MECHANICAL PROPERTIES OF GLASS FIBRE-PET COMPOSITES BASED ON WEFT KNITTED PREFORMS

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SUMMARY:

The paper investigated influence of: hybrid yarn count, PET fibre characteristics and preform textile structure on weft knitted glass/PET composite mechanical properties. Weft knitted preforms were processed on flat bed knitting machine by simultaneously knitting PET and glass yarns. It was shown that composites from finer hybrid yarn provide higher mechanical properties and lesser variation of results. Composite from unsized undrawn PET fibres with lower crystallinity exhibits 30% higher mechanical properties, as compared to drawn/sized PET fibres, as a result of improved fibre/matrix bonding. Weft knitted preform structure could influence the composite's mechanical properties.

KEYWORDS: fibre reinforced composites, glass fibre, DMTA, knitted fabric

INTRODUCTION

For the last few years the automotive industry has demanded environmental friendly, high performance, low cost and low weight engineering materials. This has given rise to research activities in the field of thermoplastic composites. It was shown that semi-finished textile preforms where matrix and reinforcement are intimately packed (hybridized) in fibrous form could be the right answer to such demands. Such preforms could be in a form of hybrid yarns and hybrid fabrics [1, 2]. Textile engineering has also responded to such demands by invention of structures and machines for technical application [3-6]. There are number of textile structures that could be applied in preforms production. Woven, warp knitted, braided and nonwoven have been intensively studied [7-11]. Weft knitted structures have also been researched [12-14], as they can successfully fulfill the gap in mechanical properties between short and long fibre reinforced composites [15]. The potential advantages for application of weft knitted composites are: high productivity; excellent drapeability; convenient for application of deep drawing techniques; near net shape manufacturing of fibre preforms; possibility of production of double curved structures with no folds; easy of handling; production of integrated 3-D forms with almost no waste *etc*. Many factors influence mechanical properties of composites, among which are: fibre/matrix interfacial bonding,

textile structure, hybrid yarn characteristics, reinforcing fibre content, production condition *etc*. Shounaike *et al.* have investigated the effect of the hybrid yarn type on the composite properties and found out that the commingled type of hybrid yarn has better impregnation properties than side-by-side yarn [16]. Offerman *et al.*, have shown that composites from commingled and core-and-cover hybrid yarn showed higher mechanical properties regarding side-by-side yarn [17]. Karger-Kocsis *et al.* have found high influence of fibre/matrix sizing and coupling agent on composite mechanical properties [15,18]. However, to our knowledge no detailed investigations have been made on influence of hybrid yarn count on composite mechanical properties. Although the fibre/matrix sizing is of primary importance to mechanical properties, the intriguing question is effect of matrix yarn without finishing treatment. The aim of this work is to investigate the effect of yarn count, glass fibre sizing, type of PET yarn and textile structure on the mechanical properties of weft knitted composites.

EXPERIMENTAL

Weft knitted Rib 1:1 preforms were produced by simultaneously knitting of glass and PET yarns on a flat bed knitting machine. In order to estimate influence of yarn count on composite mechanical properties, a number of yarn counts were chosen with equal fibre-matrix ratio. To obtain similar loop shape, the fabrics based on different count hybrid yarns were knitted on a weft knitting machines from E5 to E12 npi. The parameters of hybrid yarn and obtained weft knitted fabrics are given in Table 1. The samples being marked from A to D, where A being the preform from finest yarn count of 56 tex and D being the preform from heaviest yarn count of 482 tex. As a result of hybrid yarn count and machine gauge, knitted fabric with diverse weight were obtained. The values of loop shape factor ranged from 1.02 to 1.17, suggest that the obtained weft knitted structures have around similar loop shape but different magnitude. In order to obtain composite samples with same thickness, different number of layers were utilized according to fabric *i.e.* preform weight .

Table 1: Hybrid yarn and weft knitted fabric parameters

Sample	A	B	C	D
Tt [tex]	56	120	242.7	482
Q [g/m^2]	374	538	1108	1573
R	1.17	1.23	1.12	1.02
E [npi]	12	8	8*	5
Fibre/Matrix Weight [%]	61/39	57/43	56/44	56/44

Where:
Tt-Yarn count
Q-Fabric weight
R-Loop shape factor
E-machine gauge
*Half of the knitting needles are disengaged

The effect of fibre and matrix surface treatment has been investigated by producing weft knitted preforms from combination of variously treated glass and PET yarns. The chosen PET yarns had different sizing treatment. The first PET yarn had standard textile sizing. In the production of second PET yarn the process of drawing after spinning is avoided. Therefore such PET yarn has lower crystallinity than standard PET yarn and did not undergo standard surface treatment (sizing). To investigate the effect of sizing, each of this PET yarns were coknited with glass yarns with different sizing.

The set of weft knitted preforms with different structure were produced such as: Plain, Milano rib, Half Cardigan and the Plain structure produced by interconnecting two Plain structures. The Milano rib structure has floating stitches in its construction, while the Half

cardigan structure has tuck stitches. It was expected that composites from preforms containing floating stitches would have improved properties in course direction, while tuck stitches would attribute to improved properties in a wale direction. By constructing connected plane structure, higher thickness and stiffness of fabric were obtained.

The composites were produced by compression molding of preforms at: P=3 MPa, T=265 °C and holding time of 5 min.

The properties of the composites were characterized by tensile (ISO R 527) and bending (ISO 178) tests. DMTA was applied to determine the composites viscoelastics properties and fabric structure related stiffness anisotropy in temperature range from –20 to 200°C (single cantilever bending, 3 °C/min heating rate, 1 Hz fixed frequency mode, 20 mμ amplitude of dynamic deformation).

RESULTS

Figure 1 represents the influence of yarn count on composite bending strength. It can be seen that bending strength is sensitive to yarn count and decreases with increasing of yarn count. Remarkably, composite from finest yarn (56 tex) shows about 3 times higher bending strength than composite from heaviest yarn (482 tex). The effect is evident in both testing directions. The composite bending modulus responds same way, *i.e.* decreases with increasing of yarn

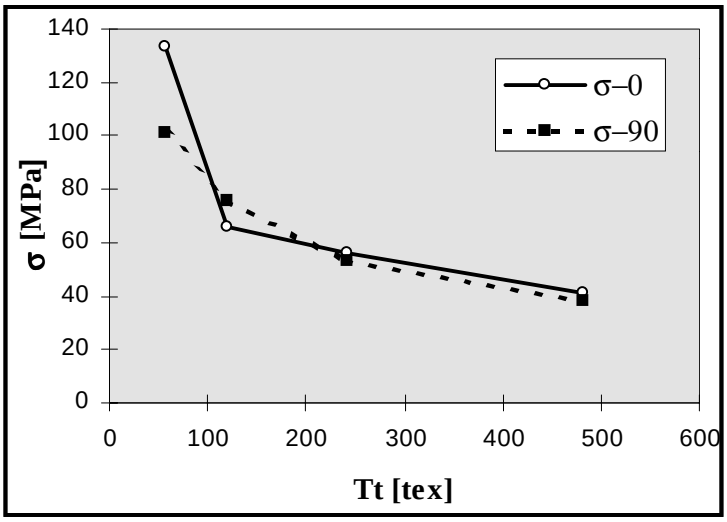


Fig. 1: Influence of yarn count on composite bending strength

count (Fig 2). It is interesting that sharp increase of strength and modulus is found for samples with yarn count lower than 120 tex. Using of finer hybrid yarn obviously increases bending strength and modulus as a result of better achieved fibre matrix distribution (more homogenous structure), and therefore better fibre impregnation. The later provide better fibre matrix interfacial bonding that results in higher composite strength. The same effects were found in the testing of composite tensile strength and modulus. Since fibre content is nearly the same for all samples, at first, conclusion should be that the obtained effect is a result of yarn count. If we consider that composite from finest yarn count and therefore lightest fabric was obtained from highest number of layers, the effect is partly due to number of fabric layers in the composite. The effect of number of layers on composite was analyzed by Verpoest [19] and Ramakrishna [20]. According to Verpoest higher number of layers effects in penetration of fibers from one layer to another and mechanical connection of layers. Ramakrishna

explains that higher number of layers decrease out of plain orientation of fibres and increase in plane mechanical properties.

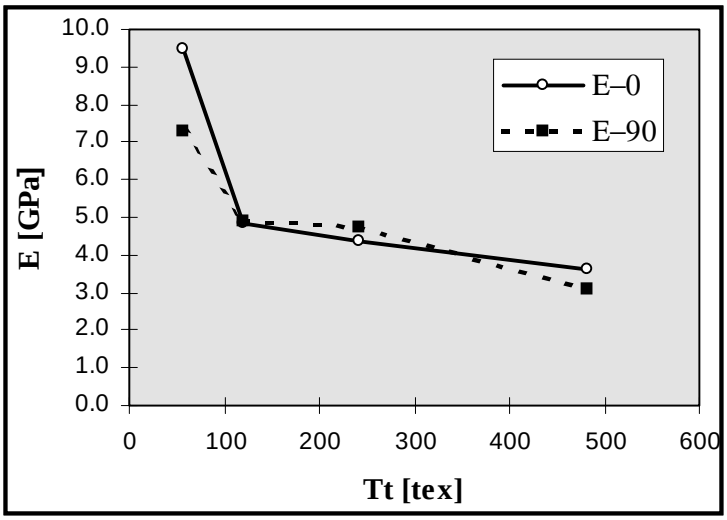


Fig. 2: Influence of yarn count on composite bending modulus

It should be mentioned that the samples from finer yarn has slightest variation of the testing results and samples with heavier yarn has highest variation. Furthermore, the samples with finest yarn had lower void content and best visual appearance which also might be a result of better fibre/matrix distribution *i.e.* higher level of homogeneity. Another point is that composites from finer counts of side-by-side hybrid yarn might approach the properties of composites produced from commingled yarns.

Results of bending test of the samples produced from variously treated PET yarns are presented in fig. 3. Sample marked P1 represents composite from standard PET yarn with textile sizing, while P2 represents sample from PET undrawn yarn with no sizing. P2 sample has about 30% higher bending strength in both direction. The bending modulus and tensile strength and modulus behave the same way. The quality of impregnation (analyzed by optical microscopy of polished cross-sections) is higher for the samples produced from undrawn-unsized PET, obviously enhancing the adhesion between glass fibres and polymer matrix.

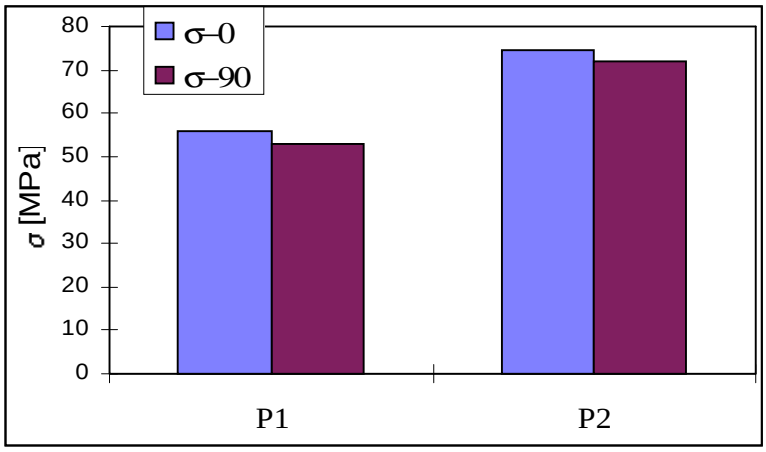


Fig. 3: Bending properties of PET/Glass weft knitted composites with variously treated PET fibre

The largest number of textile sizing agents are “oily” in order to improve textile processing characteristics of fibre. Unfortunately existing of textile sizing is an obstacle in achieving good fibre/matrix interfacial bonding. Despite high elongation of undrawn PET fibre, the process of knitting simultaneously with glass fibre succeeded. It seems that glass fibre as much stronger fibre takes a burden of mechanical processing and does not allow high stress and extension to be imposed on PET fibre that could be an obstacle for the knitting process.

Valuable information about the relationship between structure, morphology and properties of composites were provided by DMTA. The differences in mechanical properties of the composites influenced by textile structure and the adhesion between glas fibres and PET matrix were confirmed by DMTA. Fig. 4 represents the results for samples tested in wale direction. The samples marked P2 from PET fibres with no sizing shows higher modulus and lower damping values, which could be attributed to better fibre/matrix adhesion and also to developed different crystalline morphology during consolidation of the polymer with much lower starting crystallinity. The glass transition temperature of P2 sample is slightly shifted towards higher temperatures.

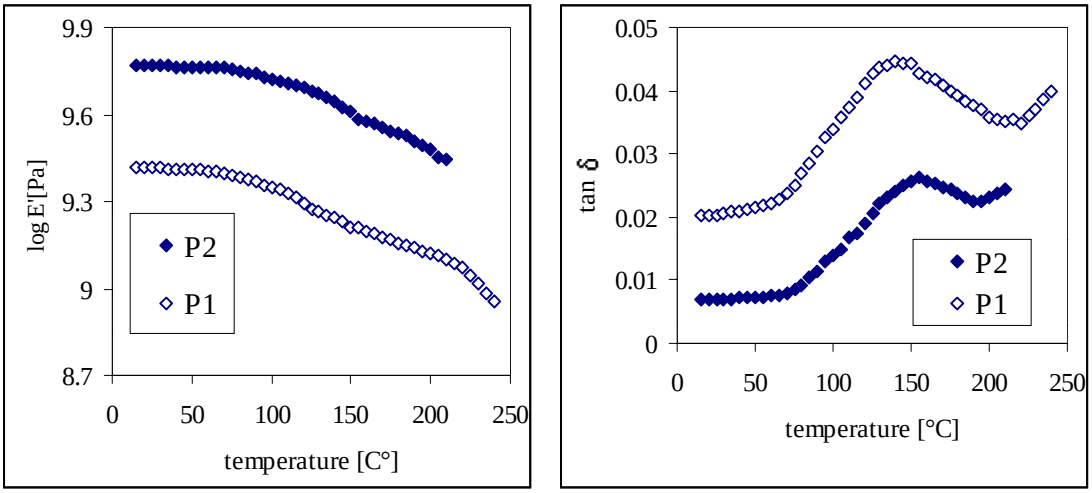


Fig. 4: Storage modulus and loss tangent of PET/glass composites with textile sized PET fibre (P1) and unsized undrawn PET fibre (P2)

Fig. 5 represents influence of textile structure on composite bending modulus. All samples reveal structure-based anisotropy, except the Milano rib sample, where bending modulus are almost identical in both direction. This is due to floating loops, *i.e.* less curved reinforcing fibre in course direction. Plain knit structure shows high anisotropy and highest modulus in wale direction. This could be partly a result of number of layers which is two-fold higher in Plain structure as compared to other preforms. Half Cardigan exhibits higher modulus in wale direction as a result of tuck stitches that contribute to orientation of reinforcing fibre and fabric stiffness in wale direction. Dynamic mechanical properties of these samples were analyzed DMTA, and results are presented in fig. 6. Although having highest fabric weight, Plain integrated structure did not prove to have highest modulus. The reason could be increased out of plain orientation obtained by yarns connecting two structures. DMTA analysis of the composite with plain integrated structure had shown highest damping values in both directions (see fig. 7). As can be seen, the position of β-relaxation remained nearly unchanged, but the peak intensity and magnitude was significantly changed depending on the textile structure. Half Cardigan and Plain structure have lower damping properties in wale direction due to less elastic textile structure. Milano Rib reveals lower

damping values in course direction, that is again result of decreased elongation achieved by floating loops.

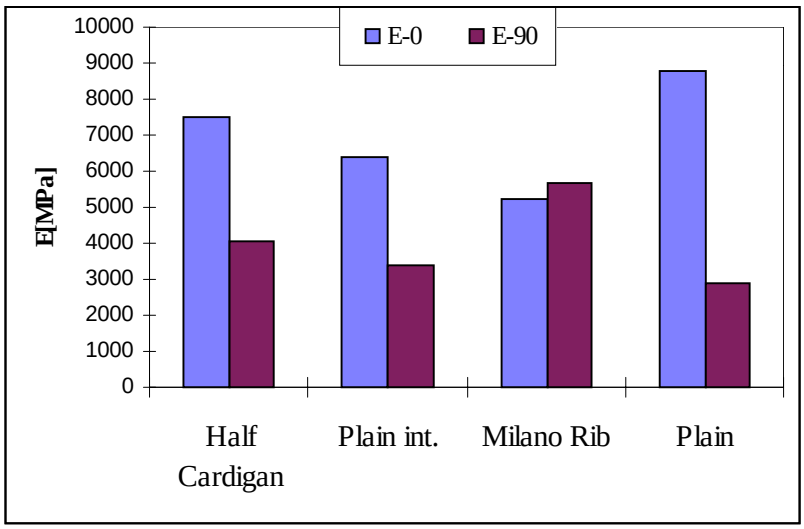
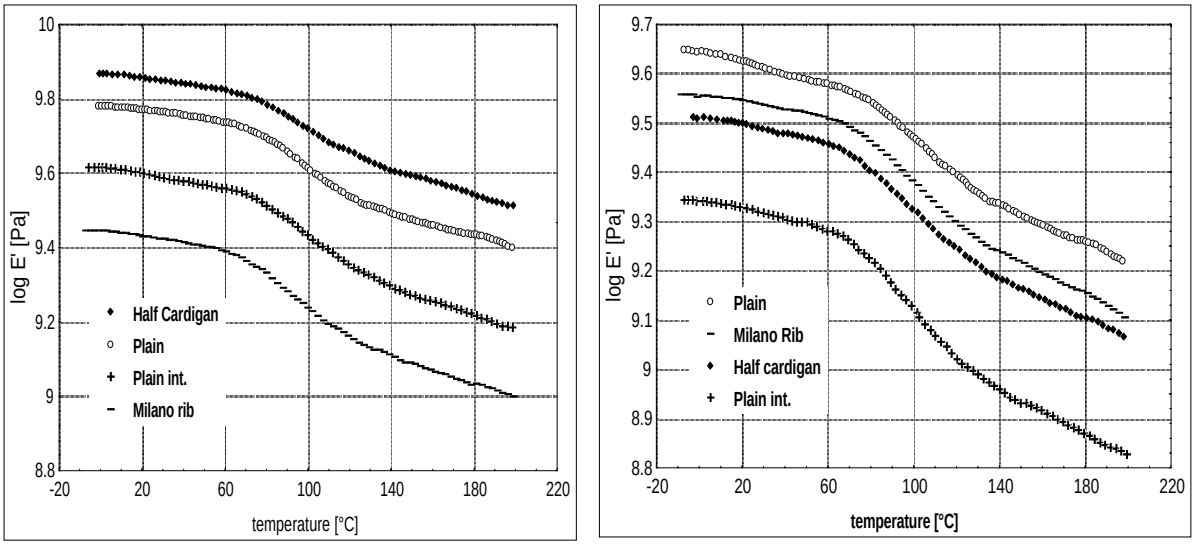


Fig 5: Influence of textile structure on composite bending modulus

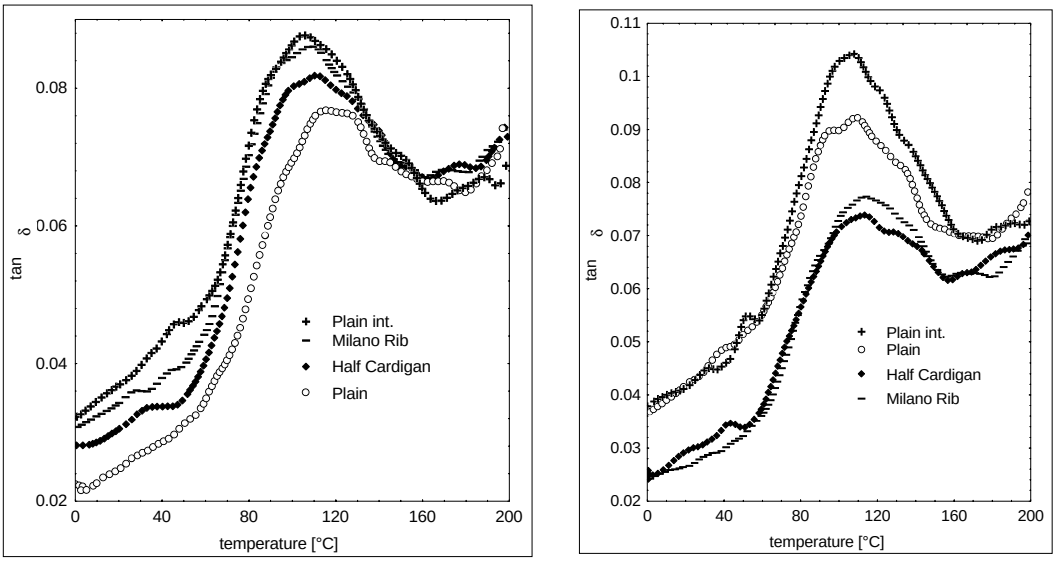


a) *b)*

Fig. 6: Storage modulus-temperature traces of composites with different textile structure in wale a) and course b) direction.

The obtained results suggest the possibility of influencing composite mechanical properties by textile preform structure, although the production of more complex weft knits might cause certain technological difficulties regarding flexural rigidity of high modulus yarn.

Comparison of differently treated glass fibres for Rib 1:1 knitted preforms has shown that improved mechanical properties are obtained when PET-compatible size was used. Tensile properties of composites produced from glass fibres with PET-compatible size reveal 20-30 % higher values, as compared to those with improper size.



a *b*

Fig. 7. Damping-temperature traces of weft knitted composites in wale (a) and course (b) direction

CONCLUSION

1. It was shown that the yarn count of weft knitted preform affects composites mechanical properties. As a result of better fibre/matrix distribution and effect of number of layers, composites from finest yarn count exhibit highest mechanical properties and lowest variation of results. Weft knitted preforms in this case had side-by-side hybrid yarn, obtained by coknitting glass and PET yarns.
2. Glass/PET preforms from undrawn unsized PET fibre were successfully processed on weft knitting machine. For this composite best mechanical properties and lower damping values were obtained.
3. Mechanical properties and anisotropy of weft knitted composites could be designed by textile structure.

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