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Effect of Yarn Parameters on the Knittability of Glass Ply Yarn

Abstract

Knitted glass fabrics as a kind of reinforcement have received great attention in the composites industry in recent years. Glass yarns, however, are very difficult to be processed in the knitting process due to their high stiffness, low elongation and high coefficient of friction. In this paper, the knittability of glass ply yarns, which are of different yarn parameters, were investigated by testing their mechanical performance using a self-developed knit simulating apparatus. The experimental results show that damage caused to glass yarn during the knitting process is closely related to yarn parameters. Composition modification, fibre diameter reduction, optimising of sizing formulation and yarn twist introduction can provide glass yarn with a much better performance during severe abrasive interaction.

Key words: *knittablility, glass ply yarn, twist level, sizing, abrasion damage resistance.*

Introduction

Knitted fabrics as a kind of reinforcements have received great attention in the composites industry in recent years [1] due to their outstanding characteristics, such as flexibility in production, conformability to complicated forms and near net-shape knitting, and their superior resistance to impact. Although they are an important material, glass filament yarns are very difficult to process in the knitting process due to their high stiffness, low elongation and high coefficient of friction [2, 3].

A number of researches on knitted glass have been described in literatures, most of which were conducted to find out the relationship between knitting parameters and fabric damage [3-5]. Some other researchers have tested yarn resistance to abrasion and other types of mechanical damage [6-10]; however, most of their objects are common yarns, such as cotton, polyester, wool, etc., which have quite different mechanical properties with glass yarns.

This article is intended to investigate the knittability of glass ply yarn by testing the effect of yarn parameters on their mechanical properties. A self-made simulating tester was used to provide the knitting actions, i.e. tensile, bending and abrasion, the yarn used during the knitting process. The cycles to failure (CTF) were recorded and the residual tensile strength (RTS) was tested after a certain number of action cycles. The results are discussed and suitable explanations are given.

Experimental procedures

Instrument

A self-developed apparatus was generated to evaluate the knittability of glass yarn by simulating the actions the yarn is subjected to during the knitting process. A sketch of the apparatus is given in ***Figure 1***. A needle hook with a diameter of 0.8 mm and curve radius of 1.5 mm is fixed on the baseplate to work as the abrasion part. The yarn sample is held at the start point, passing through the needle hook and over three frictionless pulleys, and is attached to a tension weight at the other end, hanging freely so that it can slide along the yarn if the yarn changes in length during the test. Driven by an electromotor, the abrasion part can move to and fro horizontally at a speed of 140 cycles/min to simulate yarn/needle interaction. A mechanical counter is fixed to the apparatus to record the number of cycles to failure for each yarn specimen.

Material and test details

Twelve kinds of glass ply yarns with different yarn parameters were tested. Comparisons were made between yarns with only one different parameter to evaluate the effect of yarn composition, filament diameter, yarn twist, sizing and the number of plies on the performance of the glass yarn. Details of the yarn parameters are listed in ***Table 1***. All the glass yarns were produced by Sinoma Science & Technology Co. Ltd (Nanjing, China). Using the above apparatus, knitting simulating tests were conducted in standard atmosphere, i.e. 20 ± 2 °C and R.H. 65 ± 5%, by attaching appropriate tension weights that were selected to draw a CTF distinction between the yarns under com-

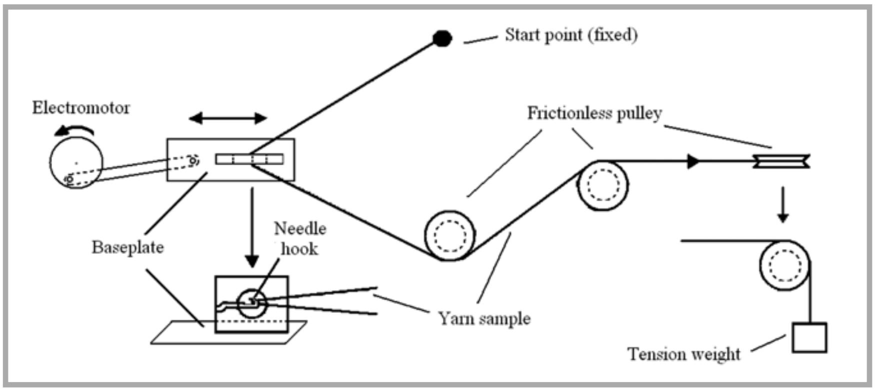

Figure 1. *Simulating apparatus for knittability testing.*

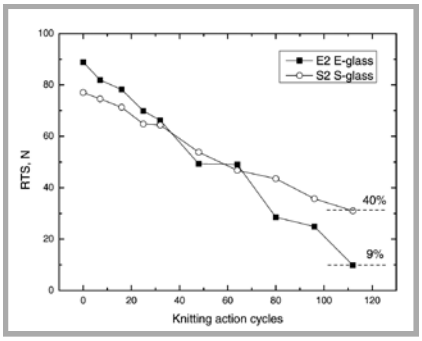

Figure 2. Damage curve of glass yarn with a yarn tension of 90 cN.

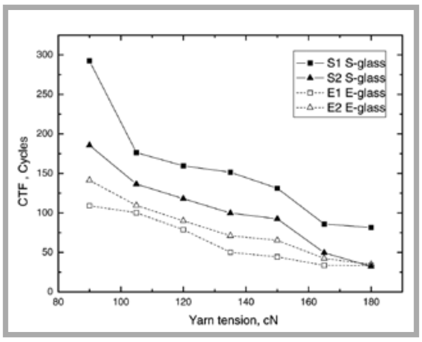

Figure 3. CTF variation in E-glass and S-glass yarns under different yarn tension (cN).

Table 1. *Parameter details of the experimental glass yarns.*

Yarn item	Composition	Filament diameter, *μm*	Ply linear density, Tex	Number of plies	Twist, t/m	Yarn density, tex	Sizing[a]
E1	E-glass	6.5	75	2	S(250)	125	SF1
E2	E-glass	6.5	50	3	S(250)	150	SF1
S1	S-glass	6.5	40	3	S(250)	120	SF1
S2	S-glass	6.5	50	2	S(250)	100	SF1
S3	S-glass	5.5	48	2	S(250)	96	SF1
S4	S-glass	5.5	48	2	S(275)	96	SF1
S5	S-glass	5.5	48	2	S(300)	96	SF1
S6	S-glass	5.5	12	2	S(55)	24	SF1
S7	S-glass	9	12.5	2	S(55)	25	SF1
S8	S-glass	9	12.5	3	S(55)	37.5	SF1
S9	S-glass	9	25	2	S(55)	50	SF1
S10	S-glass	9	25	3	S(55)	75	SF1
S11	S-glass	5.5	48	2	S(300)	96	SF2
S12	S-glass	5.5	48	2	S(300)	96	SF3
CT	Cotton	/	/	/	/	25	/

[a] *Details of size formulation are listed in Table 6.*

parison. The tensile strength of the glass yarn was tested before and after the knitting action according to ASTM D578-05 [11] on a HUALONG Strength Tester WDW-20 with a gauge of 250 mm and crosshead speed of 20 mm/min. For each kind of yarn, eight tests were made and mean values of the yarn strength, elongation, CTF, RTS were calculated. The test results are shown in ***Tables 2, 5 & 7*** (see pages 92 and 93), and in ***Figures 2 & 7***.

Results and discussion

Effects of glass composition

The property comparisons of glass yarns of different compositions are listed in ***Table 2***. We can see that S-glass yarn has a higher breaking tenacity than E-glass. Besides this the CTF of S-glass is higher than that of E-glass, even with a smaller linear density. During the knitting simulating tests, there was filament rupture and a decrease in yarn residual strength ***(Figure 2)*** accompanied with twist reduction and yarn fuzzing within the test area of the yarn specimen. Although both curves of S2 and E2 went down gradually with the action cycles, the curve of S2 shows better resistance to knitting damage. After 112 cycles of action, yarn E2 has only 9% of its strength left, while yarn S2 still retains 40% of its original breaking strength.

The CTF of the above four yarns were also tested under different yarn tensions. As shown in ***Figure 3***, the CTF curves of all four yarns decrease with increasing yarn tension. However, we cannot explain the correlation between yarn composition and yarn performance because the curves for E-glass and S-glass are very close. By dividing the yarn tension by the yarn linear density, these CTF curves were separated, as shown in ***Figure 4***, with a curve of cotton yarn used for comparison. It can be seen that the curves of two E-glass yarns came together, whereas those of S-glass yarns superposed each other, with the curve of S-glass being the highest, the one for cotton in the middle and E-glass at the bottom.

The above results could be explained by the atom network structure inside the glass fibre. E-glass is a calcium alumino-borosilicate system with a small amount of alkali content, such as Na_2O, which breaks the Si-O-Si bridges, ends the network and interrupts the continuity by donating electrons to the oxygen atoms. Compared with E-glass, S-glass is a Magnesium aluminosilicate system. The contents of both aluminum oxide and magnesia oxide work as intermediate compounds that don't form glass on their own but can participate in the tangled networks initiated by other compounds such as silica. Hence the Magnesium aluminosilicate system of S-glass has a higher bond energy and more complete networks than the calcium alumino-borosilicate system, leading to a better performance in tensile and knitting sinulating tests compared with E-glass.

Effects of yarn structure

Balanced ply yarn

Yarn structure is of considerable importance in knitting because of its influence on warping and knitting efficiency, fabric hand, appearance and physical performance. Yarns of glass fibre are analogous to other textile fibres in that the glass fibre strands are twisted and doubled for subsequent knitting into glass fabric. In order to ease the manufacture and obtain stability in the resulting fabric, the attainment of yarn balance, acquired by combining single yarns together with the same amount of twist in the opposite direction, is desirable. The twist actio, however, alters the disposition of yarn filaments by bending them into a helical shape [12]. Therefore it is necessary for us to find out the relationship between the mechanical performance and ply structure of glass yarn if more glass ply yarns are to be used in the knitting process.

Effect of yarn twist

The test results of three S-glass yarns (S3, S4, S5), which have the same yarn parameters except their twist, are shown in ***Table 3***. We can observe that the yarn breaking tenacity increases with the twist level owing to the twist helical structure, which increases the interaction between fibres by pressing them against each other. At the same time, the presence of twist increases the yarn damage resistance by reducing the area of contact between the strand of yarn and action surface, resulting in smaller friction drag and, hence, higher CTF. Although reports showed that too much twist will result in a progressive reduction in yarn strength [13], twist upwards of 300 turns per meter are not discussed here owing to seldom usage.

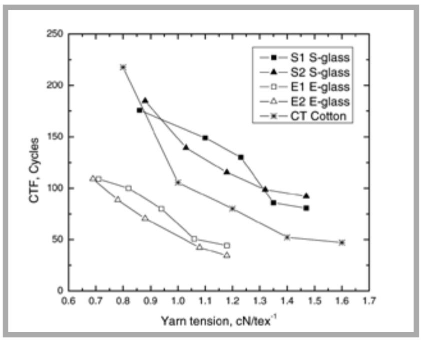

Figure 4. CTF variation in E-glass and S-glass yarns under different yarn tension (cN/tex-1).

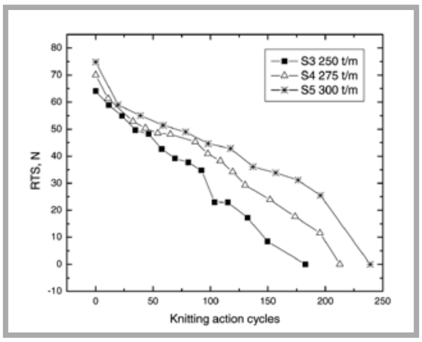

Figure 5. Damage curves of glass yarns with different twist.

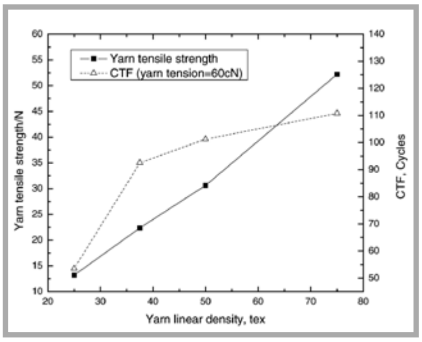

Figure 6. Mechanical properties according to the yarn linear density (S7~S10).

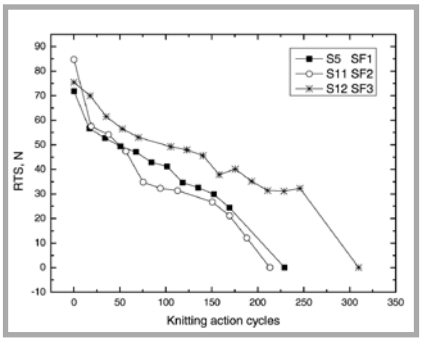

Figure 7. Effect of fibre sizing on the damage process of glass yarn.

Table 2. Properties comparison of glass yarns with different compositions.

Type	Breaking tenacity, cN/tex	Elongation, %	CTF With a yarn tension of 90 cN	CTF with a yarn tension of 120 cN
E1	57.70	2.46	109.20	78.86
E2	59.24	3.14	141.20	90.00
S1	86.59	3.24	292.40	159.71
S2	77.03	2.98	185.60	118.00

Table 3. Test results of S-glass yarns of different yarn twist.

Type	Breaking tenacity, cN/tex	Elongation, %	CTF, with a yarn tension of 50 cN
S3	64.08	2.44	182.57
S4	74.07	2.85	212.75
S5	74.82	3.02	229.13

Further analyses of the abrasion process (see ***Figure 5***) show that the shapes of the three abrasion curves are similar, which decrease gradually with the knitting action cycles. Generally, there seems a crucial point at about 25 knitting action cycles which divides the curve into two segments. Before the crucial point, the residual strength of the yarn decreases rapidly, especially for the sample with a higher twist. After that, the residual strength of the yarns goes down almost linearly with the knitting action cycles until the final yarn rupture. The yarn with a higher twist has better strength at the beginning and a flatten slop in the second decrease segment, both of which show that a higher twist will provide the glass yarn with better knittability.

Effects of yarn filament diameter

Table 4 shows the test results of two S-glass yarns of different filament diameter (S6, S7). It can be observed that the glass yarn with a finer filament diameter, S6, has a higher breaking tenacity and elongation than those of thicker filaments, S7. Under a yarn tension of 30 cN, the CTF of S6 is also much higher than (almost twice) that of S7.

These results are as a result of the interaction between filaments in the yarn. The finer the filaments , the more filaments in the yarn cross section there are, which improves yarn evenness and enhances interaction between singles, resulting in a higher yarn breaking tenacity and elongation. Although finer filaments rupture more easily during abrasion, it also increases the number of filaments that interact with the abrasion media, which lessens the forces on each single filament, reduces the possibility of filament rupture, and finally increases the CTF of the yarn.

Furthermore, the reduction in filament diameter can increase the movability of filaments inside the yarn, which makes the yarn more flexible and reduces its bending stresses, leading to better knittability of glass yarn.

Effects of yarn ply

The effects of yarn ply parameters on the yarn properties are listed in ***Table 5*** and ***Figure 6***. The results show that the tensile strength of yarns S7, S8, S9 and S10 goes up linearly and separately with the ply linear density and number of plies. The breaking load of yarns S7 and S9 experience an increase of about 70% when their ply numbers are increased from 2 to 3 in yarns S8 and S10. The same was observed for yarns S9 and S10, the breaking strength of which goes up by 132% compared with yarns S7 and S8, which is caused by an increase in the ply linear density.

Unlike the variation in tensile strength, the effect of change in ply linear density and ply numbers on knitting action resistance is neither linear nor separate. Although better yarn damage resistance was found with thicker yarn, no linear relationship can be found between the CTF and yarn linear density. These results should be attributed to the damage caused to the yarn at the contact area between the yarn and abrasion media. Although increasing linear density can reduce the yarn tension distributed on each fibre, it has little effect on the forces generated during the yarn/metal interaction, which

Table 4. Performance of S-glass yarns of different filament diameter.

Type	Breaking tenacity, cN/tex	Elongation, %	CTF with a yarn tension of 30 cN
S6	74.70	2.43	94.67
S7	52.71	1.94	42.00

Table 5. *Effect of the yarn ply parameter on the performance of glass yarn.*

Type	Breaking load, N	Breaking tenacity, cN/tex	Elongation, %	CTF with a yarn tension of 60 cN
S7	13.18	52.71	4.85	53.5
S8	22.35	59.60	5.32	92.5
S9	30.63	61.26	5.79	101.25
S10	52.19	69.59	6.31	110.75
S11	42.58	56.77	5.80	130.8

results in an increase of CTF at a gradually reducing speed.

On the whole, finer fibre diameter, higher twist and an optimised ply structure will cause less damage to the yarn and make it more durable during the knitting process.

Effects of yarn sizing

In the glass industry, fibre sizes play an important role and are primarily required to provide protection between filaments and for the whole strand as it passes through various textile processes, which comprise the forming of the fibres themselves, followed by twisting into yarns, and finally warping and knitting into a fabric. Therefore it is important to find a suitable size formulation to improve the knittability of glass yarn.

In this study, three kinds of glass yarns (S5, S11and S12) covered with different size formulations were tested to find out which kind of fibre size can better improve the performance of glass yarn. Details of the size formulations are listed in Table 6, and test results are shown in ***Table** 7* and ***Figure** 7*.

Comparison between S5 and S11 shows that an increase in film former provides glass yarn with a higher breaking tenacity but poor fray resistance. Besides this, the reinforcing effect of the film former seems to be quickly removed during the knitting action, which can be clearly seen in ***Figure** 7* where the residual strength of yarn S11 decreases very quickly in the first 30 cycles of the knitting action. After this period the damage curves of yarns S5 S11 go down gradually at a similar speed until final yarn rupture.

Table 6. *Details of the size composition.*

Ingredients	Formulation, wt %		
	SF1	SF2	SF3
Film former	30%	40%	40
Lubricant A	2.5%	2.5%	2.5%
Lubricant B			1%
Coupling agent	0.4%	0.4%	0.4%

Table 7. *Effect of fibre sizing on the performance of glass yarn.*

Type	Breaking tenacity, cN/tex	Elongation, %	CTF with a yarn tension of 50 cN
S5	71.83	3.02	229.13
S12	84.73	3.01	213.25
S13	75.41	3.00	309.75

The effect of a lubricant can be seen from the performance difference between yarn S11 and yarn S12. It is obvious that an increasing in lubricant B provides glass yarn with a much better abrasion resistance, which can be concluded from both the high CTF value and lower-slop damage curve. The only drawback is the small decrease in yarn tensile strength.

The variation in yarn performance with the size formulation should be attributed to the function of the film former and lubricant. Although film former can improve the tensile load capacity of glass yarn by healing surface microcracks or increasing bands between fibres, its effect is discounted during abrasion where bending stresses and frictional shear stresses dominate the fibre fracture. However, the lubricant may reduce the coefficient of friction, which in turn will reduce the bending rigidity of the yarn as well as the shear stress generated by frictional forces, both of which help to reduce damage caused by knitting action. Hence, appropriately increasing the proportion of lubricants while maintaining an appropriate amount of the film former will provide glass yarn with a much better performance under severe abrasive interaction. Comparing the above three kinds of sizing formulation, the protection of SF3 is the best.

Conclusions

The effect of yarn parameters on the knittability of glass ply yarn were investigated in this paper. The composition between glass yarns of different compositions shows that the Magnesium aluminosilicate system of S-glass is more stable than the calcium alumino-borosilicate system of E-glass, which provides S-glass with both better tensile strength and a longer abrasion life.

The balanced twist structure of glass ply yarn was also found to have a great effect on the performance of glass yarns. A finer fibre diameter, higher twist and optimised ply structure can make the yarn stronger and more durable during the knitting process.

Performance comparison of glass yarns covered with different sizes shows that the proportion of film former and lubricants have a great effect on the knittability of the glass yarn. Appropriately increasing the proportion of lubricants while maintaining an appropriate amount of film former will provide glass yarn with a much better performance under severe abrasive interaction.

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