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Low-velocity impact behavior of weft-knitted spacer fabrics reinforced composites based on energy absorption

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Abstract. Spacer fabrics are prefered to other types of textile fabrics in energy absorption applications due to existence of pile yarns. The particular geometry of spacer fabrics induce to increase resisting out of plane forces such as impact along their thickness. In order to investigate the low-velocity impact behaviour of composites reinforced with spacer fabric, weft-knitted spacer fabrics with different types of pile orientation and pile length were produced using E-glass yarns. Using produced fabrics and epoxy resin, composites samples were provided by hand lay-up method. Low-velocity impact test was carried out on the prepared samples based on a drop-weight method using spherical steel projectile. The indentation at maximum force was extracted as - comparative criteria used to calculate absorbed energy.The results show that the energy absorption of composites increases by increasing the pile density and pile length.

1. Introduction

Impact nature of some mechanical phenomenon such as physical strike and falling objects was led to study about impact behaviour of them. The material properties only aren't enough to gain needed resistance, therefore the structure of them was reinforced to achieve more resistance. Composite is one of the structure that combines material properties to make a strong structure. Textile composites are preferred in many fields because the textile structure leads to desired design structure according to total properties. For example, the 3D structure seems to be suitable for resisting out of plane forces. With this approach, the present study is focused on the weft-knitted spacer fabric as a 3D structure against low-velocity impact as an out of plane loading. Spacer fabric is a three-dimensional knitted fabric consisting of two separate knitted substrates which are joined together or kept apart by spacer yarns. Some attempts have been performed to investigate the impact behaviour of fabric reinforced composites[1-3]. Yip et al [2] was studied on the physical and mechanical properties of three-dimensional spacer fabrics and they reports that the compression properties depend very much on the spacer yarn type and the spacer yarn arrangement, also bending properties are closely related to the fabric type, structure, spacer yarn type and density while stretch and recovery properties depend very much on fabric type and spacer yarn type. Wang et al [3] compared the low-velocity impact behaviour between two types of 3D woven basalt/aramid hybrid composites. According to their study, the interply hybrid composite had higher ductile indices, lower peak load, and higher specific energy absorption in both warp and weft directions than those of the interply hybrid composite. The load time curves of the interply hybrid composite showed a step by step decrease of the load while those of the interply hybrid composite showed a more sudden drop of the load.

The present study focused on the effect of some structural parameters of spacer fabric as reinforcement parameters on the low-velocity impact behaviour of weft-knitted spacer composite. Many studies show that through the thickness parameters of a target has an effective role in the impact loading [4]. It seems that changing - the thickness parameters of weft-knitted spacer fabric such as spacer yarn density and spacer yarn length can change the absorbed energy during the impact.

2. Material and Methods

In order to investigate the low-velocity impact behaviour of weft-knitted spacer fabric reinforced composites, spacer fabrics with different types of pile orientation and pile length were produced using E-glass yarns. Details of yarns are presented in **Table1**.

Table1. Yarn properties

Yarn Type	Diameter (mm)	Count (Tex)	Young Modulus (Mpa)	Bending Modulus (N.mm^2)
E-Glass	0.4	87	2767	3.48

Figure1 shows side-view and needle pattern schematic of different types of fabrics knitted by flat knitting machine (CMS 330 TC) with the guage of 7. As shown, spacer fabric is created by joining two separate fabrics using spacer yarns. The structure of top and bottom layer of samples is similar, but the length[1] and density[2] of spacer yarns are different.Using epoxy resin and produced fabrics different types of the composite were made by hand lay-up method. The prepared composites have been cured at room temperature for 7 days. Wales and Course density per unit length of all samples are 3.8 ($c\;^{-1}$) and 7 ($c\;^{-1}$), respectively. More details of composites geometry and structure are presented in **Table2.**

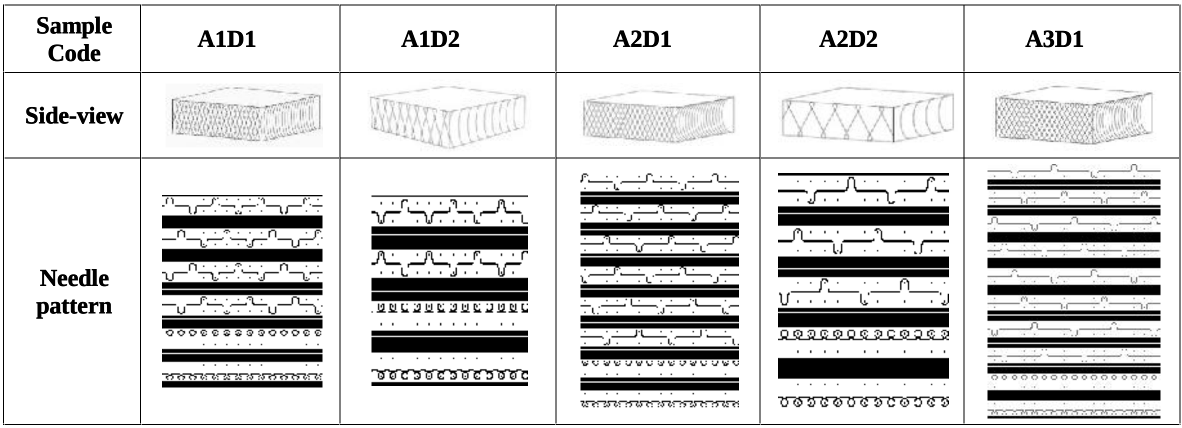

Figure1. Schematic of side-view and needle pattern of fabrics

Table2. Geometrical and structural properties of composites

Sample Code	A1D1	A1D2	A2D1	A2D2	A3D1
Thickness (mm)	4	3.5	3.2	3	2.7
Fabric Volume Fraction	70%	60%	66%	73%	66%
Pile Density ($c\;^{-1}$)	64	32	64	32	64

In order to determine the tensile properties of produced composites, the tensile test has been carried out on prepared samples in both wale and course directions by the speed of 10 mm/min on INSTRON

Length of joining yarn between top and bottom layer of spacer fabric[1]
Number of joining yarns between top and bottom layer of spacer fabric per centimeter [2]

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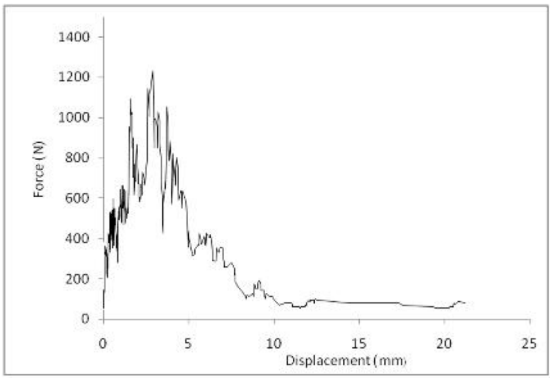
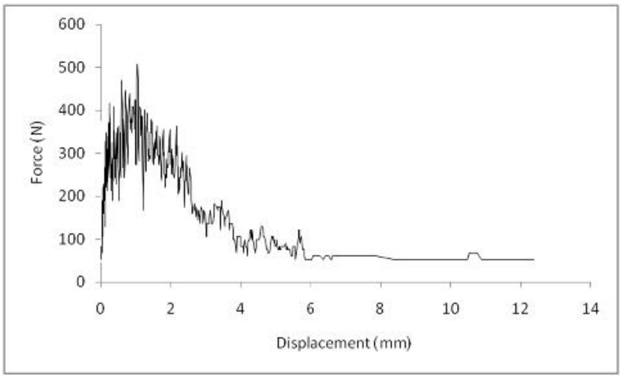
tensile tester (Model: 5566). It is well known that the young modulus is one of the effective parameters on impact behaviour of composites. Hence the young modulus of composites in the course and wale direction i.e. E_c and E_{w-} were measured and presented in **Table3**.

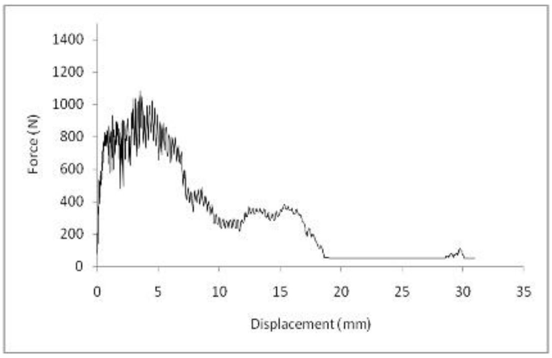
Samples with a dimension of 10 cm × 10 cm were prepared. Low-velocity impact test was carried out on the prepared samples based on a drop-weight method using spherical steel impactor. The impactor mass was 2.712 Kg and falling height was kept constant at 36 cm for all samples. The results of impact test device which are in term of acceleration-time are converted to the force-displacement relation. So, the indentation at maximum force was extracted as-comparative criteria used to calculate absorbed energy. **Figure2** shows force-displacement curves of samples that achieved by twice integration of acceleration-time curve.



(a)



(b)



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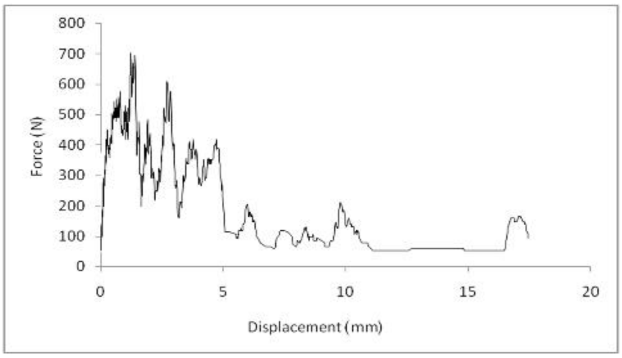
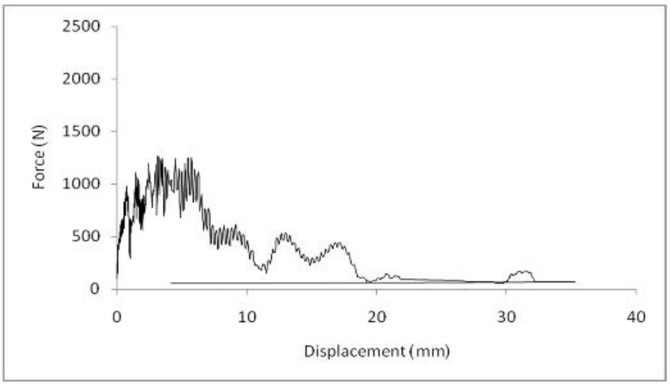


(d)



(e)

Figure2. Force-Displacement curve of composites:
(a) A1D1, (b) A1D2, (c) A2D1, (d) A2D2, (e) A3D1

Table3. Young Modulus of composites

Sample Code	A1D1	A1D2	A2D1	A2D2	A3D1
$E_c(M\quad)$	131	359	340	57	213
$E_w(M\quad)$	421	451	498	251	611

3. Results and Discussion

Absorbed Energy has been used as a benchmark for comparison impact resistance between samples with a different type. The absorbed energy of samples was calculated as area under the force-displacement curve and presented in **Table4** and **Figure3.**

Table4. Young Modulus of composites

Sample Code	A1D1	A1D2	A2D1	A2D2	A3D1
Absorbed Energy (J)	7.29	4.22	13.38	7.47	21.80

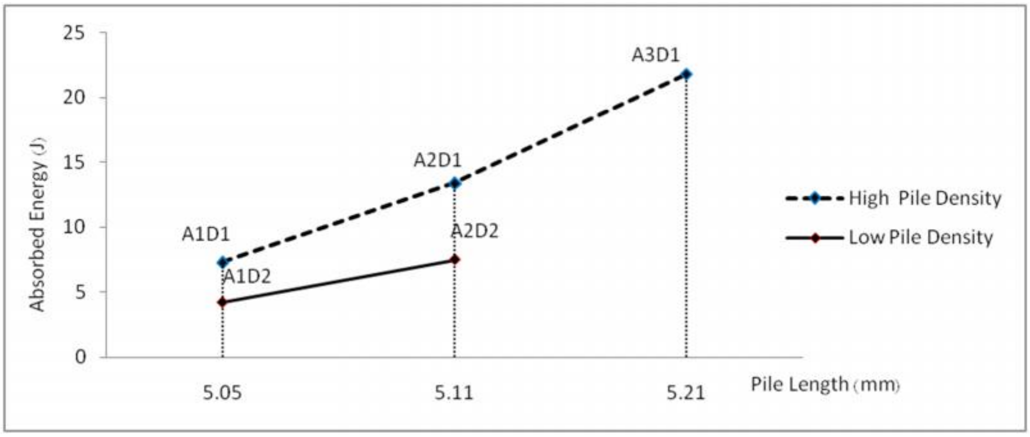


Figure3. Force-Displacement curve of composites

According to **Figure3,** the comparison of A1D1, A2D1 and A3D1 samples shows that the absorbed energy increases by increasing of pile length. The same trend is seen for A1D2 in comparison to A2D2. Since the only geometrical difference between A1D1, A2D1 and A3D1 or between A1D2 and A2D2 is the pile length, hence it can be deduced that the energy absorption increases with pile yarn increasing.

Furthermore, a comparison between A1D1 and A1D2, or A2D1 and A2D2 shows that absorbed energy in samples with high pile density is more than whose pile density is lower. Accordingly, as the second result, it's obvious that absorbed energy increases with pile density increasing.

Altogether these comparative experiments indicate that two geometry variables, pile length and pile density, are effective in impact loading response of weft-knitted spacer fabrics reinforced composites. So that when length and density of spacer yarns increase, the number of impact resisting elements increase and more energy is absorbed. The lowest absorbed energy (4.22 J) relating to A1D2 that it has lower pile length (5.05 mm) and low pile density (32 $c\quad^{-1}$) and the highest absorbed energy (21.80 J) relating to A3D1 that it has the highest pile length (5.21 mm) and high pile density (64$c\quad^{-1}$) confirm this deduction.

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4. Conclusion

The Low-velocity impact behaviour of weft-knitted spacer fabrics reinforced composite has been studied. For this purpose, 5 different types of spacer fabrics structure designed and after impregnating with resin are converted to composite. Both tensile and low-velocity impact tests are carried out to discovering impact resistance of them. The absorbed energy has been used as a comparative benchmark to detecting the structural parameters contributing to impact strength. Finally, it is observed that:

i. Some geometrical properties of weft-knitted spacer fabric as reinforcement element of the composite such as pile yarn length and pile yarn density affect the low-velocity impact resistance of the composite.
ii. The absorbed energy during impact increased when the pile yarn length is increased. In the other words impact resistance of composite increased with reinforcing pile yarn as an effective structural parameter through the thickness and supporting out of plane loading.
iii. The absorbed energy during impact increased when the pile yarn density in the unit area is increased because the number of resisting elements against the impact loading increased.

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