A COMPARATIVE RESEARCH ON THE PROCESSABILITY OF GLASS WOVEN FABRIC PREPREG

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ABSTRACT

The processability of the reinforcements used in composite components has an important influence on the manufacture. Current studies have focused on studying the effects of single factors on the shear deformation and drapability of fabric prepregs, and there is little involvement in the comparison of the deformation behavior between dry fabrics and prepregs. In this study, the deformation properties of the glass fiber fabric prepreg and its corresponding dry fabric were characterized by means of bias extension, thickness compression and hemispherical draping. The results can provide advice for the set of technological parameter.

1 INTRODUCTION

It is widely acknowledged that the processability of the reinforcements used in composite components has an important influence on the manufacture [1, 2] and the processability of dry woven fabric has been sufficiently studied by many researchers across the world [3-13]. However, relevant studies are inadequate when it comes to glass fiber (GF) fabric prepreg. In this study, processability of a kind of GF fabric prepreg called SW220/3218 which has been produced commercially was characterized by bias extension [14-17], thickness compaction [18-20] and hemispherical draping tests [21-23], for a better understanding about the processability of biaxial woven fabric prepreg, which can become the key material in the space inflatable structure for building large space structure in future space engineering [24, 25].

2 BIAS EXTENSION

The dimension of the samples is 325mm×90mm and the direction is ±45° of the prepreg. The samples were held in grips of the form shown in Fig. 1. Then they were tested under different temperature and testing velocity. A camera was set up to record the deformation process every two seconds and the photos can be used to measure the shear angle. Three samples were tested in one specific testing situation.

Figure 1: The grips used in bias extension test.

From the results of bias extension test, the shear deformation can be divided into three parts. At the beginning of the test curve, the force is low and increases slowly. Then an inflection point appears and finally the force increases dramatically. This process can be explained from the deformation mechanism. When the shear force first acts on the sample, the fiber rotates and the friction between the fiber and the resin appears, which do not need large force. However, with the increase of shear force, the fiber contacts each other and lateral compression occurs. When the compression reaches maximum value, the fiber can only have inter-ply shear deformation, and wrinkles happen at the same time.

The influence of testing temperature and testing velocity on bias extension behaviors of fabric prepreg was researched carefully. From the results of bias extension test, at temperature 20℃ and 80℃ which are chosen based on the rheological property of 3218 epoxy resin, it can be seen that bias extension load decreases along with the rise of testing temperature (Fig. 2). That is to say, at higher temperature the deformation happens easier. That can be explained as the lower viscosity of epoxy resin at higher temperature and the decrease of friction between the fiber and the resin. Moreover, at higher temperature, the step located at the beginning of the curve disappears, which means the fiber can rotate freely owing to the weaker constraint from the resin. This situation is similar to dry GF woven fabric.

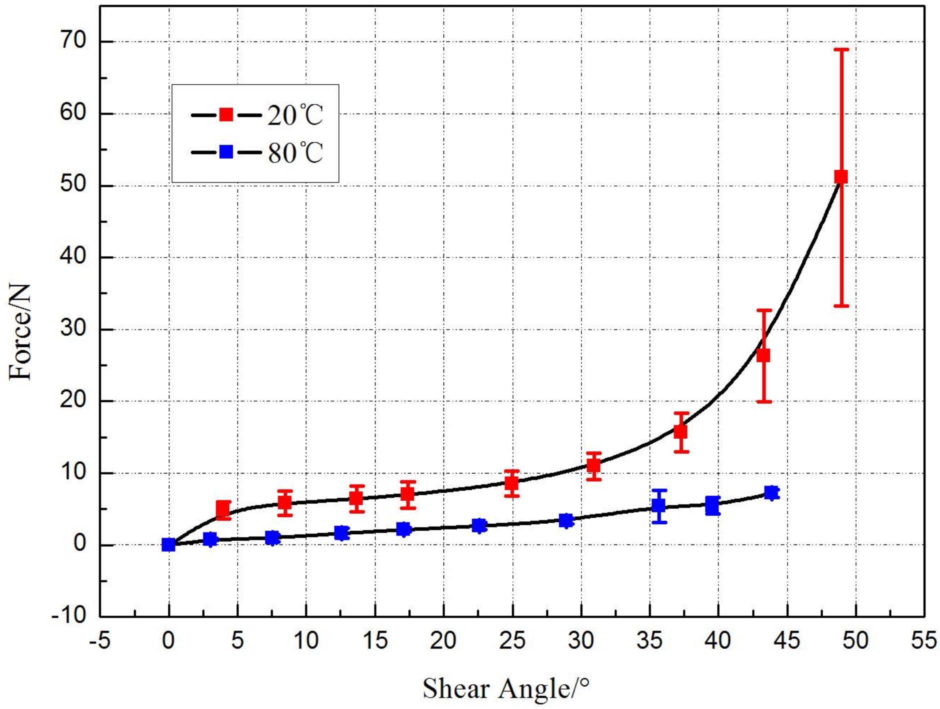
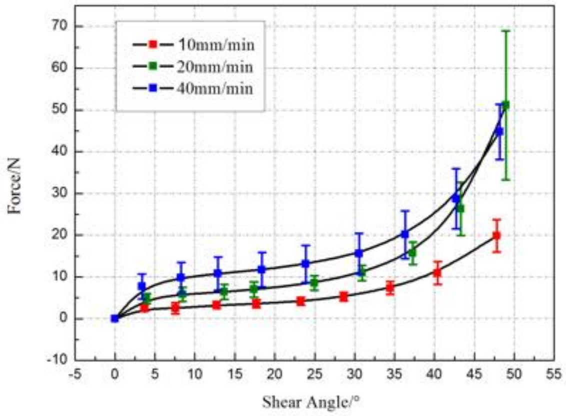
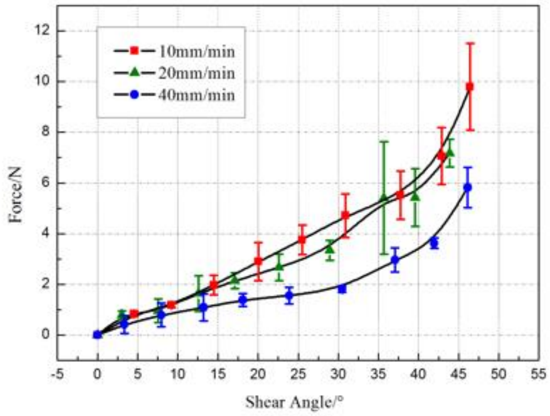


Figure 2: Effects of temperature on bias extension behaviors of SW220/3218.

Under the chosen testing velocity including 10mm/min, 20mm/min and 40mm/min, the force increases with the rise of testing velocity at 20℃ (Fig. 3a). After the test, if the shear angle of the sample is kept, the force will decrease obviously. From this stress relaxation we can infer that the resin cannot shrink as fast as the quick testing velocity, but when the testing velocity is slower the resin is able to deform with the fiber uniformly and the force is lower. However, the situation is different at 80℃ (Fig. 3b). The force decreases with the rise of testing velocity. The reason can be concluded that the epoxy resin has low viscosity at 80℃ and the shear deformation behavior of prepreg is similar with dry woven fabric. At higher testing velocity there exists over-deformation which makes the prepreg deforms easier.



(a)



(b)

Figure 3: Effects of testing velocity on bias extension behaviors of SW220/3218 at (a) 20℃ (b) 80℃.

Comparing the shear deformation behavior of prepreg with that of dry woven fabric (Fig. 4), it can be observed that it needs larger force to make the prepreg deform, since the effect of the resin including splice and fixation makes shear deformation more difficult. Moreover, there is a rising step on the curve of prepreg at the beginning of the test, but when it comes to dry woven fabric, the force keeps a lower value in the corresponding area. The reason is that in prepreg there is full of the resin between the fiber and the fiber has to overcome the force from the resin first in order to rotate. This kind of force can be shown as a step on the curve. Finally, the inflection point on the curve of prepreg occurs earlier than that on the curve of dry woven fabric, since the resin limits the maximum value of the lateral compression of fibers.

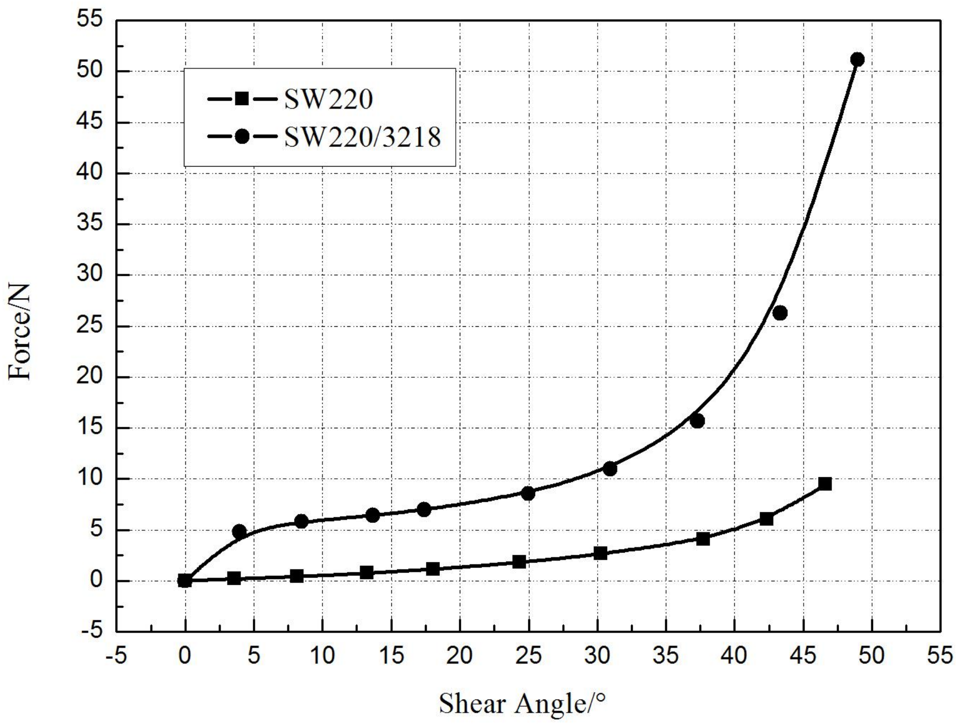


Figure 4: Comparison on bias extension behaviors between SW220 and SW220/3218.

3 THICKNESS COMPACTION

The dimension of the samples is 75mm×75mm. There are two kinds of single layer, one of which follows ±45° direction of the prepreg and the other one follows 0°/90° direction. In order to research the effect of the number of layers on thickness compaction behaviors, 4 layers and 8 layers are used in this test. The order of layers is shown in Table 1. Then multi-layers samples were put on the platform of the testing machine (Fig. 5) and each sample was tested three times.

Number of layers	4 layers	8 layers
Order of layers (from top to bottom)	0°/90°	0°/90°
	45°/-45°	45°/-45°
	45°/-45°	0°/90°
	0°/90°	45°/-45°
		45°/-45°
		0°/90°
		45°/-45°
		0°/90°

Table 1: The order of layers in thickness compaction test.

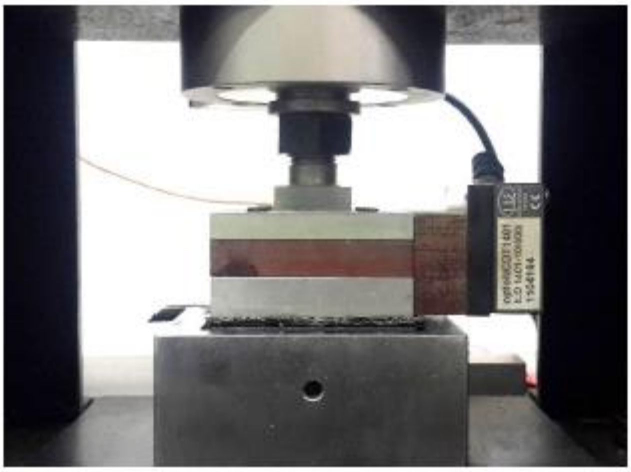


Figure 5: Testing machine for thickness compaction test.

Effects of cyclic testing, temperature and number of fabric layers on thickness compaction behaviors of SW220/3218 were investigated. The thickness of prepreg declines following the increase of cycle times and curves of second and third cycle have similar shape (Fig. 6). The reason is that the first compression of GF prepreg mainly reflects inelastic deformation, second and third compression mainly reflects elastic deformation.

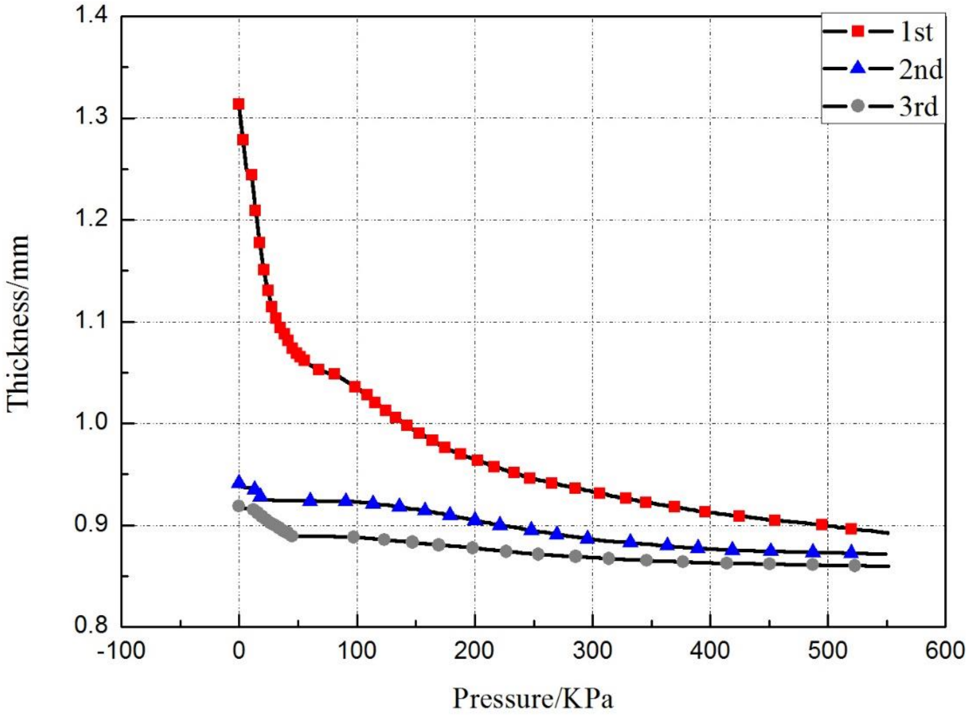


Figure 6: Effects of cyclic testing on thickness compaction behaviors of SW220/3218 of 4 layers at 20℃.

At selected temperature 20℃ and 80℃, epoxy resin flows more easily when compaction temperature is higher, as a result, the compaction thickness decreases with the rise of temperature (Fig. 7).

Based on the thickness compaction curves for different number of fabric layers, per layer thickness in eight layers compaction test is smaller than that in four layers test. Moreover, differences of per layer thickness become more obvious along with the increase of testing temperature (Fig. 8). This phenomenon can be explained from the effect of resin. With the increase of interface inside layers of GF fabric prepreg, buffering effect from epoxy resin becomes intensified, leading to larger per layer thickness.

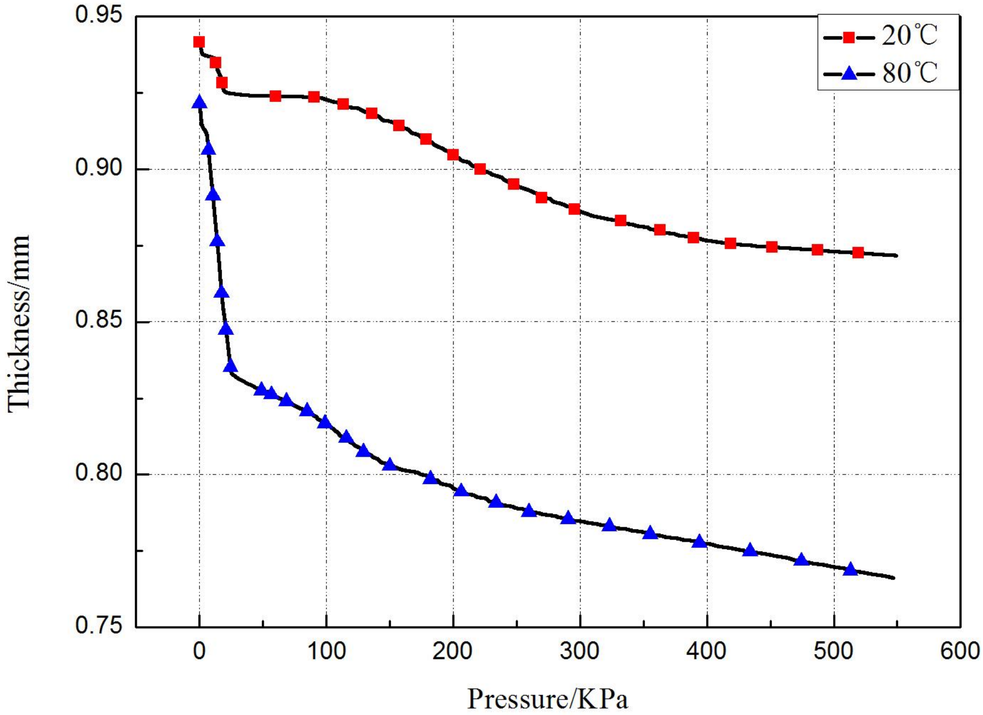


Figure 7: Effects of temperature on thickness compaction behaviors of SW220/3218 of 4 layers.

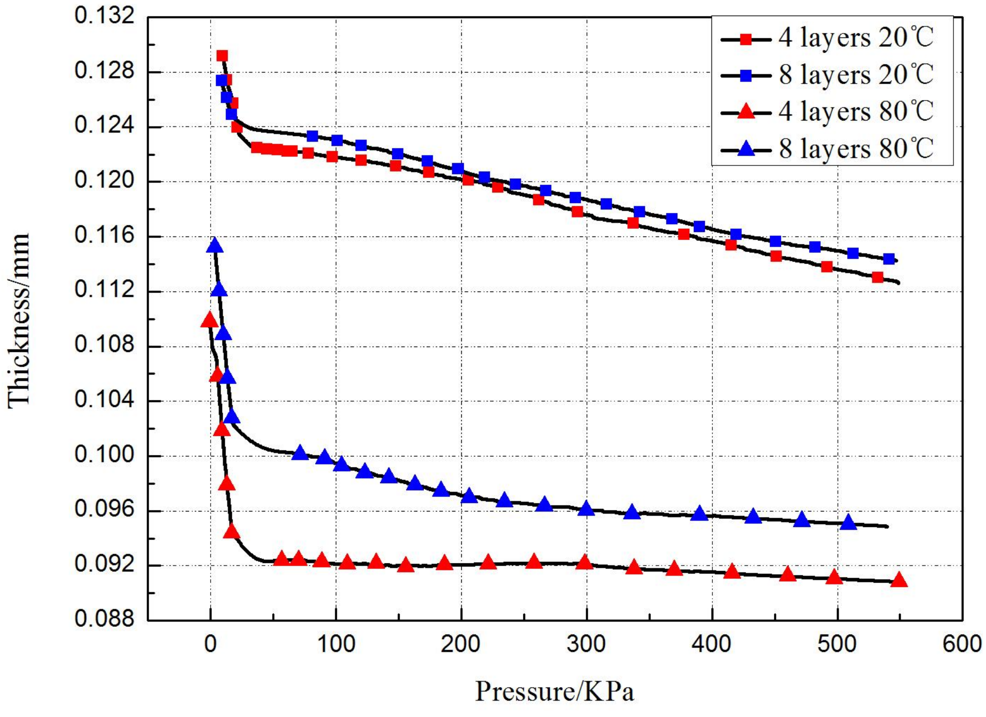


Figure 8: Effects of number of fabric layers on thickness compaction behaviors of SW220/3218 under 2nd cycle at 20℃ and 80℃

In order to prove the effect of the resin on the thickness of single layer, thickness compaction of dry woven fabric including 4 layers and 8 layers (Fig. 9) was researched. The two kinds of testing curves show similar shape, which is very different from prepreg under the same testing condition. When the pressure exceeds 300KPa, the thickness of single layer from 4 layers fabric is larger. From the theory of nesting effect, we know that there are many gaps among fibers and during the compaction process the fiber can enter the gaps in adjacent layers, as a result, the thickness of sample declines. The more layers exist, the more obvious nesting effect appears, so the thickness of single layer from 4 layers fabric is larger.

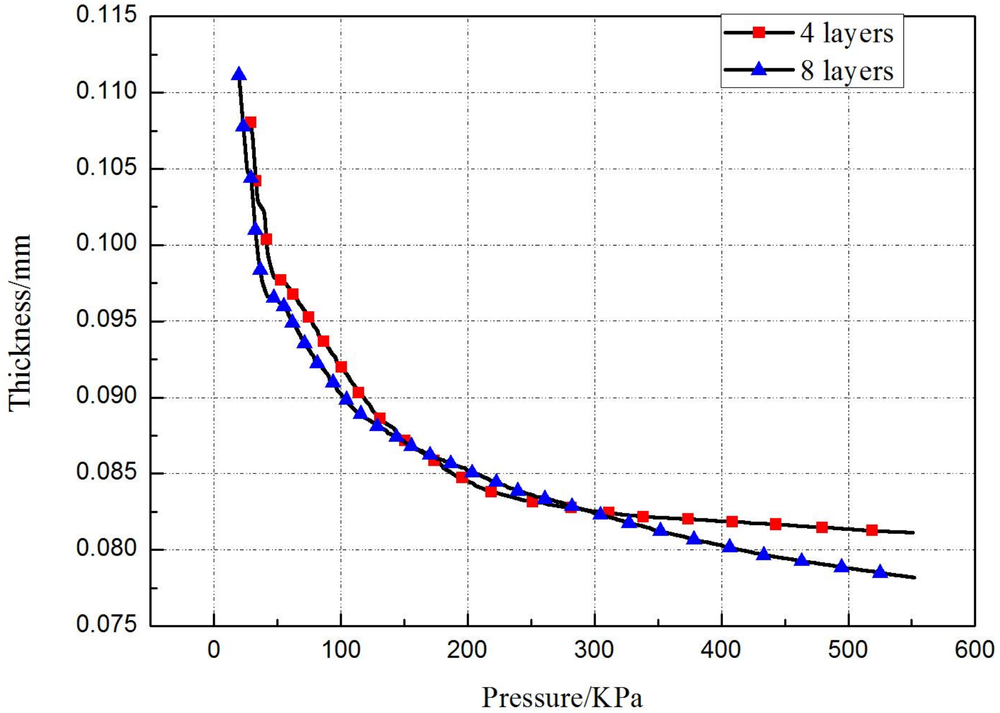


Figure 9: Effects of number of fabric layers on thickness compaction behaviors of SW220 under 2nd cycle at 20℃

4 HEMISPHERICAL DRAPING

Hemispherical draping test gave a research about the forming ability of fabric prepreg on hemispherical surface.

The dimension of the samples is 310mm×310mm. The research focus on the longitude of 0°, 45°, 90°, 135° and latitude of 60°N, 30°N to characterize the drapability of prepreg in detail. The mould and installation are showed in Fig. 10.

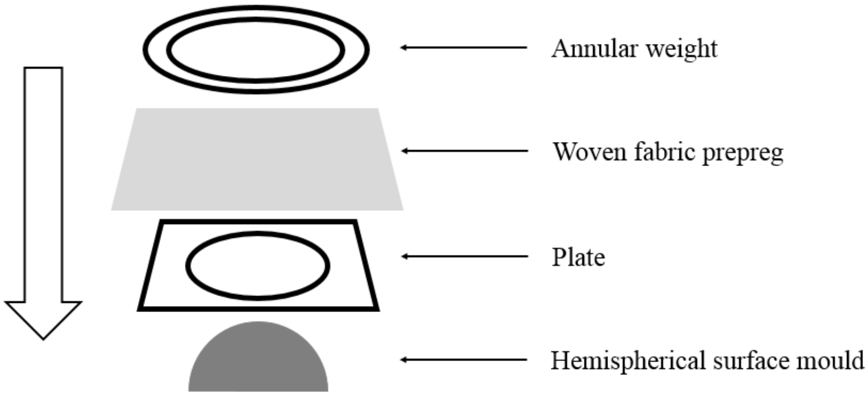


Figure 10: The mould and installation of hemispherical draping test

In hemispherical draping test, shear angle changes of fiber tows from the original state reflect the resistance for shear deformation in different directions of woven fabric prepreg, and give a comprehensive understanding about the drapability of GF woven fabric prepreg.

From the texting curve of shear angle changes of fiber tows along the longitude (Fig. 11), we can find that in the direction of 0° and 90°, the shear angle changes little with the increase of arc length and in the direction of 45° and -45°, the shear angle changes a lot with the increase of arc length. From the texting curve of shear angle changes of fiber tows along the latitude (Fig. 12), the drapability of fabric prepreg mainly accords with the rule of sine function.

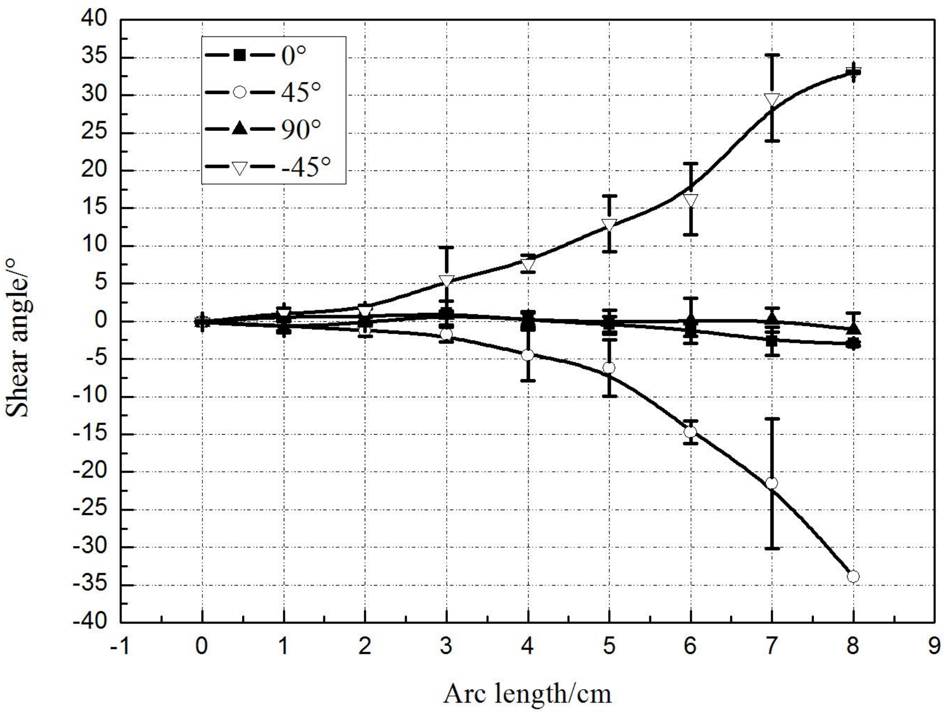


Figure 11: Shear angle changes of fiber tows along the longitude.

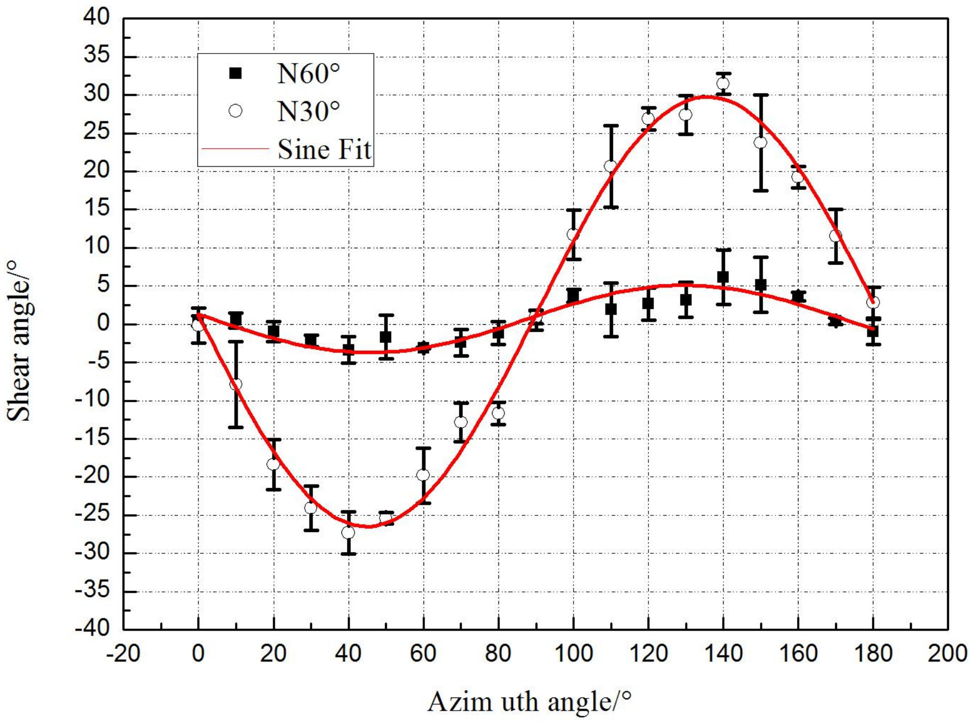


Figure 12: Shear angle changes of fiber tows along the latitude.

At room temperature, the drapability is poor and many wrinkles occur near the equator (Fig. 13). At higher temperature, wrinkles are hard to find and drapability improves a lot, meaning that rising temperature is beneficial to improve efficiency and quality in double curvature surface forming.

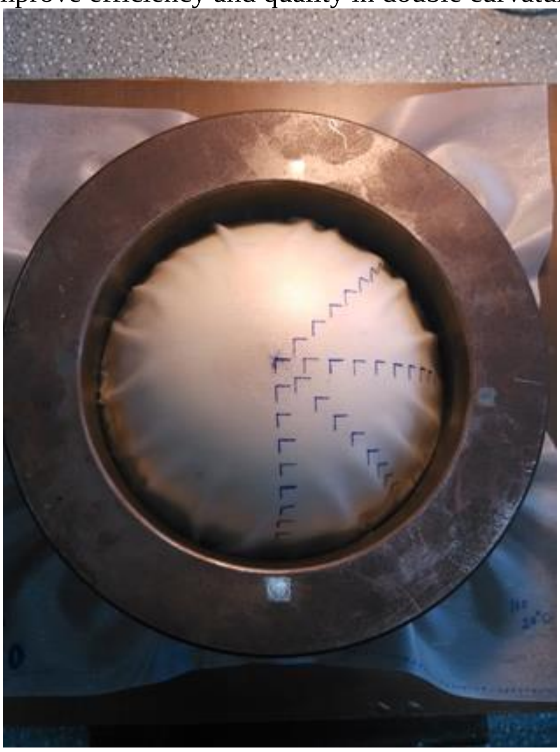


Figure 13: Wrinkles of SW220/3218 occurred during hemispherical draping test at 20℃.

The hemispherical draping test curve of dry woven fabric is similar to that of fabric prepreg (Fig. 14 and Fig. 15), that is to say, the existence of resin does not change the deformation rules of the fabric. The drapability of dry woven fabric is better than prepreg because its fit coefficient is larger (Table 2).

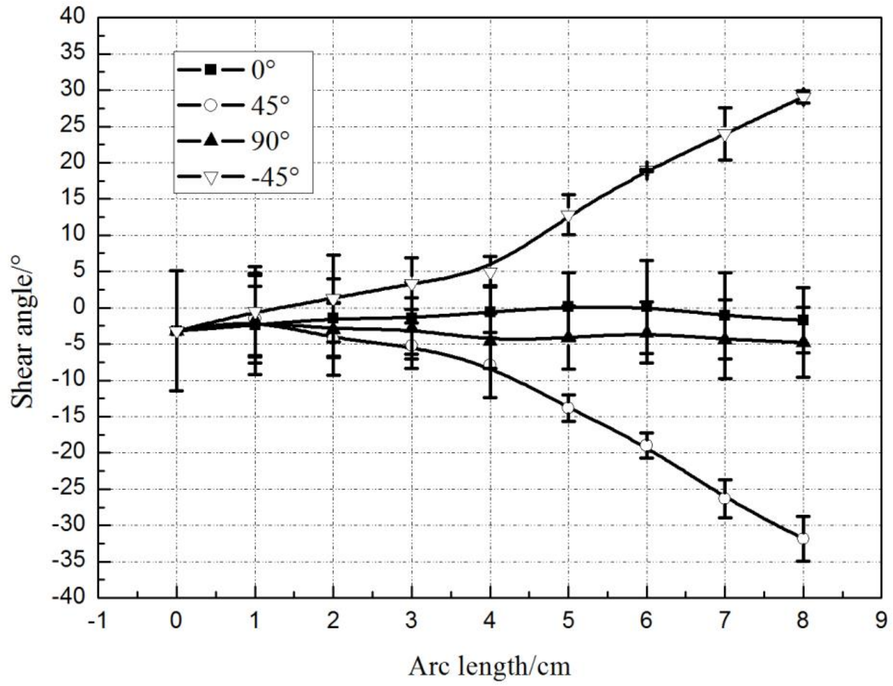


Figure 14: Shear angle changes of fiber tows in dry woven fabric along the longitude

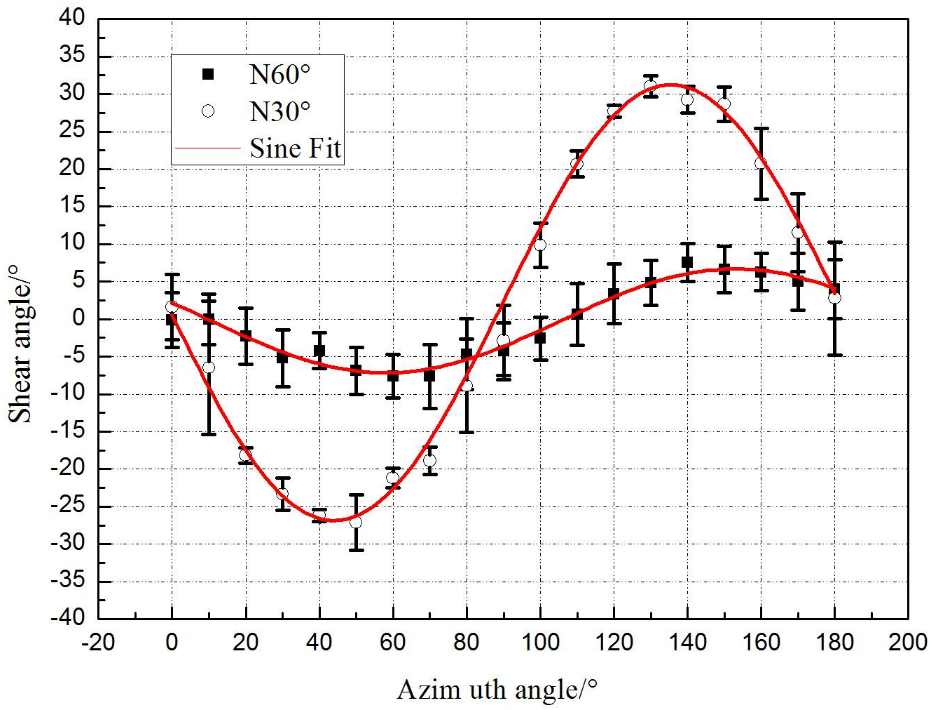


Figure 15: Shear angle changes of fiber tows in dry woven fabric along the latitude

Parameters	SW220	SW220/3218
20℃、30°N	0.9977	0.9934
20℃、60°N	0.9596	0.9485

Table 2: The fit coefficient in hemispherical draping test.

5 CONCLUSIONS

Bias extension test, thickness compression test and hemispherical draping test are used to test and evaluate the processability of fabric prepregs and corresponding dry fabrics.

Bias extension test shows that when testing at 20℃, the force corresponding with the specific shear angle increases with the rise of testing velocity. At 80℃ the situation is opposite. The load decreases along with the rise of testing temperature. That is to say, at higher temperature the deformation happens easier. Comparing the shear deformation behavior of prepreg with that of dry woven fabric, it can be observed that making the prepreg deform needs larger force and the locking angle of fabric prepreg is lower.

Thickness compression test shows that the thickness of prepreg declines following the increase of cycle times and curves of second and third cycle have similar shape. The compaction thickness decreases with the rise of temperature. To fabric prepreg, per layer thickness in eight layers compaction test is smaller than that in four layers test. To dry woven fabric, the more layers exist, the more obvious nesting effect appears, so the thickness of single layer from 4 layers fabric is larger.

In hemispherical draping test, from the texting curve of shear angle changes of fiber tows along the latitude, the drapability of fabric prepreg mainly accords with the rules of sine function. At 20℃, the drapability is poor and many wrinkles occur near the equator. At 80℃, wrinkles are hard to find and drapability improves a lot, meaning that rising temperature is beneficial to improve efficiency and quality in double curvature surface forming. The hemispherical draping test curve of dry woven fabric is similar to that of fabric prepreg, meaning that the existence of resin does not change the deformation rules of the fabric. The fit coefficient of dry woven fabric is larger than that of prepreg.

To sum up, the deformation ability of fabric prepreg is worse than dry fabric at room temperature, but at higher temperature the processability of prepreg improves. As a result, in storage and transportation stage, the prepreg can be used in order to avoid the ruinous deformation. And in process stage, the temperature can be improved to achieve better processability.

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