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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Utilizing Recycled High Density Polyethylene Caps of Polyethylene Terephthalate Bottles in Composite Plates

Kompozit Plakalarda Polietilen Tereftalat Şişelerinin Geri Dönüştürülmüş Yüksek Yoğunluklu Polietilen Kapaklarının Kullanımı

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Abstract

In this study, composite plates that are consisted of recycled high density polyethylene (HDPE) polymer matrix and reinforced with woven fabrics (cellulosic fiber content; flax and jute) are manufactured in order to contribute polymer waste management. Used HDPE bottle caps are collected for recycling and hot press method is used to produce HDPE matrix plates. Plates are than reinforced with 100% jute and 100% flax woven fabrics with different fabric sequence combinations by hot press machine. Temperature, production time, pressure and cooling rate are the crucial parameters that are optimized for forming composite materials. These bi-layered and three-layered composite plates are physically and mechanically tested for appropriate end use areas.

Keywords: Composite, recycling, packaging waste, textile

Öz

Bu çalışmada, polimer atık yönetimine katkıda bulunmak amacıyla geri dönüştürülmüş yüksek yoğunluklu polietilen (HDPE) polimer matrisinden oluşan ve dokuma kumaşlarla takviye edilmiş (selülozik elyaf içeriği; keten ve jüt) kompozit plakalar üretilmiştir. Kullanılmış HDPE şişe kapakları geri dönüşüm için toplanmış ve HDPE matris plakaları üretmek için sıcak presleme yöntemi kullanılmıştır. Plakalar, sıcak pres makinesi ile farklı kumaş sıralımlarına sahip %100 jüt ve %100 keten dokuma kumaşlarla takviyelendirilmiştir. Sıcaklık, üretim süresi, basınç ve soğutma oranı, kompozit malzemeleri oluşturmak için optimize edilmiş kritik parametrelerdir. Bu çalışma kapsamında üretilmiş olan iki katmanlı ve üç katmanlı kompozit plakalar, uygun son kullanım alanları için fiziksel ve mekanik olarak test edilmiştir.

Anahtar Kelimeler: Kompozit, geri dönüşüm, ambalaj atığı, tekstil

I. INTRODUCTION

Composite structures are the materials composed of at least two types of materials by physical bonding [1]. They are generated in an attempt to obtain outstanding performance features and matchless mechanical properties with constitution of different materials that have especial internal and external structure [2]. It is aimed to improve many properties by combining the best properties of different materials such as thermal conductance, fracture toughness, fatigue strength, corrosion resistance, abrasive strength and aesthetic appearance [3]. In composite materials, mostly fibers are used as reinforcement materials [4]. Fibers are the critical elements of composite structures, as they satisfy the favored situations and transfer strength to the matrix material. The overall performance of a fiber composite depends on fiber's form, orientation, composition and the mechanical properties of the matrix material [5].

The usage of natural fibers as renewable resources in composite industry have increased due to increased awareness of people [6]. Flax and jute are the most preferred natural fibers that are used as reinforcement materials. Flax fiber has

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low specific weight, low energy consumption during processing and relatively low cost. It is stated in the literature that, flax fiber reinforced composites exhibit good mechanical properties due to the distinctive surface morphology of the flax. However, the incompatibility of flax fiber with polymeric resins results in poor fiber/matrix interfacial bonding strength [7]. Jute fiber and its composites are non-abrasive, porous, good insulator and combustible materials. It is a promising reinforcement material due to its low cost, low density, high specific strength and modulus, easy availability and renewability. The drawback of the jute fiber is its high moisture absorption [8].

Packaging is surrounding materials, which is made for protecting products from the environment and also preserves the products' quality, thereby reducing damaged products and waste [9]. There are 5 main types of packaging which are metal, glass, cardboard, carton and plastics and these can be found in the market in several types and forms. Plastics are the most used material for packaging goods due to their lightweight barrier properties and flexibility [10]. In the last 5 years, 3 million tons of plastic materials are used in Turkey just for packaging sector and 37% of it belongs to polyethylene (both high density polyethylene and low density polyethylene) packaging [11]. It is one of the most widely used thermoplastic material owing to its toughness, low moisture absorption, excellent chemical inertness, low coefficient of friction, ease of processing and low electrical conductivity [12].

High density polyethylene (HDPE) is a strong, high density, moderately stiff plastic with a highly crystalline structure. It is frequently used in milk jars, laundry detergent bottles, garbage bins, and cutting boards [12]. High density polyethylene (HDPE) is one of the most common polyethylene type especially used in polyethylene terephthalate (PET) bottle caps which can be reusable after melting and re-shaping processes owing to its thermoplastic characteristics. When its huge percentage in solid wastes and ease of accessibility are taken into consideration, recycling of HDPE package wastes becomes a very important issue in environmental aspects.

Recycling has been a significant matter in last decades, related to increasing environmental pollution. There is an increasing tendency among state and local governments about recycling action [13]. Recycling includes reusing the materials when their life cycle is ended, by regaining these materials in production of new goods [14].

In this context, in this study HDPE bottle caps in the waste state were collected and reinforced with jute and flax woven fabrics and aimed to contribute to waste management as well as making an innovative material design.

II. EXPERIMENTAL SET-UP AND PROCEDURE

2.1. Materials

In this study, high density polyethylene (HDPE) bottle caps having density of 0.74 g/cm^3 are used as matrix material whereas flax and jute woven fabrics are used as reinforcement materials.

Properties of reinforcement materials are given in Table 1.

Table 1. Physical properties of reinforcement materials

Sample Code	Fiber content	Weave Type	Yarn Count	Areal Density (g/m^2)	Fabric Count (e.p.c x p.p.c)
F	Flax	Basket (2x1)	Ne 3.2 (weft) Ne 5.9 (warp)	294	16 x 9
J	Jute	Plain	Ne 2.8 (weft) Ne 2.6 (warp)	241	7 x 6

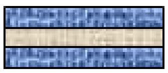
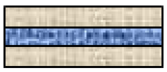
*e.p.c.: ends per cm, p.p.c: picks per cm

2.2. Composite Production

For composite production, hot press machine is used. Several preliminary productions are performed to determine the most suitable form of matrix and reinforcement material and optimum production parameters. Based on the experience of preliminary experiments, recycled HDPE matrix plates are pre-produced by hot press machine. 36 plastic water bottle caps made of HDPE are placed in a 6 x 6 matrix to ensure homogeneous distribution for larger plate productions. They are covered with Teflon sheet to prevent contact between machine and polymer materials before starting hot press operation. Optimum production parameters are performed (160 °C, 20 tons, 1.5 hours with pressure + 3 hours without pressure). The compressed HDPE plate is slowly cooled under decreasing pressure for 3 hours in order to get a homogenous and smooth matrix plate. The pre-produced matrix plates and fabric reinforcement material (jute and flax) are covered by Teflon paper together and place into the hot plate machine. The same optimized production parameters are applied to the composites.

Different composite designs are prepared by changing fabric and matrix plate layout. The details of these composite designs are listed in Table 2.

Table 2. Sample codes

Specimen Code	Layers	Components
HF		Recycled HDPE Plate Flax Fabric
HFH		Recycled HDPE plate Flax Fabric Recycled HDPE Plate
FHF		Flax Fabric Recycled HDPE Plate Flax Fabric
HJ		Recycled HDPE Plate Jute Fabric
HJH		Recycled HDPE Plate Jute Fabric Recycled HDPE Plate
JHJ		Jute Fabric Recycled HDPE Plate Jute Fabric

The pictorial views of the composite designs are given in Figure 1 and Figure 2.

Figure 1. H-F-H, H-F and F-H-F composites (left to right)

Figure 2. H-J-H, J-H-J and H-J composites (left to right)

III. ANALYSES

Thicknesses of composite materials are measured by digital thickness gauge. The densities of the composite structures are calculated from the measured average weight and calculated volume data.

Composites are tested by their water absorption and tensile properties. In water absorption test, both composite and fabric thicknesses are measured and surface areas are calculated. After their dry weights are measured by using precision scale, samples are immersed in water one by one and their wet weights are measured. Immersion period is 30 seconds. Results of this experiment are given as % water absorption of produced composite.

Tensile test is conducted by using Titan Tensile Tester according to TS EN ISO 13934-1 standard.

IV. RESULTS AND DISCUSSIONS

4.1. Thickness

Thicknesses of HDPE matrices are measured as 0.30 mm whereas thickness of flax and jute fabrics are 0.61 and 0.58 mm, respectively. When composite structures are taken into consideration, it can be said that designs including 1 matrix and 1 fabric layer (HF and HJ) have very similar thicknesses (0.51 and 0.63 mm, respectively) with fabric thicknesses. On the other hand, especially designs including 1 matrix plate in the middle of the 2 fabrics have the maximum thicknesses (0.87 mm for FHF and 1.02 mm for JHJ).

4.2. Density

Densities of the samples are listed in Table 3. According to the calculated data, it can be said that due to the air gaps in the structure, fabrics have less densities than matrix plates. Especially for jute fabric reinforced composites, the increment in the amount of matrix plate increase the density while the increase in jute fabric layers decrease the density of the composite structure. For flax fabric reinforced composites, it is not possible to say such clear comments which can be resulted from unwanted air gaps regarding to un-wetted fibers in the structure.

Table 3. Densities of samples

Sample Codes	Average Weight (g)	Volume (cm^3)	Density (g/cm^3)
H	3.40	4.57	0.74
HF	8.19	7.74	1.06
HFH	9.72	9.71	1.00
FHF	11.71	13.13	0,89
HJ	6.71	9.51	0.71
HJH	9.13	10.38	0.88
JHJ	10.57	15.29	0.69

4.3. Water absorption

Water absorption test results are given in Table 4. According to the data calculated, water absorbency percentages of HDPE plates are zero, as expected based on the hydrophobic characteristics of polymers. Similarly, composite designs composed of 2 matrix plates in both sides of core fabric have almost 0% water absorbency which means that the reinforcement fabric is covered by HDPE matrices as well. On the other hand, owing to hydrophilic characteristics of natural fabrics, in designs composed of two fabrics in both sides and core matrix in the middle have higher water absorbency percentages which means the inner matrix plate does not have capability to wet all the outer fabric layers to make them waterproof.

Table 4. Water absorbency test results

Samples Codes	Dry Weight (g)	Wet Weight (g)	Water Absorbency (%)
H	0.53	0.53	0.00
HF	0.95	1.08	13.68
HFH	1.43	1.43	0.00
FHF	1.47	2.28	55.10
HJ	0.98	1.02	4.08
HJH	1.63	1.63	0.00
JHJ	1.56	1.92	23.08
J	0.63	1.62	157.14
F	0.7	1.69	141.43

4.4. Tensile Test

Tensile test results are given in Table 5. According to the results, tensile strength of jute fabric is lower than flax fabric. In all two layer designs (HF; HJ), tensile strength increases with reinforcing fabrics in comparison to both single fabrics and matrix plates. Moreover, when three layered designs are compared with each other, all samples including matrix side layers (HFH; HJH) have higher tensile strength values than fabric side layers (FHF; JHJ). This can be explained by poor wetting of the core matrix. It is known that our matrix plates are softened under pressure and heat but not be as liquid as water therefore its wetting ability is limited. With the designs including two matrix plates in side layers together with fabric core had better wetting ability, which results in better fiber to matrix interactions leading to improved mechanical properties.

Table 5. Tensile strength test results

Sample Codes	Tensile Strength (MPa) ± SD	
	Warp Direction	Weft Direction
H	18.05±1.25	
HF	53.76±0.80	25.05±0.82
HFH	54.78±3.50	54.97±1.66
FHF	47.48±1.26	54.20±0.76
HJ	21.22±1.30	13.72±0.07
HJH	28.74±3.25	23.70±10.47
JHJ	16.25±0.39	10.52±0.40
J	17.54±0.70	16.95±1.10
F	26.19± 0.24	33.23±0.19

V. Conclusions

Packaging waste constitutes the main part of the solid waste problem around the world. HDPE, used in PET bottle caps, becomes municipal solid waste that accumulates in nature eventually. Thus, composites designed in this study are mostly focused on reducing packaging waste by recycling the bottle cap waste and regaining of used HDPE polymer. Results of experiments show that appropriate designs can be selected for the end use application in which moderate tensile strength and good waterproof properties are required. Mechanical properties of the composite panels can be improved with additional chemicals for future works.

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