(REFEREED RESEARCH)

LOW VELOCITY IMPACT RESPONSE OF BIODEGRADABLE PLA COMPOSITES REINFORCED BY RECLAIMED COTTON PREFORMS

GERİ KAZANILMIŞ PAMUK PREFORMLAR İLE TAKVİYELENDİRİLMİŞ BİYOBOZUNABİLEN PLA KOMPOZİTLERİN DÜŞÜK İVMELİ DARBE TEPKİLERİ

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ABSTRACT

Along with the environmental awareness, biodegradable composites, produced from biodegradable polymers and fibres, have gained more attention. Polylactic acid (PLA) offers a possible alternative to the traditional non-biodegradable polymers since their recycling is difficult or not economical. As being a natural fibre, cotton is very attractive in reinforcement of green composites. In this study biodegradable composites were obtained from PLA and knitted preforms manufactured from raw cotton and reclaimed cotton, by using compression molding method. Impact properties of composites comprised of different preform structures were tested. The promising impact property of reclaimed cotton/PLA composite shows the potential of reclaimed fibres in the usage of biodegradable composites. Also the results of the low velocity impact tests showed that variation in yarn twist and loop length has an influence on cotton/PLA composite characteristics.

Keywords: Cotton fibers, reclaimed cotton, PLA resin, knitted performs, green composites, biodegradable composites.

ÖZET

Çevresel farkındalık ile birlikte, biyobozunabilir polimerler ve liflerden üretilen biyobozunabilir kompozitler daha fazla dikkat çekmiştir. Polilaktik asit (PLA), geri dönüşümleri zor veya ekonomik olmadığından dolayı biyolojik olarak bozunamayan geleneksel polimerlere bir alternatif sunmaktadır. Doğal bir lif olarak, pamuk, yeşil kompozitlerin takviyesi için oldukça çekicidir. Bu çalışmada, PLA ile ham pamuk iplik ve geri kazanılmış pamuk iplikten üretilen örme preformlardan, basınçlı kalıplama metodu ilei biyobozunabilir kompozitler elde edilmiştir. Farklı preform yapılarından oluşan kompozitlerin darbe özellikleri test edilmiştir. PLA/geri kazanılmış pamuk kompozitin gelecek vaadeden darbe özelliği, geri kazanılmış liflerin biyobozunabilir kompozitlerde kullanım potansiyelini göstermektedir. Ayrıca düşük hızlı darbe deneyinin sonuçları iplik mukavemeti ve ilmek boyutundaki değişimlerin PLA/pamuk kompozitin özelliklerinde etkili olduğunu göstermiştir.

Anahtar Kelimeler: Pamuk lifleri, geri kazanılmış pamuk, PLA reçine, örme preformalar, yeşil kompozitler, biyobozunabilir kompozitler.

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1. INTRODUCTION

Composites made of natural fibres and biopolymers are completely biodegradable and are called ‘‘green composites” because of their environmentally beneficial properties [1]. With increasing environmental awareness and ecological risk, green composites have gained more and more research attention, as they have the potential to be attractive than the traditional petroleum-based composites which are toxic and nonbiodegradable [2].

Many polymers that are claimed to be biodegradable are in fact *bioerodable*, *hydrobiodegradable* or *photo-biodegradable*. These different polymer classes all come under the broader category of *environmentally degradable polymers*. The *biodegradability* of plastics is dependent on the chemical structure of the material and on the constitution of the final product, not just on the raw materials used for its production [3]. Therefore, biodegradable plastics can be based on natural or synthetic resins. Natural biodegradable plastics are based primarily on renewable resources and can be either naturally produced or synthesized from renewable resources [3]. PLA, as being one of these biodegradable polymers, can either be synthesized by condensation of lactic acid or ring opening polymerisation of lactide which is the diester of lactic acid. Lactic acid is produced by fermentation of dextrose which itself is gained from annually renewable resources like corn [1]. PLA has good mechanical properties. The temperature at which PLA can be melt processed with available standard processing equipment is safe for natural fibers because natural fibers do not degrade at the processing temperature [2].

After decades of high-tech development of artificial fibres such as carbon, aramid and glass, it is remarkable that natural fibres have attracted renewed interest [4]. The advantageous characteristics of these fibres are their lightweight, high specific modulus, non-toxic and easy for processing, absorbing CO_2 during their growth and their relatively cheaper price [5]. Another important aspect of natural fibers is the general availability of these materials around the world [6]. There are varieties of natural fibres (cotton, flax, kenaf, sisal, etc.) which can be used as reinforcements in green composites. This study however focused on cotton fibre since it is the most common used and accessible natural fibre in worldwide. This feature also makes cotton goods to be one of the most reclaimed and recycled textiles. According to Mussig, the use of natural fibres like cotton in technical applications has a great potential and combining natural fibres like cotton with a biodegradable polymer is an innovative concept with the goal to produce a composite which can be composted after use [7].

While many detailed review papers about the potential of biodegradable composites and natural fibres [2-5, 8-15] have been published, very few investigations were made on the utilization of cotton fibres and reclaimed cotton fibres in green composites. Graupner, investigated the usability of lignin as a promoter in thermoplastic cotton fibre reinforced PLA composites [16]. The results showed that that the addition of lignin had an influence on the cotton/PLA composite characteristics. Kamath et al., focused on producing compostable cotton fibre based composites that can be safely disposed off after their intended use [17]. For this aim they combined cotton and other cellulosic fibres with a biodegradable binder fibre in order to produce a nonwoven fabric that can be used in automotive composite panels.

Based on these considerations, the present study focuses on manufacturing biodegradable green composites from cotton preforms and PLA. The knitted preforms were produced from raw cotton and reclaimed cotton yarns. In order to obtain good interface properties and bonding with PLA, alkali treatment was made to cotton preforms. The composites were manufactured by compression molding method and low velocity impact properties of composites were investigated.

2. PREFORM FABRICATION AND COMPOSITE PRODUCTION

2.1 Preform Fabrication

Yarns used in the production of knitted preforms were obtained from raw cotton and reclaimed cotton (Table 1). Both yarns have a yarn count of Ne 30/1 and their twist rate was altered as low and high.

Single jersey knitted preforms were produced on 32 inch diameter 28E circular knitting machine by using yarns mentioned above. Four types of loop length were chosen in the production of preforms, by this way totally nine types of preforms were obtained.

PLA resin which belongs to the family of aliphatic polyesters was supplied from NatureWorks. The resin was in the pellet form. PLA is a thermoplastic, high strength, high modulus polymer and can be degraded by simple hydrolysis of the ester bond and does not require the presence of enzymes to catalyze the hydrolysis [8]. Thereby, it is a good choice in the production of biodegradable composites reinforced with cotton preforms.

Table 1. Preforms used in the study

Fibre type	Twist rate of yarn	Loop length of knitted preform (cm)	Codes of the preforms and composites
Cotton	Low twisted	0,26	C1
Cotton	Low twisted	0,29	C2
Cotton	Low twisted	0,32	C3
Cotton	Low twisted	0,36	C7
Cotton	High twisted	0,26	C4
Cotton	High twisted	0,29	C5
Cotton	High twisted	0,32	C6
Cotton	High twisted	0,36	C8
Reclaimed cotton	Low twisted	0,26	C9

2.2 Alkali Treatment

The main disadvantages of natural fibers in composites are the poor compatibility between fiber and matrix, which causes poor interface properties [18]. Actually, for fibre reinforced systems, the interface plays a major role in the stress transfer from the matrix to the fiber and thus behaves as reinforcement [18]. The surface adhesion between the fibre and the polymer may be improved by several modification methods like alkali treatment, surface fibrillation, plasma technique, silane treatment and etc. The basic objective, however, remains the same; removal of surface contamination and to provide an intimate contact between the surfaces. The simplest way is to roughen the surface so as to enhance the contact area and facilitate mechanical interlocking [19].

The treatment of natural fibres by sodium hydroxide (NaOH) is widely being used to modify the cellulosic molecular structure. It changes the orientation of highly packed crystalline cellulose order and forming an amorphous region. It also takes out a certain portion of hemicelluloses, lignin, pectin, wax and oil covering materials. As a result, the fibre surface becomes clean. In other words, the fibre surface becomes more uniform due to the elimination of microvoids and thus the stress transfer capacity between the ultimate cells improves. In addition to this, it reduces fibre diameter and thereby increases the aspect ratio (length/diameter). This increases effective fibre surface area for good adhesion with the matrix [20]. Also, according to Bajpai, composites with alkali treatment had got the highest impact strength when compared to other modification methods [2].

Based on these considerations, in this study, alkali treatment was selected as modification method. The cotton performs were treated with 4% NaOH solution at 95°C for 1 hour maintaining the liquid ratio of 1:20. After removing from the device, the preforms were first washed with 1 g/l non ionic washing agent at 95°C for 10 minutes and then with distilled water. Then the preforms were dried in oven for 12 hours. The photographs of alkali treatment are given in Figure 1.

2.3 Composite Production

To ensure that all absorbed moisture was removed and to prevent void formation, the cotton preforms were dried at 80°C for 3 hours before processing.

Pellet type PLA resin was converted into films of 2mm thickness by a compression molder using picture frame molds at 180°C for 10 minutes. Next without decreasing the pressure, they were left for cooling in the mold for 10 minutes. Obtained PLA films were stored at laboratory under ambient conditions.

PLA and various cotton preforms were molded under pressure using film stacking procedure (Figure 2). One layer of cotton preform was placed between two layers of PLA films. The weights of PLA sheets were kept constant in order to obtain same weight ratio of resin.

Figure 1. Alkali treatment in ATAC Lab Dye device

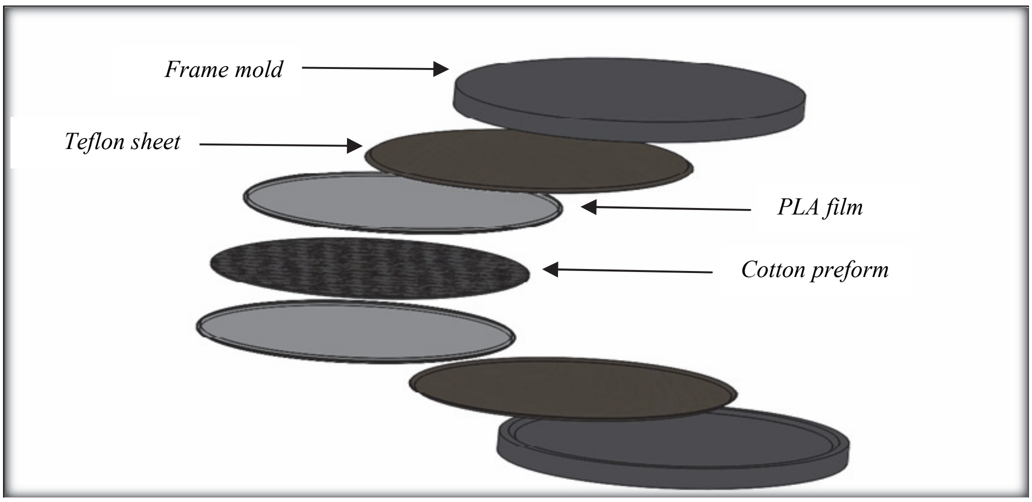

Figure 2. Fabrication procedure of laminated composite

During compression molding the materials kept in constant pressure of 5 tones and 12 minutes. In the next step, the materials were left for cooling in the mold for 12 minutes. Afterwards the composite plates were not cut since the specimens were manufactured in the dimensions of test procedure.

3. EXPERIMENTAL PROCEDURE

In the experimental part, low velocity impact energy of 5 Joule was applied on each specimen in order to obtain the impact loads and the impact energy absorption of PLA/cotton reinforced composites. The mass of the impact actuator was 4.926 kg and its diameter was 76 mm. Each specimen was fixed pneumatically on the low velocity impact tester support. In this procedure, Fractovis Plus Impact Tester was used. The impact tester was illustrated in Figure 3.

Figure 3. Experimental setup of the low velocity impact test

4. RESULTS AND DISCUSSION

Low velocity impact responses of PLA/cotton composites were assessed by energy-time curves and impact loads. Low-velocity impact of loading can occur when tools are dropped onto the surface of a composite structure or from the impact of debris, fragments, or projectiles [21].

The impact test was applied via 4.926kg mass impactor on the PLA/cotton composites. For each impact, the position and acceleration of the impactor were continuously monitored. Absorbed energy is calculated as the difference between total energy and energy at maximum load. When composite materials are subjected to impact load, impact energy is initially absorbed through elastic deformation till a threshold energy value. At and beyond the threshold energy value, impact energy is absorbed through both elastic deformation and creation of damage through various failure modes. Failure type depends on material and geometric properties of impactor [22].

Energy curves as a function of time were given in Figure 4-6 for each twist rate of yarn. Energy-time curves of low twisted cotton PLA composites showed that absorbed energy decreased by increasing the loop length from sample C1 to sample C7 (Figure 4). Similarly, the absorbed energy decreased with the increasing loop length from C4 to C8 as seen in Figure 5. These results clearly remind that knitted preform reinforced composites exhibit better impact energy absorption as the loop length decrease and loop density increase. The reason for this better impact performance could be attributed to less space for the penetration of the impactor.

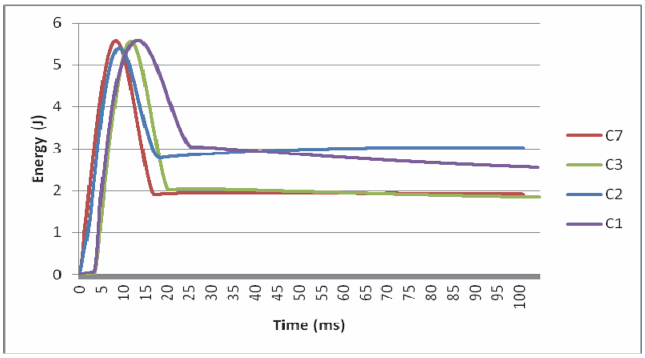

Figure 4. Impact energies of low twisted cotton-PLA resin composites

Furthermore, absorption of the energy changes as a function of impact can be seen in Figure 4 and Figure 5. The absorbed energy in the low twisted PLA resin composites does not change after impact whereas the absorbed energy in the high twisted PLA resin composites is decreasing. Figure 4 shows the absorbed energy is between 2-3 J for low twisted cotton PLA resin composites whereas this energy is between 1-2 J for high twisted cotton PLA ones. These results indicate that the low twisted cotton PLA resin composites absorb higher energy than high twisted cotton PLA resin composites. Although the amount of twist and strength of staple yarn is directly proportional, since the low twisted yarn take up more space than high twisted yarn, less space remains for the penetration of the impactor which cause an increase in energy absorption of composites.

Figure 6 shows the energy curves versus time for low twisted reclaimed cotton-PLA resin composites. It is clear to see that low twisted reclaimed cotton-PLA resin composites are able to absorb the higher energy when compared to other reinforced PLA resin composites.

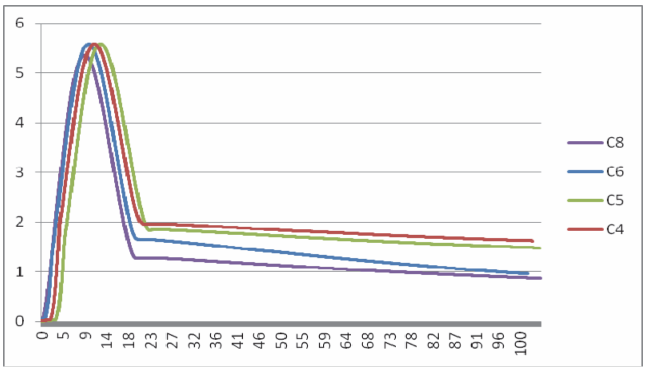

Figure 5. Impact energies of high twisted cotton-PLA resin composites

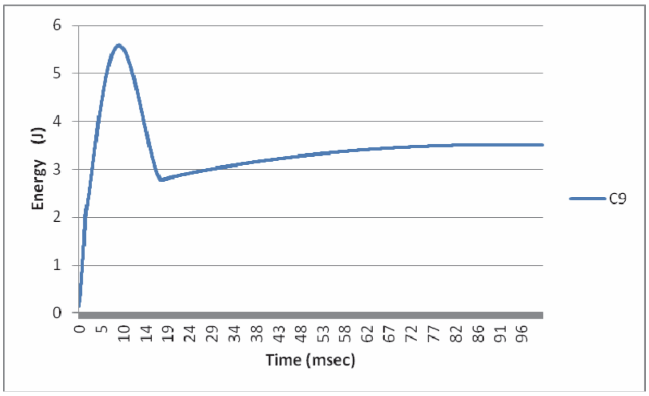

Figure 6. Impact energy of low twisted reclaimed cotton-PLA resin composite

The applied impact loadings values for different types of composites are shown in Figure 7. Impact loading values decreases as the absorbed energy amount increased.

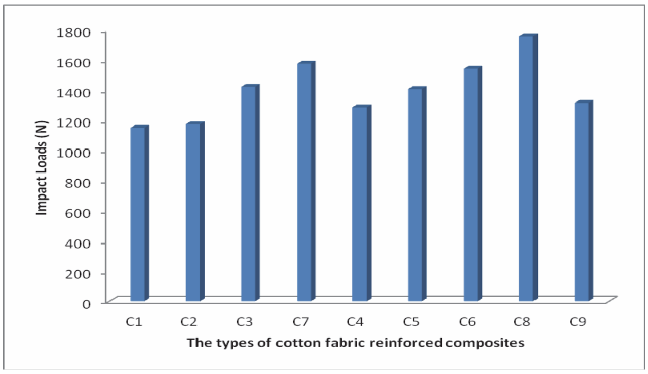

Figure 7. Impact loads of cotton fabric reinforced composites

5. CONCLUSION

Most of the researches about biodegradable composites to date have used flax, jute and sisal fibres. However, cotton fibre has also a great potential for supporting a green sustainable society. Biodegradable nature of cotton is an important quality that makes it attractive where waste disposal is becoming a major concern [17]. Moreover reclaimed cotton provides a big opportunity since it is recycled from wastes. Although cotton as being a plant fibre is a resource intense crop in terms of water, pesticides and insecticides [23], beside its cost benefit using reclaimed cotton lead to energy savings and natural sources.

The experimental work reported in this paper presented a study about low velocity impact properties of cotton/PLA and reclaimed cotton/PLA composites. Totally nine biodegradable PLA composites were made by using cotton knitted preforms with different loop lengths and yarn twist. The promising impact properties of reclaimed cotton/PLA composites showed their potential as an alternative to traditional composites. The findings from this research are indicative to further studies about biodegradable composites made from cotton and reclaimed cotton fibres.

Future work on biodegradable cotton/PLA and reclaimed cotton/PLA composites should be focused on environmental durability and diversity in mechanical properties in comparison with other conventional composites.

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