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Mechanical and Thermal Properties of Wool Waste Fabric Reinforced Composites

Yün Atık Kumaş Takviyeli Kompozitlerin Mekanik ve Termal Özellikleri

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MECHANICAL AND THERMAL PROPERTIES OF WOOL WASTE FABRIC REINFORCED COMPOSITES

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ABSTRACT: Today, felt and woven fabrics are used as a reinforcement material in textile composite structures. In these structures glass and carbon fibres are the widely used ones. However for almost a decade, researchers have also shown some interest on natural fibre reinforced composites. In this study, it has been aimed to use wool waste fabric to be able to produce a lightweight composite material. For this purpose, the composite samples were produced by using wool fabrics in warp direction together with their waste blends as a reinforced material. The produced reinforced wool composite structures were then tested for both their mechanical properties, i.e. Izod impact and tensile strength tests, and for their thermal properties. The fracture surfaces of the samples were also inspected on the scanning electron microscope. According to the results, it has been evaluated that wool fabrics and their waste may be used as a reinforcement material for the application of textile composites presenting in lightweight structures for the construction industry. The wool waste fabric reinforced composites' mechanical properties can be improved by studying various waste percentages in future studies to gain better mechanical properties. The thermal conductivity of the composites was increased as the waste increases within the structure. As a result, wool waste materials can as well be used for future recycled textile materials in lightweight reinforced composites.

Keywords: Wool, waste, fabric, mechanical properties, thermal properties, reinforced composites

YÜN ATIK KUMAŞ TAKVİYELİ KOMPOZİTLERİN MEKANİK VE TERMAL ÖZELLİKLERİ

ÖZET: Günümüzde, tekstil kompozitlerinde dokusuz ve dokuma kumaşlar takviye materyali olarak kullanılabilmektedir. Bu yapılarda, yaygın olarak cam ve karbon elyafının kullanıldığı görülmektedir. Bununla birlikte aşağı-yukarı son on yılda, araştırmacılar doğal elyaf takviyeli kompozitlere de ilgi göstermektedir. Bu çalışmada ise, yün atık kumaş kullanılarak hafif ağırlıkta kompozit malzeme üretimi hedeflenmiştir. Bunun için, çözgü yönünde yün kumaş ile birlikte bunların atık karışımları takviye malzemesi olarak kullanılmıştır. Daha sonra, üretilen yün takviyeli kompozit yapıların izod darbe, mukavemet gibi mekanik özellikleri yanında termal özellikleri de test edilmiştir. İlaveten, numunelerin elektron mikroskobunda kırık yüzey morfolojileri incelenmiştir. Elde edilen sonuçlara göre, yün kumaş ve bunların atıklarından üretilen takviyeli kompozit malzemelerin tekstil kompozitleri olarak hafif ağırlıklı yapılar üretebilmek gayesi ile yapı endüstrisinde kullanılabileceği görülmektedir. Gelecekte de, yün atık kumaş takviyeli kompozitlerin mekanik özelliklerini iyileştirmek için çeşitli atık yüzdelerde çalışma imkânı mevcuttur. Üretilen kompozitlerin termal iletkenlikleri, yapıdaki atık miktarı arttıkça artmaktadır. Sonuç itibarı ile gelecekte, yün atık malzemeler tekstil materyallerinin geri dönüşümünde hafif ağırlıklı takviye kompozitleri olarak kullanılabilir.

Anahtar Kelimeler: Yün, atık, kumaş, mekanik özellikler, termal özellikler, takviyeli kompozitler

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1. INTRODUCTION

Natural fibres are ecological and are low priced. Today, environmental protection and production of textile fibres and their end uses are much more important than ever before. Hence, this environmental awareness leads many scientist and technologists to consider natural fibre reinforced composites in recent years. Natural fibres have good mechanical properties with a low density; some of these natural fibres are compared with E-glass in Table 1. As can be seen from Table 1, wool fibre has the lowest tensile strength and modulus among the six different fibres presented here.

As seen below, some researchers studied various natural fibres in composites more than a decade. Here, some of these studies are mentioned briefly: The early work [1] was carried out with woven flax and jute fabrics where polyurethane-based composites were produced. They have found that woven flax fibre have shown better mechanical strength than the woven jute fibre composites. Also increasing the fibre content have resulted an increase on the impact strength and on the shear modulus. Later, Barone et al. [4] used chicken feathers for their polyethylene-based composites. In their work; they studied compounding time, temperature, speed, fibre dispersion and established that keratin feather fibres presented increase on stiffness in HDPE but provided lower tensile breaking stress. The produced samples were thermally stable for long periods of time up to 200^{o}C. On the other hand, Barone et al. [5] also used keratin fibres of similar diameter with various ratios in mixing with LDPE and have observed that keratin feather fibres were incorporated into the polymer using thermomechanical mixing techniques and the density of the introduced fibres were reduced by 2%. Later in 2008, wool fibre waste was used by Aluigi et al [6] and produced translucent composite films from wool/cellulose acetate blends; in their work the composite materials have exhibited good tensile, thermal and water absorption properties. Yukseloglu and Yoney [7] studied various reinforcement ratios of bamboo sliver vinyl ester composites and reported their good mechanical properties where bamboo slivers showed an increase on the elastic modulus of the pure resin about 10-30 % and their bending resistance for about 3-4.4 times. Prasad and Rao [2] compared the mechanical properties of the sisal, bamboo and jowar fibre reinforced polyester composites. For this purpose, fibre extraction was achieved from jowar culms and was used for the reinforcement in polymer matrix. Jowar fibre composites have shown higher tensile strength and

Table 1. Some fibre properties [1],[2],[3]

Properties	**Flax**	**Jute**	**Sisal**	**Wool**	**Bamboo**	**E-glass**
Density (g/cm^3)	1.5	1.3	1.5	1.3	0.91	2.5
Tensile strength (MPa)	254-1035	350-770	380-635	98-172	440-600	2000-3400
Specific tensile strength (MPa/(g/cm^3))	169-690	269-592	253-423	75-132	484-659	769-1346
Young's modulus (GPa)	12-28	12-26	9.4-22	3.3-3.5	35-46	70-73
Specific Young's modulus (GPa/(g/cm^3))	8-22	9-20	6-15	2.5-2.7	38-51	27-28

tensile modulus than those of sisal and bamboo fibre composites. Because of the lower density of jowar fibres, it can be used for designing lightweight materials compared to other natural fibres i.e sisal. Later, new commodities has been seen in composite industry where by means of agricultural and industrial biomasses taken places for the interest in producing recycle and wastes from many resources. One of those recent studies where Conzatti et al.[8] produced polypropylene composite films containing different amounts of wool fibres. The most successfully produced material was isotropic polypropylene-based composites which contains up to 60 wt.% of well dispersed wool fibres by melt blending. They have studied the morphological, mechanical and thermal characterization of the produced composite materials. The overall results showed that irrespective of wool fibre content, PPC05 (polypropylene grafted with maleic anhydride, C05) presented higher strength than the PP-based materials. However, just recently Conzatti et al.[9] also successfully prepared simple melt blending procedure for PP-based composites containing only 20wt.% wool fibres too. For this, they have functionalised wool fibres with silane-based coupling agent. The morphological studies have revealed that composites containing the silanised fibres have enhanced adhesion between the fibres and the polymer matrix. Etaati et al. [10], used 10-60 wt.% short noil hemp fibres and determined the mechanical and viscoelastic properties of the short hemp fibre polypropylene composites. The tensile strength and storage modulus of the composites were improved by the addition of MAPP (maleic anhydride grafted polypropylene) and MAPOE (maleic anhydride grafted poly ethylene octane) coupling agents. The composites revealed better temperature when fibre content was increased or coupling agents were added.

As seen above, a few researches were performed on the wool fibres composites only. Hence, the primary focus of the present study is to produce a lightweight composite material made of wool waste. Therefore, we use very little amount of wool fabric in warp direction together with its waste blends as a reinforced material where polyester based composites can be produced. By doing this, we also would like to give an attention to use textiles wastes in various technological fields and for future recycled textile materials in the reinforced composites.

2. EXPERIMENTAL

2.1. Sample Preparation

In this work, composite samples were produced by using 100% wool fabrics (see Table 2) as a kind of a ribbon in warp direction together with their waste blends as a reinforced material. All of these composite samples were produced by the hand lay-up method using the polyester resin (see Table 3) in different percentages. We have added 0.15% Cobalt, 1% hardening and 2 drops of retarder. Reinforcement ratios used for this study is given in Table 4.

First, wool fabrics (in warp direction) and their waste were placed in to the mould and later polyester resin was watchfully added. Composite samples kept in a room temperature for about 8 hours and later were post-cured for an hour consecutively at the temperatures of 50°C, 80°C and 110°C.

Table 2. Wool fabric properties

Fabric weight (g/m^2)	Fabric thickness (mm)	Mechanical properties in warp direction		
		Force (N)	Strain (%)	Elongation (mm)
106.3	0.32	187.06	15.387	31.086

Table 3. Tensile strength, izod impact and thermal conductivity properties of the pure resin

Strain strength (MPa)	Elongation on max. load (%)	Izod impact (kj/m^2)	Thermal conductivity factor λ (W/m^{o}K)
11.338	2.5600	4.7600	0.336

2.2. Tests

2.2.1 Tensile Strength

Samples for the tensile strength were prepared according to the TS 1398 EN ISO 527 [11]. The samples were prepared in shape of dog-bone (dimensions of 195 x 115 x 5 mm) and were tested at the speed of 50 mm/min. and their results are given in Table 4 and the related graphs are presented in Figures 1-2.

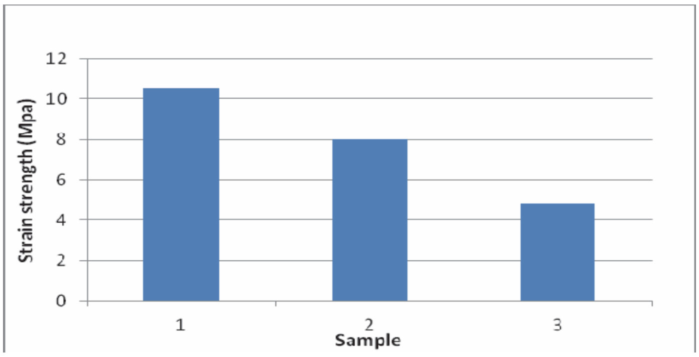

Figure 1. Strain strength graph of wool waste fabric reinforced composites

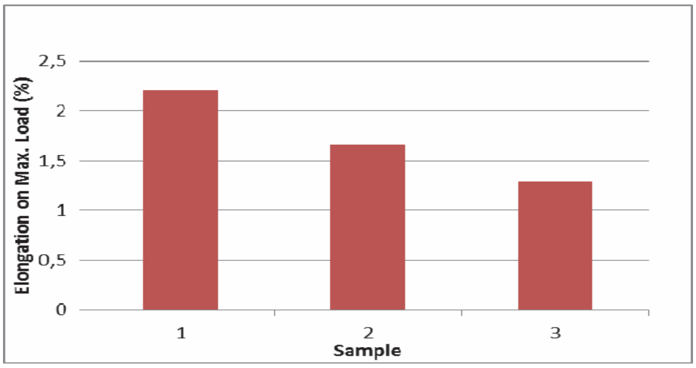

Figure 2. Elongation on Max. Load graph of wool waste fabric reinforced composites

2.2.2 Izod Impact

Izod impact test samples were also prepared according to the TS EN ISO 180 [12]; the samples were tested under the 5.4 J of pendulum and with the angle of 124^0. The results of these composite samples are presented at the Table 5 and the graph is given in Figure 3.

2.2.3 Thermal Conductivity

Thermal conductivity of the composite samples was measured on the THISYS THI01 thermal conductivity measurement tester for 45 and 90 min. The results of the samples on their thermal conductivity factor (λ) were obtained same in both durations (see Table 6).

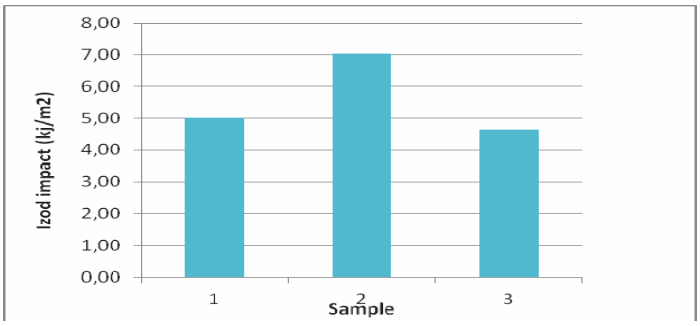

Figure 3. Izod impact graph of the wool waste fabric reinforced composites

2.2.4 Electron Microscopy Studies

The fracture surfaces of the tensile strength and izod impact samples were examined by the scanning electron microscope JEOL JSM-6060 LV. The photographs of the wool waste fabric reinforced composite samples are given in Figures 4-9.

3. RESULTS AND DISCUSSIONS

In this study, the wool fabrics in warp direction (wf) were used as a ribbon form together with wool fabric waste (wst) as a reinforced material. Five samples were produced for each tensile strength and Izod impact tests and the mean results of these composite samples are given in Tables 4-5 and in Figures 1-3.

It was observed that as the percentage of wool waste increases the tensile strength of the composites decrease. This may be due to amount of short wool waste fibre which exists within the reinforced structure. Even though if a similar decrease on the impact behaviour of the samples has been expected; surprisingly a slight increase was observed on the 4% of wool waste reinforced composites (see Table 5 and Figure 3). It is thought that this higher impact value might be the way waste fibres mixed and added well onto the mould.

Table 4. Tensile strength properties of the wool waste fabric reinforced composites

Sample	Weight of reinforced material in (%) (wool fabric+waste)	Strain strength (MPa)	Elongation on max. load (%)
1	4% wf+2% wst	10.540	2.2140
2	4% wf+4% wst	7.994	1.6620
3	4% wf+6% wst	4.810	1.2940

Table 5. Izod impact properties of the wool waste fabric reinforced composites

Sample	Weight of reinforced material in (%) (wool fabric+waste)	Izod impact (kj/m^2)
1	4% wf+2% wst	5.00
2	4% wf+4% wst	7.04
3	4% wf+6% wst	4.64

Table 6, presents the thermal conductivity factor (λ) of the composite samples. Heat transfer by conduction depends on the materials' heat conductivity. It was determined that as the waste percentage increases the thermal conductivity factor of the wool waste composites increases.

Table 6. Thermal conductivity factor of the wool waste fabric reinforced composite samples

Sample	Reinforced composite samples made of wool fabric(wf) and waste (wst)	Thermal conductivity factor λ (W/m^{o}K)
1	4% wf+2% wst	0.348
2	4% wf+4% wst	0.387
3	4% wf+6% wst	0.392

Figures 4-9 show fracture surfaces of the composite samples. If the wool waste reinforced composite structures were studied, the SEM photograhs of the tensile strengths can indicate that during the the test some of the wool fibres were broken. At a good matrix-inter surface cohesion, break is very much expected. Conversely, there are some fibre gaps where can be seen in the Figures 5 and 6. These gaps are much more in amount where the waste percentage gets higher than the 2% (see Figure 4) at the produced reinforced composite samples. This also indicates that there is a lack of inter surface mixture and perhaps that is why these composite samples presented lower tensile strength values than the sample 1 (see Table 4). Also, Figure 7 reveals that there is no gap between matrix and the wool fibre which is good and yet again broken fibre can be observed on the top left of the SEM photograph.

Figures 8-9 show SEM photographs of the sample 2 (see Table 45 where it has the highest Izod impact value (7.04 kJ/m^2). It indicates that there are some fibre breaks (Figure 8) after the impact. Also some gaps at the broken surface are a sign of the wool fibre that is drawn out the impact.

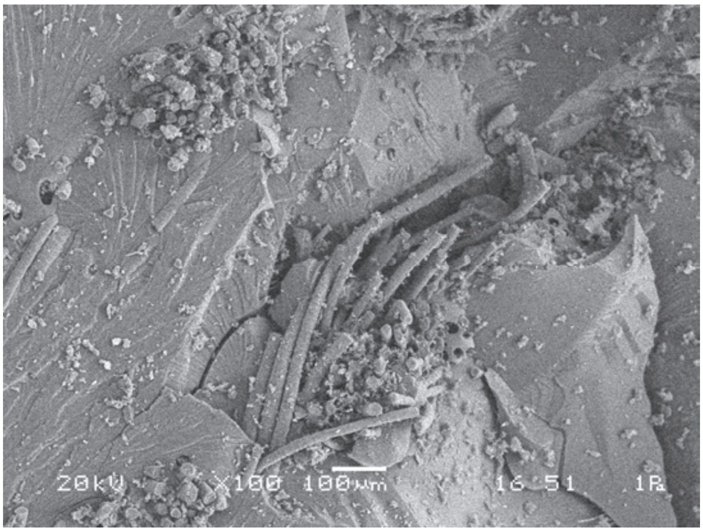

Figure 4. SEM photograph of the tensile strength of 4% wf+2% wst reinforced composite sample (X100)

Figure 5. SEM photograph of the tensile strength of 4% wf+4% wst reinforced composite sample (X100)

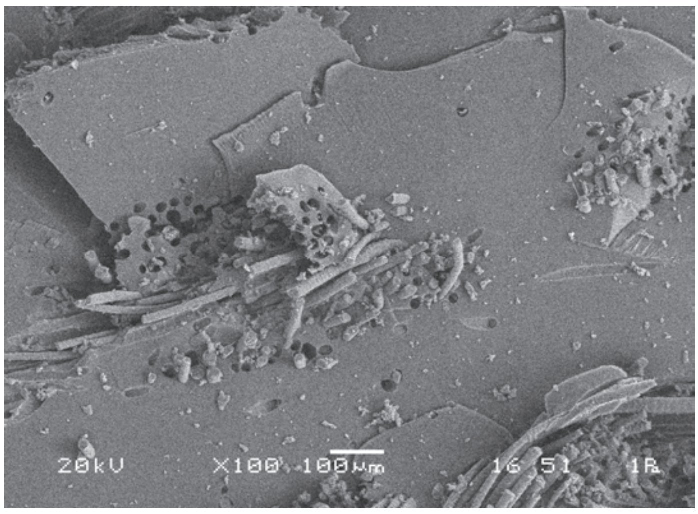

Figure 6. SEM photograph of the tensile strength of 4% wf+6% wst reinforced composite sample (X100)

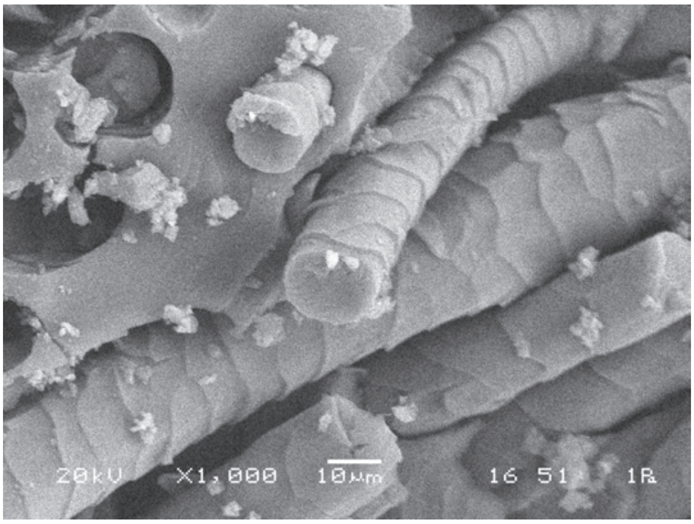

Figure 7. SEM photograph of the tensile strength of 4% wf+6% wst reinforced composite sample (X1000)

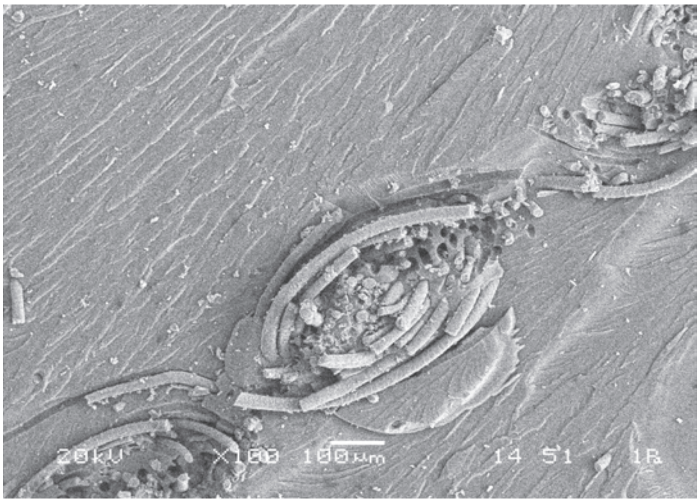

Figure 8. SEM photograph of the Izod impact of 4% wf+4% wst reinforced composite sample (X100)

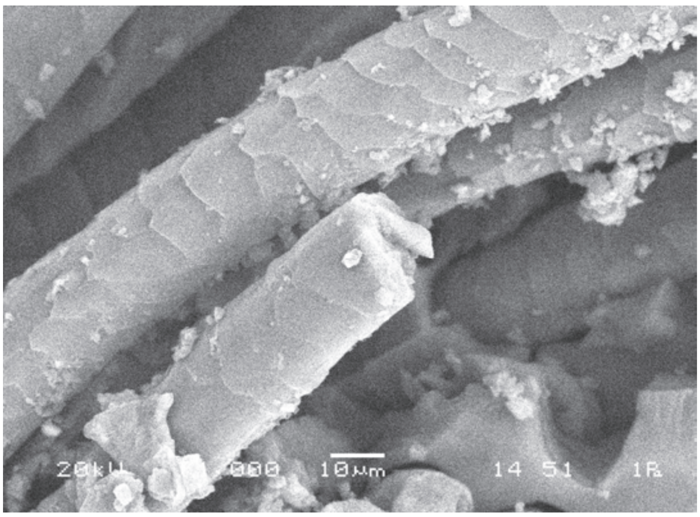

Figure 9. SEM photograph of the Izod impact of 4% wf+4% wst reinforced composite sample (X1000)

4. CONCLUSIONS

Based on the overall results and observations of this study, the following conclusions can be drawn:

- Both wool fabrics and their waste can be used as a reinforced material in the composites.
- Wool wastes have shown a linear decrease on the tensile strength of the composites. The closer record to the pure resin in the tensile strength values was obtained at the 4% wool fabric + 4% waste fibre mixed reinforced materials. Therefore elongations on the max. load increases as the wool waste fibre percentage regularly decreases within the reinforced composite structures.
- Even though Izod impact value of the pure resin is low almost all the reinforced materials have shown higher impact values than the resin itself. For this study, the highest impact was obtained at the 4% wf+4% wst reinforced composites.
- Thermal conductivity factor increases as the percentage of wool waste fibre shows a regular increase within the reinforced composite structures.

With this study, we have tried to get an attention to use natural waste fibres i.e. wool waste in the composite structures. Natural fibres are eco- friendly materials and can be recycled too. It would be worth to try “natural resin” instead of synthetic resins with wool waste materials to see how “green composite” and environmental friendly reinforced composites can be achieved.

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