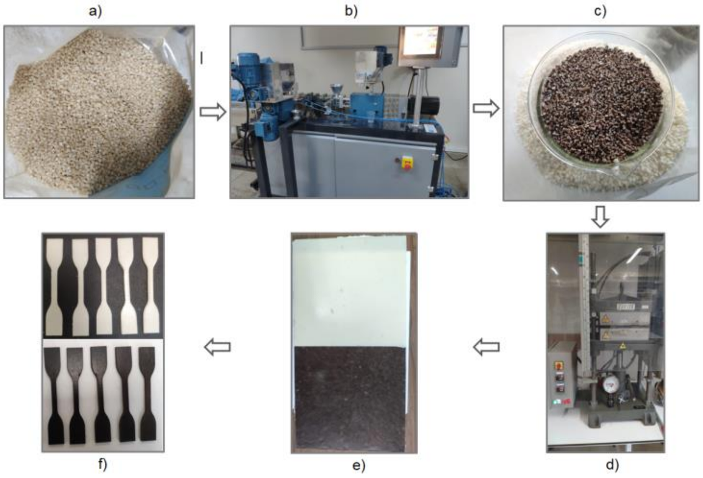

Figure. The preparation of WPCs; a) mixture of composite, b) Polmak Plastic Twin Screw Extruder Machine, c) crushed materials and pure ABS granules d) Carver hot press machine, e) WPC panel and pure ABS panel (200 mm x 200 mm x 3 mm), f) test specimens.

Aim

Determination of fruit shell reinforced wood plastic composite (WPC) materials materials.

Design & Methodology

Production of fruit shell reinforced wood plastic composite (WPC) materials with twin screw extruder.

Originality

Previous studies have not discovered the study of reintroducing fruit shell residues grown in Turkey into production as a means of reducing the use of plastic materials.

Findings

A wood plastic composite (WPC) materials has been produced to be used in designs that want a wooden look.

Conclusion

With the study, a new material that can endure 12,6N less load than pure ABS has been obtained to be used in I type snap-fit designs.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Determination of Mechanical Properties of Fruit Shell Powders Reinforced Wood Plastic Composite (WPC) Materials and Case Study for I-Type Snap-Fit Model

Araştırma Makalesi/Research Article

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ABSTRACT

High quality material production has been among the work of many researchers in recent years. These materials, which are obtained mostly by the production of composite materials, enable the production of lighter, more durable and less costly products. Increasing environmental pollution in recent years, protection of natural resources and ensuring recycling have increased the importance of wood plastic composite material production. In this study, wood plastic composite material was obtained by using ABS (Acrylonitrile butadiene styrene) plastic material and six different fruit shell powders (walnut, pistachio, peanut, almond, hazelnut and apricot shell). The mechanical properties of the obtained composite material were determined and its effect on the I type snap-fits was analyzed in ANSYS software. When the resulting composite material's mechanical properties were tested, it was found that the density and tensile strength decreased while the Vicat softening point value and melt flow rate increased. In the analysis performed using the ANSYS software, it was found that the composite I type snap-fit design of the same size can resist 12.6% N less force when the material is subjected to its maximum values when it achieves the elongation at break value.

Anahtar Kelimeler: Wood plastic composite (wpc), fruit shells, acrylonitrile butadiene styrene (abs), snap-fits.

Meyve Kabuğu tozları Takviyeli Ahşap Plastik Kompozit (APK) Malzemelerin Mekanik Özelliklerinin Belirlenmesi ve I-Tipi Snap-Fit Modeli için Örnek Çalışma

ÖZ

Kaliteli malzeme üretimi son yıllarda birçok araştırmacının çalışmaları arasında yer almaktadır. Daha çok kompozit malzemelerin üretimi ile elde edilen bu malzemeler daha hafif, daha dayanıklı ve daha az maliyetli ürünlerin üretilmesini sağlar. Son yıllarda artan çevre kirliliği, doğal kaynakların korunması ve geri dönüşümün sağlanması ahşap plastik kompozit malzeme üretiminin önemini artırmıştır. Bu çalışmada ABS (Akrilonitril bütadien stiren) plastik malzeme ve altı farklı ağaç malzeme (ceviz, antep fıstığı, fıstık, badem, fındık ve kayısı kabuğu) kullanılarak ahşap plastik kompozit malzeme elde edilmiştir. Elde edilen kompozit malzemenin mekanik özellikleri belirlenmiş ve I tipi snap-fit bağlantılara etkisi ANSYS yazılımında analiz edilmiştir. Mekanik özellikler incelendiğinde elde edilien kompozit malzeme yoğunluğunun, çekme mukavemetinin azaldığı buna karşın eriyik akış hızının ve Vicat erime noktası değerinin arttığı gözlemlenmiştir. ANSYS yazılımında yapılan analizde malzemenin kopma uzaması değerine ulaştığında alabileceği maksimum değerler incelendiğinde, aynı boyuttaki kompozit I tipi geçmeli tasarımın %12,6 N daha az kuvvete dayanabileceği gözlemlenmiştir.

Keywords: Ahşap plastik kompozit (apk), meyve kabukları, akrilonitril bütadien stiren (abs), snap-fits

1. INTRODUCTION

Agricultural residues and food waste can bring about serious environmental pollution. These wastes can be retrieved as an important renewable energy source that can be provide for increasing energy demand with the rapidly increasing population and industrialization, or by combining them with plastic materials and transforming them into an industrial product that provides the demands of the industry. These industrial products can be obtained by combining agricultural wastes such as nut shells, coconut shells, corn cobs, rice husks, and plastic materials such as PLA (Polylactic acid), PP (polypropylene), PE (polyethylene) etc. [1-3]. These composites, also called green composites or biocomposites, are defined as different types of bio-composite materials consisting of both reinforcements and polymer matrix phase originating from renewable resources or biological materials [4]. One of these green composites is wood-plastic composites (WPC) which includes a lower moisture absorption rate, improved fire resistance, better stiffness and compression properties.

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Moreover, It is used for various structural applications due to fiber-reinforced polymeric composites have high specific strengths according to metals [5].

Matheus et al. investigated the chemical degradation properties of pecan nut and its association with the polymer matrix. Chemical degradation was tested using the Flynn-Wall-Ozawa and Criado method. Pecan shells thermal degradation starts at 250°C and takes place in three steps and ıt shows that pecan shells have high extractive content (12.6 wt.%) and holocellulose (55.7 wt.%). The study showed that pecan shells are more suitable for joining with thermoplastic materials in matrix polymer composite applications that require a processing temperature below 220 °C [6]. In addition, Alvarez et al. obtained wood-plastic composite by using degreased pecan walnut shell powder and PLA polymer matrix. Composite material was formed by using 0.5% and 7.5 wt. % powder .The mechanical and thermal properties of the obtained materials were determined and the morphological analysis of the matrices was made. It was observed that there was a significant decrease in mechanical and thermal properties, while the rate of water absorption increased [7]. Moreover, composite materials formed by walnut shells, which are in the same family as pecan nut, with polymer materials have been the subject of research. Ander et al. obtained a biocomposite using 10 wt. % plasticized PLA and alkali-treated walnut shell flour. In the study, linseed oil was used to bind the compound together and examined its mechanical properties [8]. Meysam and his scholars combined polypropylene and walnut shell at a rate of 50% and examined the mechanical properties of the resulting composite [9]. Apart from the composite material consisting of only walnut and polymer material, shells such as walnut-almond and walnut-hazelnut-sunflower shells were brought together to obtain wood-plastic composite materials [10-12].

In addition to walnut shells, almond shells, hazelnut shells and peanut shells are also in high demand for wood plastic composites. In this context, many studies have been carried out. Quiles et al. have obtained a new sustainable composite material by combining PLA and 30 wt.% almond shells. The thermal stability of the obtained composites was low and the ductility property decreased. The composite materials were retested by adding certain proportions of maleic anhydride and the mechanical properties of the composite materials were determined [13]. Quiles et al also investigated the effect of using multifunctional epoxy-based styrene-acrylic oligomer (ESAO), aromatic carbodiamide (AC) and masculinized linseed oil (MLO) as binders to PLA and 25 wt.% almond shells. The study showed that these binders have positive contributions in terms of strength and ductility [14]. McCaffrey et al. combined polypropylene-polyethylene and almond shells at 0% and 50 wt. %. The mechanical, thermal and crystalline properties of the obtained composites were compared. As a result of the study, it was obtained that the particle size did not have an effect on the percent crystallinity of the powder size added by weight [15]. In addition, Torun et al. formed a hazelnut-high density polyethylene (HDPE) composite exposed to accelerated weather conditions for 672 hours. The morphological and mechanical properties of the obtained composites under these conditions were investigated. As a result of the study, a decrease of 62% was determined in the tensile and bending strengths in the modulus of elasticity [16]. Moreover, there are studies conducted with hazelnut and polypropylene, hazelnut and high density polyethylene. In order to define the mechanical properties of the obtained composites, tests such as shock test, tensile and bending test, water absorption test were performed and the usability of the composite material formed with this material was investigated [17-20]. Walnut is an agricultural waste material produced all over the world. Pradhan and Satapathy, obtained composite material by mixing polyester resin and walnut shell powders (4, 8,12 wt%) at a certain rate. The experimental setup was established according to the L9 orthogonal array of Taguchi's experimental design and the finite element analysis was compared with the experimental data [21]. The productive sustainable utilization of biomass residues has been stimulated by the global population growth. Due to the walnut application's 67% shell composition, a significant proportion of walnut shell is wasted globally. In contrast to shell powders, walnut shells are produced in large quantities with minimal industrial waste. Consequently, a number of researchers have previously examined the mechanical and tribological behavior of polymer composites contained by walnut shell powders [22-23]. Palaniyappan et al. an appropriate binding agent is introduced after the walnut shell/PLA biopolymer composite filament is extruded with 10% walnut shell particles. To assess the generated composite material using 3D printing technology, a lattice structure was created. The combined walnut shell/PLA polymeric composite's mechanical properties of the cage structure are optimized [24].

On the other hand, peanut shells are one of the most commonly used shells to create wood-plastic composite materials. Zaaba et al. obtained a wood-plastic composite material using 0 wt. % and 40 wt. % peanut and polypropylene material and tried to determine the mechanical properties of the obtained material [25]. In another study, the effects of this factor on the composite material were explained by adding polyvinyl alcohol to the composite material prepared with the same weight [26]. Finally, a review was prepared and explained which polymer material the peanut shells were used with and the effects of these materials [27]. García et al combined peanuts and high-density polyethylene (HDPE) material at 2, 4, 6, 8, and 10 wt. %. The effect of the obtained material on the dynamic mechanical and tribological properties was investigated. In the study, it was observed that the increase in the amount of peanut shell improved the mechanical properties, while the increase in weight ratios such as 8 and 10 wt. % had a negative effect [28].

In addition, Garcia-Garcia et al. obtained a composite material using polyethylene and peanut shell. In the study, the effect of additional supplementary material changes on peanut powders added at the rate of 10 wt. % was investigated [29]. Ahmet, polymeric composite particle board made from peanut shell doesn't burn and doesn't hold water. He discussed the composite material's mechanical characteristics that he had discovered via his research [30].

Coconut and its shells, which are widely used in the decoration and kitchen sector, generate about 15-20% of agricultural waste [31-32]. For this reason, after walnuts and hazelnut shells, one of the agricultural waste materials whose reusability should be investigated the most is coconut shells. For instance, Andrzej et al. combined 40 wt. % of coconut and Barley husk shells with polypropylene to obtain a composite material. The surface properties, chemical properties and physical properties of the obtained composite material were sought [33]. Moreover, Nasmi et al. used 5% and 10% vol. coconut husk to combine with polyester material combined with cornhusk fiber in different proportions by volume. When the proportion of coconut increased in the obtained composites, the tensile strength properties of the material decreased by 10-15%, while an increase in flexural strength was observed [34]. On the other hand, Babji et al. compared the effect of coconut shells on polypropylene and polyethylene. Mechanical properties such as thermal stability, tensile strength and bending strength of composite materials prepared with coconut shells in varying proportions between 10 and 25 wt. % were determined [35]. Due to two key problems in recent decades serious resource depletion and excessive energy consumption sustainable development has drawn a lot of attention in an effort to support an environmentally friendly future [36-37]. One of the most efficient ways to advance the recycling economy is to use ecologically friendly biomass-derived products and naturally renewable resources responsibly to meet this goal [38]. For this purpose, the use of recycled materials is increasing. In this context, there are many recycling studies in ABS, which is one of the most used plastic materials [39]. In the present work, 6 wt. % of wood powder consisting of walnut, almond, hazelnut, peanut, pistachio and apricot kernel shells at a rate of 1 wt. % is combined with ABS granules. The mechanical properties of the obtained composite material were determined and compared with pure ABS material. ABS is frequently used in automotive body parts such as covers, door and chest liners, spare tire, and interior panels. These components are assembled with snap-fits. Plastic composite materials have become popular recently, thanks to weight reduction efforts in the automotive industry [40]. In order to evaluate the use of wood plastic composite material instead of the components obtained by using ABS in the automotive sector, an I-type snap-fits model was analyzed in the ANSYS environment and the results were examined.

2. MATERIAL VE METHOD

2.1. Materials

Nuts are obtained from fruits grown in various regions of Turkey. Walnut shell materials were obtained from Samsun, apricot shell materials were obtained from Malatya, almond shell materials were obtained from Muğla, hazelnut shell materials were obtained from Ordu, pistachio shell materials were obtained from Gaziantep and peanut shell materials were obtained from Osmaniye. The volume moment mean (De Brouckere Mean Diameter) reflects the size of the particles that make up the mass of many samples. This value, indicated by D [4,3], is most sensitive to the presence of large particles in the size distribution. The particle sizes obtained for these shells are shown in Figure 1. They were oven-dried at 100 °C for 1 h prior to use.

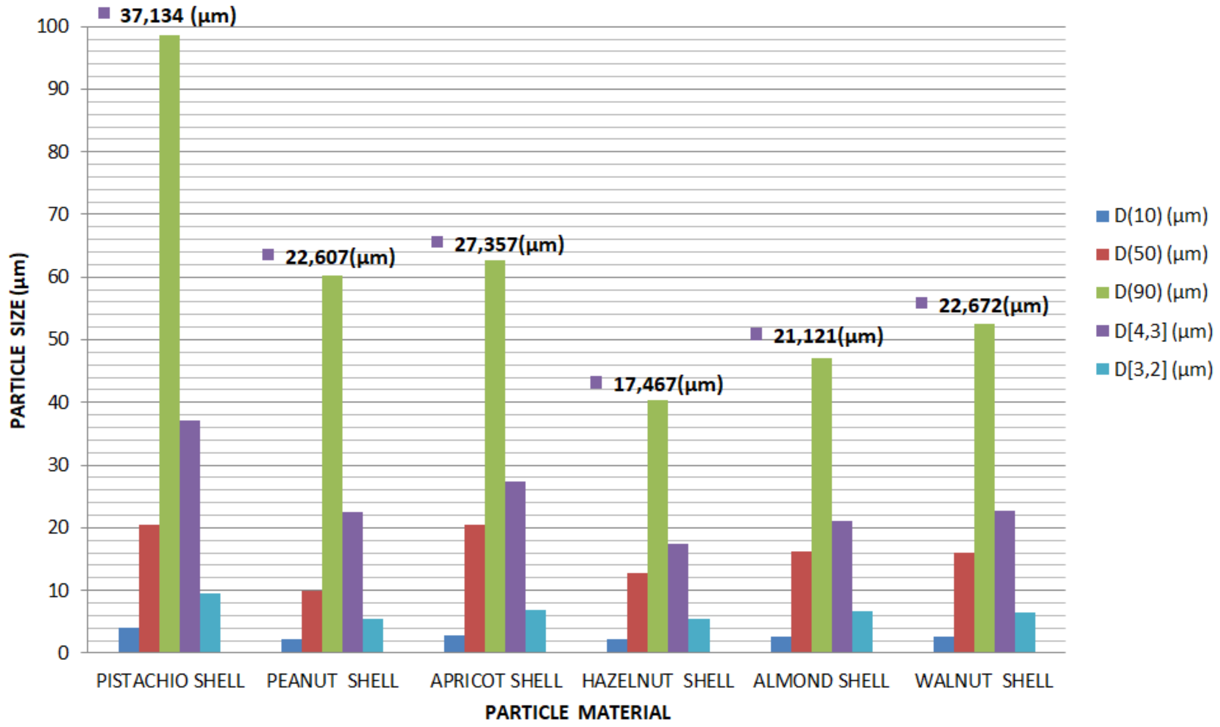


Fig. 1. Particle sizes of nut shells.

2.2. Methods

2.2.1. WPC Preparation

The shell powders shown in Figure 2 are combined with ABS material. The shell powders of 1wt % from each shell was uniformly mixed with ABS granulates, which were processed in a twin-screw mixer at 200 °C for 30 min with a feeding speed of 25 rpm using Polmak Plastic Twin Screw Extruder Machine. After natural cooling, it is crushed into particles with a grinder. A particle size of about 0.03 cm^3 was obtained.

Moreover, the particles were spread in a mold with a size of 200 mm x 200 mm x 3.2 mm to make a WPC panel by the hot pressing at 180°C for 2 bar pressure. Tensile test specimens were obtained according to the ASTMD638-02 standard. The preparation of WPCs is shown in Figure 3.

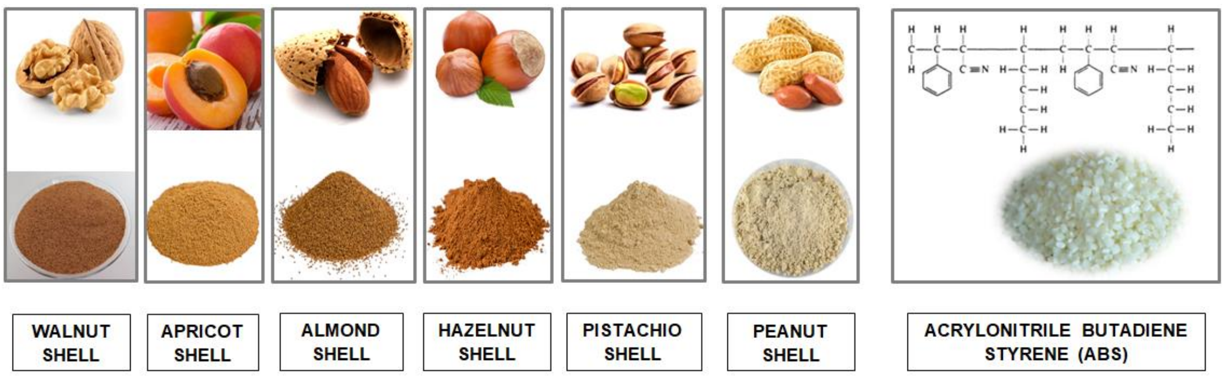


Figure 2: Combined materials.

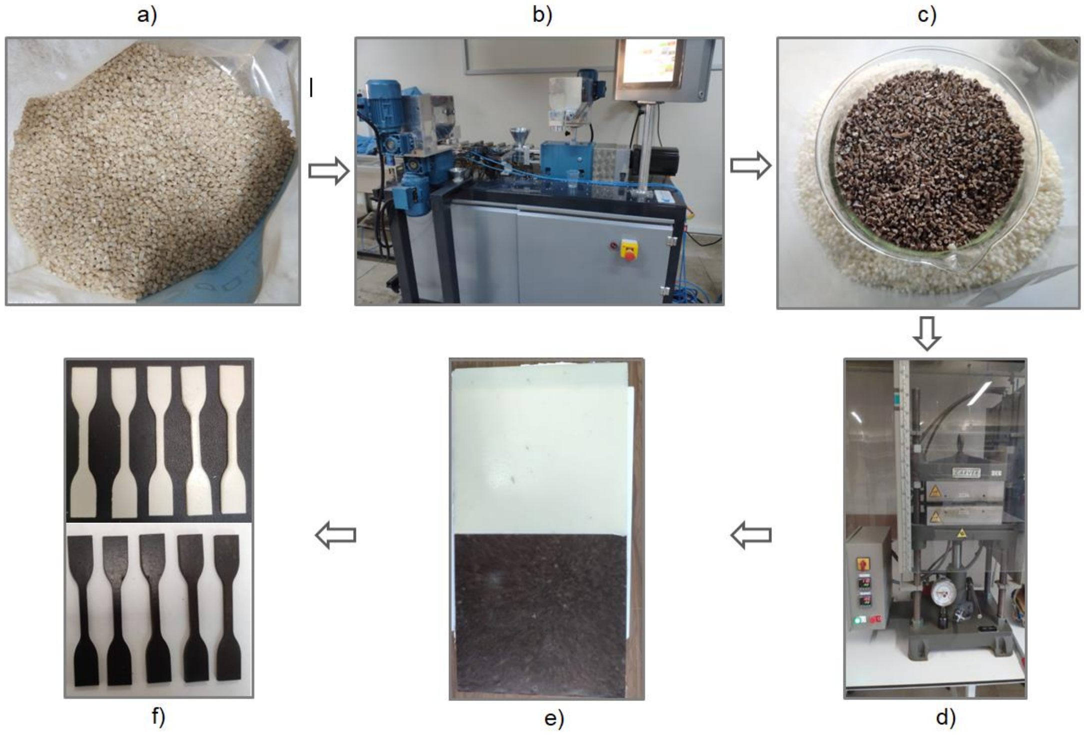


Figure 3: The preparation of WPCs; a) mixture of composite, b) Polmak Plastic Twin Screw Extruder Machine, c) crushed materials and pure ABS granules d) Carver hot press machine, e) WPC panel and pure ABS panel (200 mm x 200 mm x 3 mm), f) test specimens.

2.2.2. Morphology Analysis

The composite surface was analyzed using a scanning electron microscopy (SEM) at Mineral Research and Exploration General Directorate in Turkey. The materials are gold/palladium (Au/Pd) coated because the materials that the SEM scanned are not conductive.

2.2.3. Physical-Chemical Properties Analysis

The density of the composite material was carried out according to the T EN ISO 1183-1 standard. The test specimens conditioned for 24 hours at 23°C±2 were tested by putting them in ethyl alcohol immersion liquid. Their density calculation was done as shown in Equation 1.

$$P_s = \frac{m_{S,A} * P_{IL}}{m_{S,A} - m_{S,IL}} \quad (1)$$

(Where, mS,A (mass of test specimen in air (g));mS,IL(mass of test specimen in immersion liquid (g));PIL(density of mmersion liquid (g/cm3)); PS (density of test specimen (g/cm3)).)

2.2.4. Melt Flow Rate (MFR) Analysis

Melt flow rate test was carried out according to the TS EN ISO 1133-1 standard at 190°C and 2,16kg load.

2.2.5. Vicat (Vicat Softening Temperature) Analysis

The vicat of the composite material was carried out under 50 N load, heating rate 50°C/h according to the ASTM D 648 standard.

2.2.6. Mechanical Performance Analysis

To determine the tensile strength of WFP composites, they were cut to the dimensions shown in Figure 4 and tested according to ASTM 638-02 standard. The standard specimen dimension was 165 × 13 × 3,2 mm.

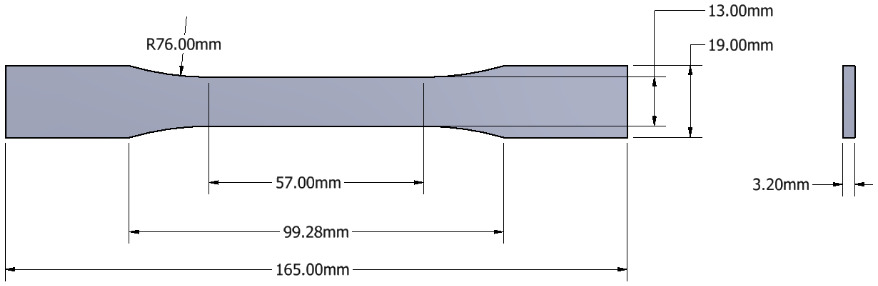


Figure 4: Geometry of tensile specimen.

2.2.7. I Type Snap-fits Analysis

I type snap-fits design was made in ANSYS software. Analysis boundary conditions were determined as shown in Figure 5 and mesh optimization for the design was done as shown in Figure 6 [41]. After determining the composite material properties, it was analyzed.

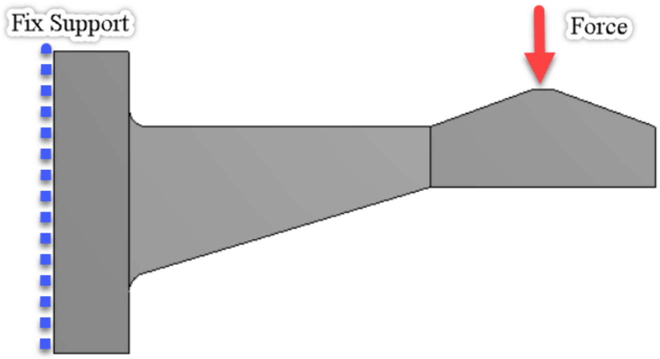


Figure 5: Boundary conditions for I type snap-fits design was done.

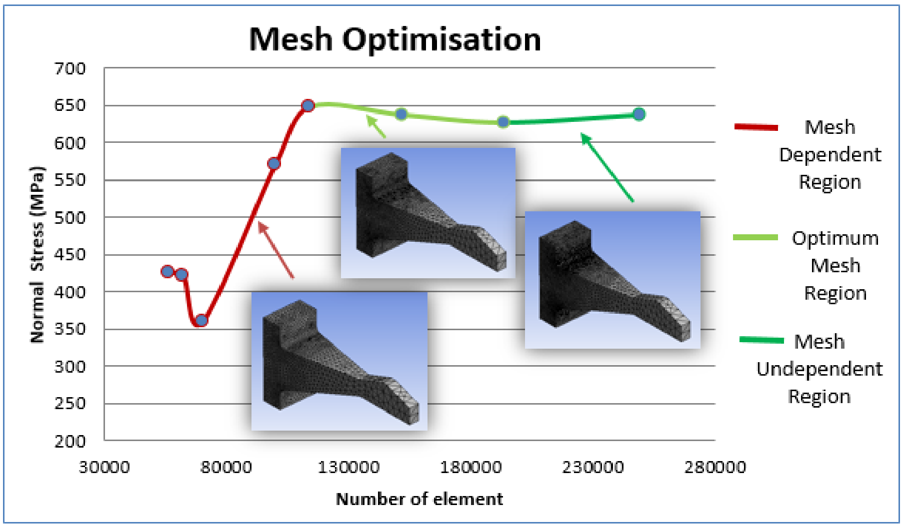


Figure 6: Mesh optimization for I type snap-fits design was done.

3. RESULTS AND DISCUSSION

3.1. Physical,Thermal and Mechanical Properties of WPC and Pure ABS Panel

Figure 7a–d shows the SEM micrographs of prepared pure ABS panel and WPC panel. Figure 7a describes the pure ABS panel for 40 µm. It can be seen that the ABS granules combined clearly. Figure 7b describes the pure ABS panel for 40 µm. It can be seen that the presence of cavities or gaps around particles can be observed clearly. Since the amount of additives is low, filling materials were seen in some regions. Due to the addition of a natural additive material, no compatibilizer or agent was used while adding the additive. For this reason, it is normal for the cheese-like filler to appear in the image. The pure ABS panel with EDS analysis is shown in Figure 7c.Carbon and oxygen elements are seen in areas selected area1, EDS spot 1 and EDS spot 2. In this case, considering these selected points of the material, it can be concluded that this material consists of pure ABS.The pure ABS panel with EDS analysis is shown in Figure 7d. Carbon and oxygen elements are seen in areas selected area 2 however, elements such as sodium, calcium and potassium were detected in the selected area1, EDS spot 1, except carbon and oxygen. Although the dust particles vary in size, it was observed that while they were very well combined in some regions, it was not good in some regions.

Figure 8 shows detailed graphs from the EDS analysis. Figure 8a shows the EDS graphic results for ABS material that is pure, while Figure 8b shows the results for ABS material that is composite. The coating materials Au and Pd elements are present in the peaked and unlabeled regions.

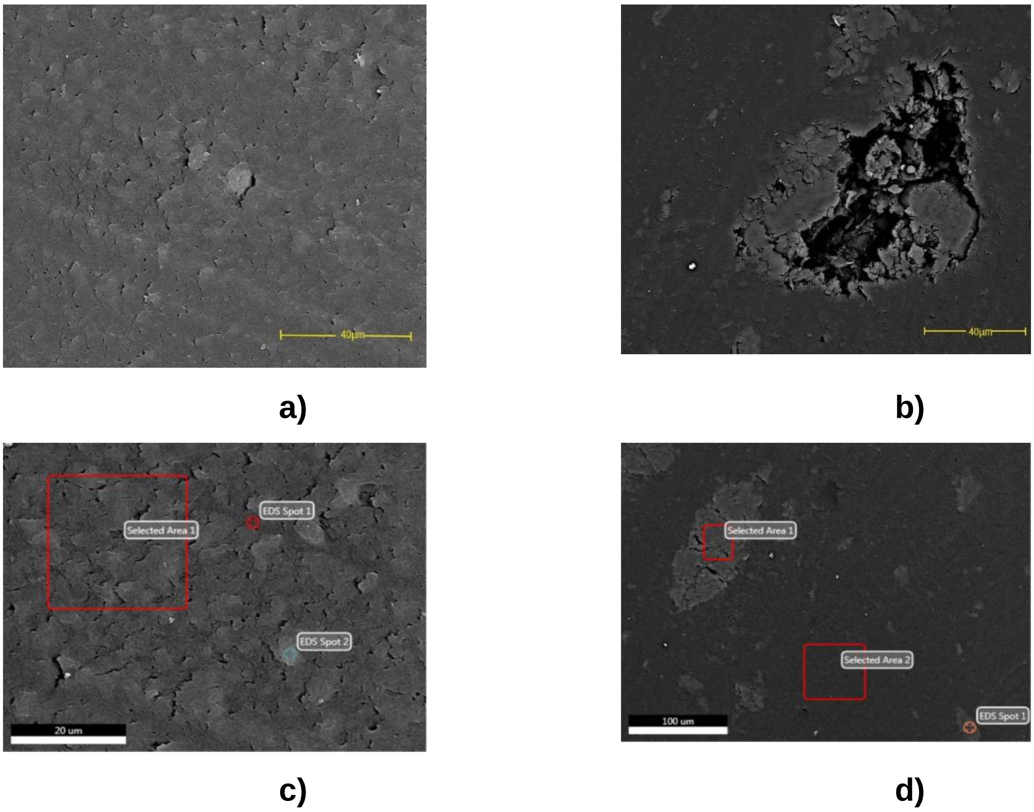


Figure 7: SEM micrographs of; a) pure ABS panel, b) WPC panel, c) EDS for pure ABS panel, d) EDS for WPC panel.

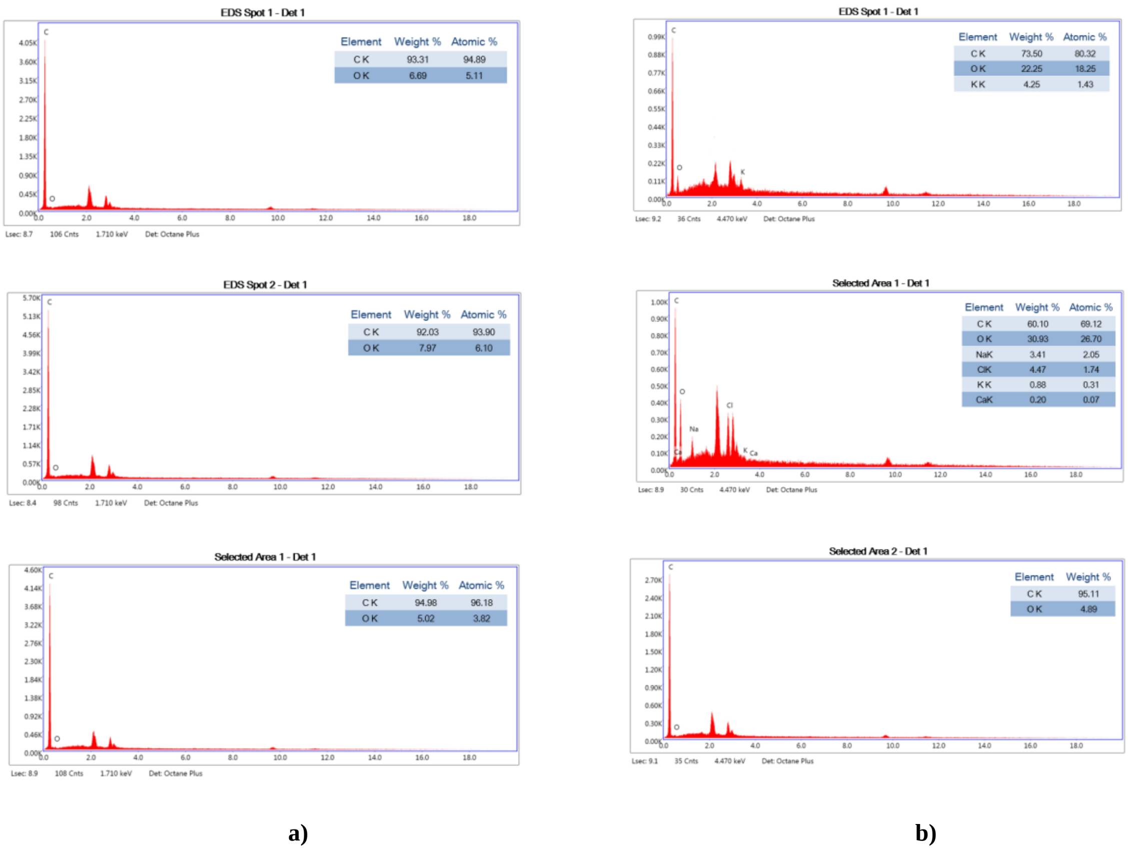


Figure 8: EDS graphs of; a) pure ABS panel, b) WPC panel.

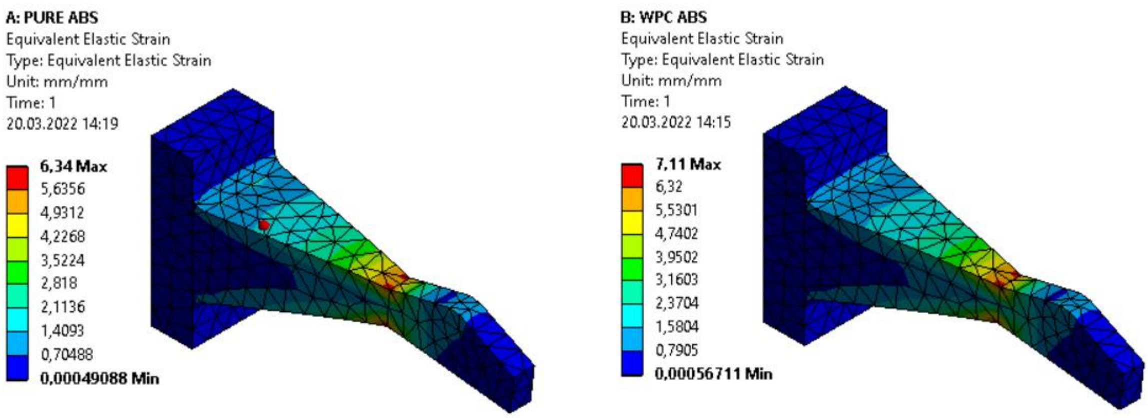
The physical, thermal and mechanical test results of the composite samples are given in Table 1. When the density values were examined, it was observed that the amount of density decreased by 8% with the addition of fruit shell powders to the pure ABS material. Despite the decrease in the amount of density, it was observed that the MFR value increased from 0.30 g/10min to 0.35 g/10min. Moreover, when we examined the mechanical test results of the composite samples, it was observed that the tensile strength property decreased from 40.12 MPa to 33.99 MPa. It has been obtained that adding 6% amount of fruit shell powdersreduces the material strength by 15.22%. Although the addition of fruit shell powders reduced the polymer material density, reducing the material mass and using less material, the material became brittle and the tensile strength decreased. It was observed that the tensile strength decreased depending on the decrease in the plastic ratio in the thermoplastic polymer matrix. Vicat softening point increased from 116°C to 122°C with the addition of fruit shell powderson polymer material. Thus, we can say that the composite material obtained will endure 5.17% more than pure ABS material when exposed to high temperature.

Table 1. Physical, thermal and mechanical properties of WPC and pure ABS panel.

	Properties	**Test Method**	**Test Data**	**Unit**
Pure ABS panel	Density	TS EN ISO 1183-1	1,037 ± 0,005	g/cm^3
	MFR	TS EN ISO 1133-1	0,30 ± 0,001	g/10min
	Tensile Strength	ASTM 638-02	40,12 ± 0,1	MPa
	Young's Modulus	ASTM 638-02	6,38 ± 0,05	GPa
	Elongatıon At Break %	ASTM 638-02	6,34 ± 0,02	%
	Vicat Softening Point	ASTM D 648	116± 0,1	°C
WPC panel	Density	TS EN ISO 1183-1	0,954 ± 0,005	g/cm^3
	MFR	TS EN ISO 1133-1	0,35 ± 0,001	g/10min
	Tensile Strength	ASTM 638-02	33,99 ± 0,1	MPa
	Young's Modulus	ASTM 638-02	4,98 ± 0,05	GPa
	Elongatıon At Break %	ASTM 638-02	7,11 ± 0,02	%
	Vicat Softening Point	ASTM D 648	122± 0,1	°C

3.2. I Type Snap-fits Analysis

Unit elongation resulting from stretching in the critical region amount and the unit elongation limit of the material to be used for Snap-fit designs are the most important factors. The material effects on the I type snap-fits were investigated by performing the flexural analysis according to the unit elongation limit. The % Elongation at Break for pure ABS is 6.34%. Pure ABS is assigned as the material for the I type snap-fits design shown in



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4.CONCLUSIONS

The raw material selection of the parts is generally based on the place of use. In this study, the use of more environmentally friendly wood-plastic composite material instead of ABS material, which is frequently used in the automotive industry, was investigated. Six different fruit shells were added to the pure ABS material at the rate of 1% without using any agent. The physical, thermal and mechanical properties of the obtained composite material were determined. The properties of the pure ABS material supplied in granular form were determined under the same conditions. Material properties were used for the designed I type snap-fit and flexural analysis was performed according to the unit elongation limit.

Material specified as design input after design and mold production very poor selection approach. The choice of material, the place of use of the part and the desired aesthetic made to specifications. In addition, the material selection to be made after the part design and mold production may cause an increase in the cost of the part. For this reason, the dimensional relationship of the part geometry is determined before the design by selecting the material. With the study, a new material that can endure 12,6N less load than pure ABS has been obtained to be used in I type snap-fit designs.

Businesses with strong market positions in production and management technology can succeed with the correct reforms. employment in the automotive industry, technical advancements made both domestically and overseas with its amount of commerce, it ranks among the most significant industries for our country. (Demirci, R., Semiz, S., ve Gölcü, M. 2008). In future studies, the effect of fruit shell powders ratio and the effect of agent usage will be investigated and material improvement will be made. Considering that around 80 million cars (passenger cars & light commercial vehicles) are sold in the world every year, a significant reduction in the rate of plastic material usage will be achieved with the new material obtained.

ACKNOWLEDGMENTS

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DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Fulya ERDEMİR: Carrying out the experiments and analsys the results. Wrote the manuscript.

Murat Tolga ÖZKAN: Carrying out the experiments and analsys the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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