BIAS EXTENSION MEASUREMENTS ON CROSS-PLIED UNIDIRECTIONAL THERMOSET PREPREG

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ABSTRACT

The presented study aims to investigate the deformation mechanism of prepreg stack at elevated temperatures using bias extension method. Investigated parameters include layer -up sequence, test temperature, loading speed, pre-heating time were considered. The results show that an increase of test temperature will result in the reduction of load lever. The load required to deform is influenced by the cross-head speed and pre-heating time. Different stacking sequences result in different deformation modes.

1 INTRODUCTION

In recent years, the composite automatic placement technology has rapidly developed and has been used widely, including the automatic tape laying(ATL) and the automatic fiber placement (AFP). Both of ATL and AFP increase the layup rate and the precision compared to hand layup. However, ATL only suit for flat or slightly curved surfaces, and AFP is only suitable for large curvature of complex surface manufacturing, both of them are difficult to product beam structures with complex shapes. Recently, sheet forming has been an promising manufacturing method for automate the shaping of thermosetting composites with continuous fibers. The pre-stacked planar sheets deform into complicated shapes by force applied by matched dies or diaphragm [1]. A successful forming requires understanding of the properties of the uncured material. The deform mechanism of thermoplastics has been extensively studied especial for woven fabrics [2-4]. Pin-jointed net (PJN) has been widely used to describe the deformation behavior of woven fabrics. The theory assume that draping occurs through shear, and it deforms through rotation at the crossover points between warp and weft [5-6]. In-plane shear deformation of weave is limited by shear locking angle, this does not seem to exist in the same way for cross-plied UD prepreg [7]. There is currently little investigation about the deform behavior of cross-plied stacks of unidirectional thermosetting prepreg. For diaphragm forming process, the in-plane shear is of outermost importance to enable adaption to the three dimensional geometry [8]. Thus, the work presented herein aims to investigate the in-plane properties of cross-plied unidirectional prepreg. There're two methods known as the bias-extension and the picture-frame testing methods to characterize the intraply shear properties. In the picture-frame test, it's difficult to properly align the fiber with the frame, this lead to bad reproducibility of the results, on the other hand, and the prepreg should be punched before being clamped into the rigs, this hinders the test's accessibility. Hence, the bias extension method was used in this paper. The influences of test temperature, loading speed and lay-up sequence on the deformability of prepreg were investigated in this paper.

2 EXPERIMENTAL

2.1 MATERIALS

The prepreg used in this investigation is CYCOM X850® (Cytec Industries, USA). The resin content of the CYCOM X850 is 35% by weight, and the fabric areal weight is 191 g/m^2. The manufacturer-specified out-life of the prepreg was 30 days. The initial out-time of all material was 0 days, and samples were stored frozen prior to use.

2.2 SAMPLE PREPARATION

Each sample has an ungripped sample size of 150mm ×60 mm and the nominal thickness is 0.2 mm for X850 and the thickness of specimen depends on the number of layers. Lines were marked on the surface of the specimens as shown in Fig.1 for ease and clear observation. Line1 and line2 The length of the ungripped specimens must surpass two times the width so the uniform shear zone can be inspected. In this paper, the prepreg stacks were vacuum compacted at room temperature for 30 minutes at -1 bar pressure to improve thickness uniformity. The specimens were held in grips as shown in Fig.2. The grips are wider than the specimens, so there is no need to punch on the specimens. Specimens were heated up to the processing temperature at a rate of 20℃/min and 10 min preservation. In order to investigate the influence of pre-heating at mold temperature on the formability of prepreg, some specimens with [±45]$_s$ were first vacuum consolidated at 80℃ in the oven for different time, and then the specimens were taken out for bias extension test.

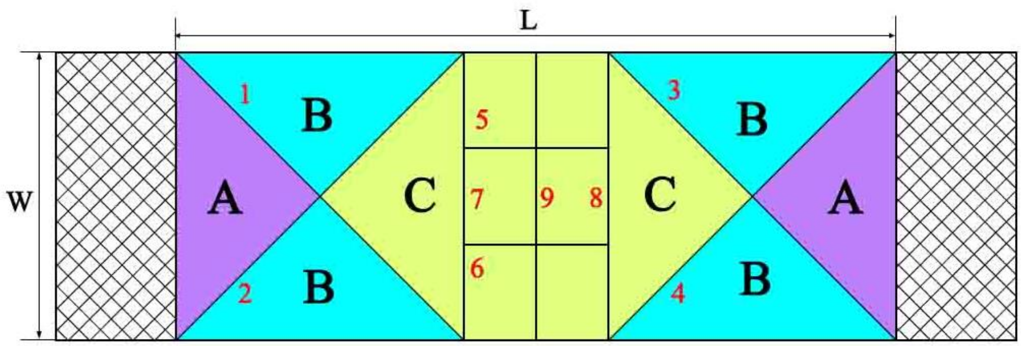

Fig.1 Bias extension test specimens with three different zones and the lines marked on the specimens

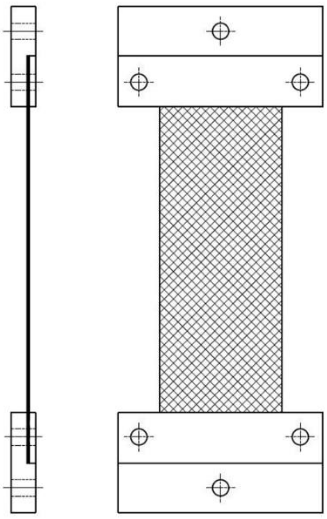

Fig.2 Bias-extension device.

2.3 EQUIPMENT

An Instron wdw-100 machine equipped with a 100kN load cell was used for all tests. To control the temperature, an environmental chamber surrounded the test set-up. The environmental chamber is built to suit the Instron and can be used within a temperature interval of between -120℃ and 300℃. In this paper, the testing temperatures ware set based on the viscosity - temperature curve and the experiences from the workshop during real formation. For each test, a camera was set up outside the conditioning chamber to record the whole process of experiment, then other software named PotPlayer was used to intercept pictures at intervals of time over the whole test process. The software PicPick was used to measure the rotation of the fibers on the surface of material stack and the distances between lines mark on the specimens from those screenshots.

3 RESULTS AND DISCUSSIONS

The bias extension test is used to investigate some of the mechanisms that occur during forming. In order to simplify the comparison, the load responses were normalized with respect to thickness for the different layers used in the test.

In Fig.3 it can be seen that the load required to deform decrease as the temperature increase. The results indicating a significant reduction in load level at the higher temperature. Due to the viscosity of rein at 40°C is fairly high, the load lever test at 40°C is obviously higher than 60°C and 80°C. There are common defects generating during deform process such as in-plane fiber buckling, laminate wrinkling, fiber split and so on. Ylva R. Larberg [9] defined the wrinkling initiation as the first visible expansion of fiber tows out of plane. Splitting of the samples and fiber wrinkling as shown in Fig.4 can be seen as the limit of deformation. When the displacement reach 15mm, there are only some wrinkling generate on the surface for specimens tested at 40℃. No significant slippage could be seen during the test. This seem to happen when the load required for fiber to rotation were lower than the friction between the layers. With the rising of temperature, the lines marked on the surface which perpendicular to the fiber direction broken into bands, and more buckling generated at the same time. It’s worth noting the influence of temperature on the width of bands. It was found that with the increase of the deformation, the center lines were broken up into bands and the width of bands decrease while the temperature increase. What’s more, there are obvious split occurring on the uniform deformation zones when the test temperature was 100℃。It may due to the decrease of viscosity. The increase of temperature not only reduces the friction between layers but also reduce the cohesive force between fiber tows, so the prepreg was easily to broken up into bands. To reduce the generation of defects the deform temperature should be set based on the viscosity and the slip ability of prepreg. Furthermore, since that the load required for deformation deeply influences the slippage of fiber, the initiation of wrinkles, thus it’s important to adopt reliable methods to improve the homogeneity of temperature through the thickness of stack.

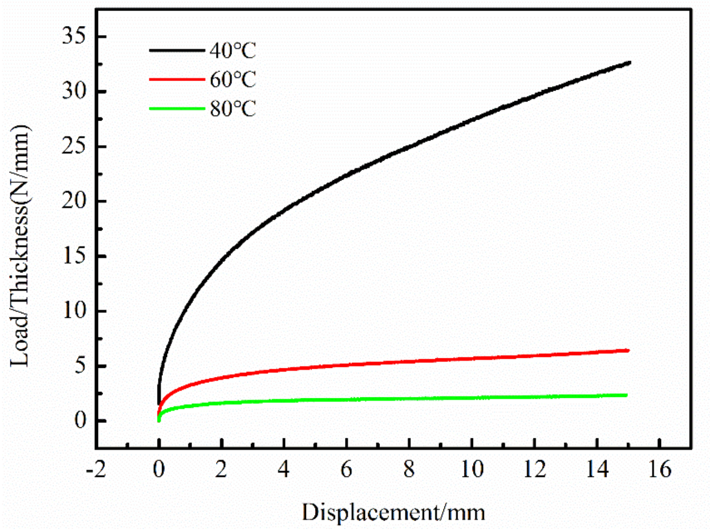

Fig.3. Bias extension test on X850 at 5mm/min and different temperatures.

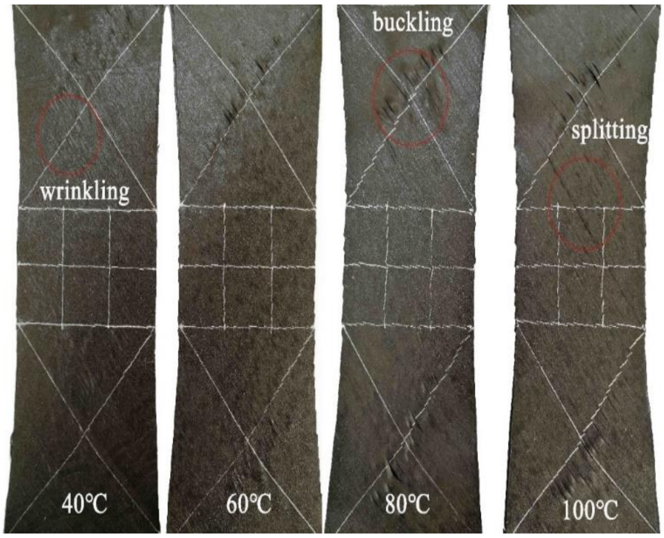

Fig.4 Specimens after bias extension test at different temperatures tested at 40mm/min.

The force required to deform the bias extension specimen is relative to the strain rate: the higher the strain rate, the higher the load required. This holds by X850(see Fig.5), the materials were tested at 80℃ at different cross-head rates. The trend was the same as shown in [5]. Thus, the vacuum rate cannot be neglected during the process of diaphragm forming.

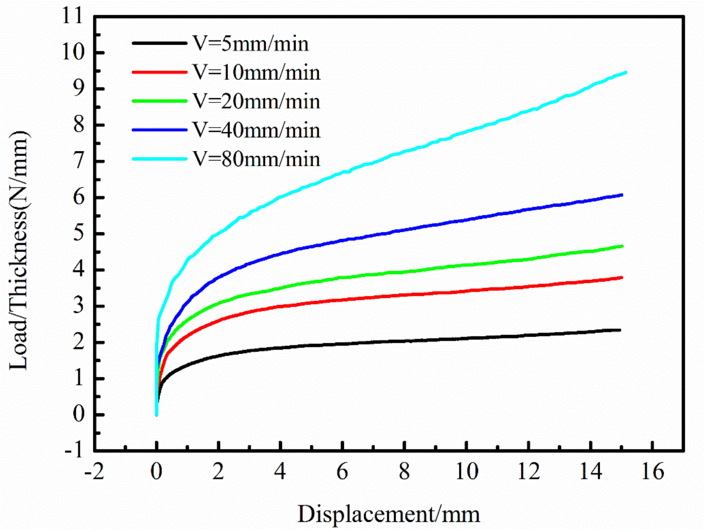

Fig.5 Bias extension test on X850 at 80°C and three different crosshead rates.

Fig. 6 shows the load responses for three different stacking of X850 prepreg. It can be seen that the load required to deform for $[\pm45]_s$ is lower than $[45/90/-45]_s$ and $[45/-45/90]_s$. Worth noting that the load decrease after about 30mm displacement for $[45/-45/90]_s$ stack and $[45/90/-45]_s$ stack. Furthermore, $[45/90/-45]_s$ showed nearly similar resistance to deformation compared to $[45/-45/90]_s$, the load of $[45/-45/90]_s$ decreased slowly when the load reach the maximum, while $[45/90/-45]_s$ reached its peak and declined fast thereafter. Visual observations of the samples during deform process find that lower fiber rotation for $[45/90/-45]_s$ than the other two stacking. As present in Fig.6, the uniform deformation zones of specimens with $[45/90/-45]_s$ split into strips, and the lines marked on the surface broken into bands. Fig.6(a) and Fig.6(b) both show that the width of the 45-layers was smaller than the 90-layers. This is due to the rotation of fibers of the 45-layers or -45-layers. Comparing Fig.6(a) and Fig.6(b), it can be find that putting the 90-layer in the center of ±45-layer will accelerate split of the 45-layer. This confirmed that the load of $[45/90/-45]_s$ decreases quickly when it reaches maximum.

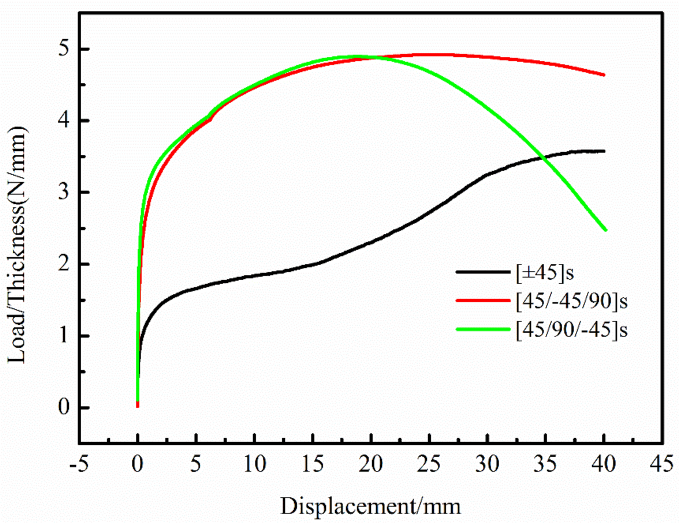

Fig.6 Bias extension test on X850 with different stacking at 80°C and 5 mm/min.

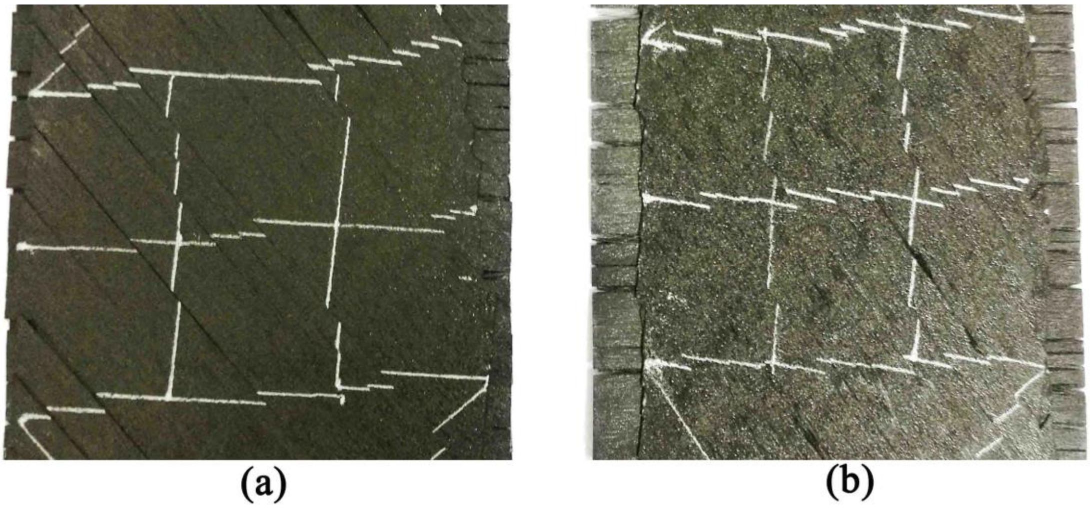

Fig.7 Specimens for [45/90/-45]s(a) and [45/-45/90]s(b) after bias extension test tested at 80℃and 5mm/min.

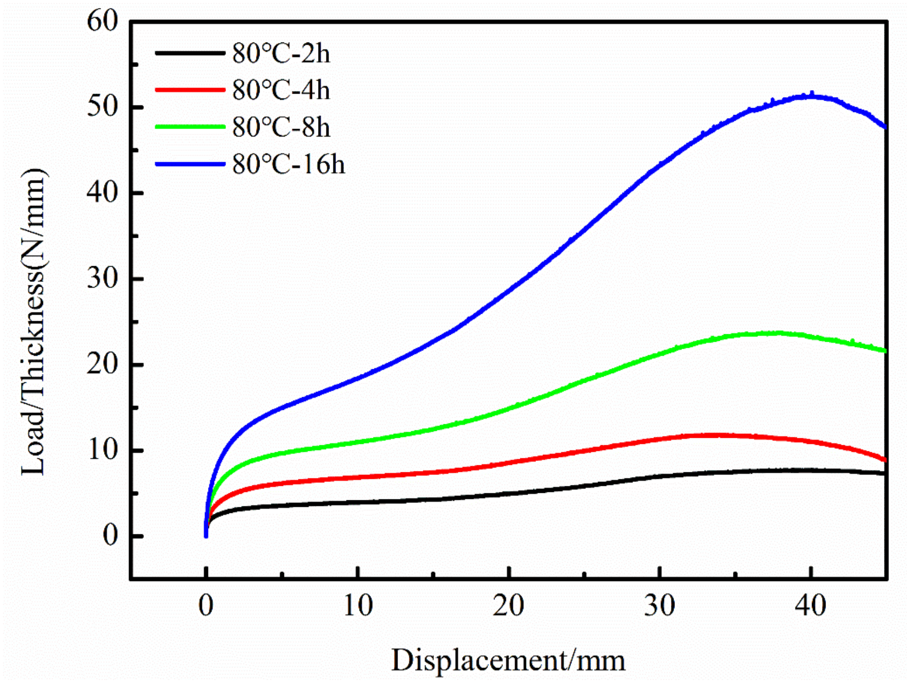

Fig.8 Bias extension test on X850 with different preheating time.

Ambient aging is inevitable for the production of large parts, as the lay-up of large-scale structures can take several hours and even days. Research has confirmed that exposure prepreg to elevated temperatures prior to cure can induce polymerization/cross-linking of the resin, which adversely affects tack and drape [10]. Hence, to understand the influence of preheated time on in-plane shear, we put the specimens in oven at 80°C for different time. Fig.7 shows that the slip resistance increase as the increase of preheating time. Furthermore, no splitting was detected during the deformation, while the wrinkling was unambiguously detected. Pre-heating at elevated temperature promotes the curing of the resin and thereby increases the cohesive force between layers. Though the tests were under elevated temperature, pre-heating still produces significant increases in loads required for fiber to rotate. To reduce the load lever of fiber slip, the preheating time should be as little as possible. In the process of diaphragm forming, especially for structure parts with large size and large thickness, it usually costs long time to elevate the temperature to the set temperature. Once the mold reaches the set temperature as the prepreg stacks it's hard for them to cool down. Thus, it needs a set of accelerate heating and cooling system to reduce the forming time.

4 CONCLUSIONS

The sheet forming deeply depends on the deforming rate and temperature, the increasing of cross-head rate and temperature both increased the loads. The influence of stacking sequence on the in-plane deformation was also studied. Different deformation mechanisms were observed among $[45/-45/90]_s$, $[45/90/-45]_s$ and $[\pm45]_s$. Putting the 90° layer in the center of ±45 layers reduce the rotation of fiber obviously and make the prepreg split into strips easily. In general, [45/-45/90]s stacks and [45/90/-45]s stacks show a much higher load response in comparison to [±45]s. The load to deformation was significantly increased with the increase of pre-heating time at 80℃ when the viscosity of rein reaches the minimum value.

5 FUTURE WORK

The forming of prepreg stacks is influenced by lots of factors, except the aspects were mentioned in this paper, the specimen aspect ratio, thickness, ply-orientation and so on should also be investigated. In addition, developing the finite element model to predict the deform modes of prepreg stacks during bias extension test and diagram forming process is the vital work in the future.

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