IN-PLANE DEFORMATION ANALYSIS OF NCF REINFORCED THERMOSET PREPREGS FOR AUTOMOTIVE STRUCTURAL APPLICATIONS

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ABSTRACT:

In order to meet the new environmental regulations about the low carbon dioxide emissions to the atmosphere the automotive industries have been working to develop lightweight composite body structures for the new passenger cars. The use of NCF (Non-Crimp Fabric) reinforced carbon composites in the luxury cars have now been stretched to the passenger cars. The in-plane deformation behaviour of bi-axial NCF based structural thermoset prepregs is determined and analysed keeping in view to their potential use in the car body parts. Two types of stitched carbon fabrics, pillar and tricot with an aerial weight of 400gsm of each, used in the epoxy based thermoset prepreg are considered for the measurement of in-plane shear behaviour. The de-facto standard methods of bias extension and picture frame tests for intraply shear characterisation have been used at the relevant processing conditions for high volume manufacturing applications. It has been observed that the prepreg deformation behaviour is significantly influenced by the selection of process parameters. Moreover, the suitability of each of the two methods for the particular types of NCF based thermoset prepregs will be discussed. Further to the above, the in-plane deformation tests have also been performed on the dry reinforcement of the same prepreg materials in order to determine the influence of resin on the drapeability of the material as well as its response to the processing parameters.

Keywords: NCF, Thermoset prepregs, Inplane shear, Automotive structures

1. INTRODUCTION

Presently the automotive industries are actively engaged to exploit the lightweight structural composite materials in order to improve the energy efficiency and reduce the vehicle emissions. The nature of work for the automotive sector necessitates developing high volume manufacturing processes and very short production cycle times. The development of affordable and snap cure thermoset prepregs along with automation of the prepreg compression moulding (PCM) stages has been supporting to pursue the desired results for building automotive structural body parts [1,2].

In the context of exploiting automation in compression moulding of thermoset prepregs for high volume production applications, the efforts in automotive industries are underway to acquire an acceptable level of useful solution. Automation of PCM would induce higher deformation rates in the material and material behavior should be known at different rates compatible to the processing of thermoset prepregs for high-volume applications. Contrary to the processing of thermoplastic prepregs, the preheat of thermoset prepreg plies prior to preforming can be restricted well below the melting stage i.e. lower than the initiation of cure. The preheat of prepreg softens the material and facilitates in smooth preforming thereby assisting the in-plane (intra- and inter-ply) and out-of-plane deformation of plies in multiple stack.

The drapeability of the biaxial-fibre reinforced materials attributed to their shear compliance is determined from the in-plane shear tests of picture frame (PF) and bias extension (BE) tests

[3-7]. The forming behaviour of biaxial engineering fabrics is indeed facilitated by their ability to undergo large shear strains, while strains along their fibre directions remain relatively low. Generally the problems associated with these two test methods are well-documented: the picture frame test produces almost homogenous kinematics throughout the test specimen but is extremely sensitive to specimen misalignment issues. In contrast, the BE test is relatively insensitive to specimen misalignment but induces non-homogenous kinematics across the test specimen making it more difficult to interpret results and the test is also susceptible to intra-ply slip as the fabric reaches relatively high shear angles. This slip limits the maximum shear angle that can be explored using the BE test [7]. However, in the case of thermoset prepregs, the tests being performed at relatively low temperatures can avoid the issues of fibre-slippage even at high shear angles. Here, the shear tests are performed at high strain rates that can be considered equivalent to high volume manufacturing applications.

2. MATERIALS INVESTIGATED

Following are the details of the rapid cure thermoset prepreg materials used to investigate for their in-plane shear behaviour:

CEP-PS: Carbon/Epoxy Prepreg with biaxial Pillar Stitched non-crimped fabric having an aerial weight of 400gsm

CEP-TS: Carbon/Epoxy Prepreg with biaxial Tricot Stitched non-crimped fabric having an aerial weight of 400gsm

Both types of materials have been supplied by Cytec Industrial Materials. The materials have been purposely built for compression moulding process with a short cure cycle time to meet the production-rate requirements of automotive industries. The resin system of these thermoset prepregs have been designed for high rate manufacture of components and offer mechanical performance to suite the applications. For the purpose of studying the intraply shear behaviour the viscosity of epoxy based resins is an important factor to affect the mechanical behaviour of the reinforcement. The viscosity is largely dependent upon state of the epoxy resin due to change of temperature. The role of viscosity on the in-plane shear behaviour of the prepregs will be shown. The main deformation mechanisms of the prepregs believed to dependent upon the fibrous reinforcements will also be investigated for the selected materials.

3. EXPERIMENTAL TESTS FOR IN-PLANE SHEAR CHARACTERISATION

Bias extension (BE) and Picture Frame (PF) tests are used to determine the in-plane shear behaviour of the selected thermoset prepreg materials. These methods are considered de-facto standard tests for characterising the intraply shear properties for dry and viscous materials having bidirectional reinforcing fibres [3-7]. Both methods have got their own advantages and disadvantages in terms of the implementation and usefulness for a wide range of continuous fibrous materials. BE and PF tests are performed on Instron-5800R testing machine. The temperature dependent tests are conducted using environmental chamber case with a nominal heating rate of 3-5°C per minute. A load cell of 500N was used to record the data for force.

3.1 BIAS EXTENSION (BE) TESTS

The effective sample dimensions used for testing are 74mm wide and 220mm long. The test specimens have been prepared on Zund CNC cutter which essentially helped to minimize the possibility of any misalignment of fibre orientations as compared to manual cutting. Tensile stretching of the prepreg is carried out at ±45° orientation of fibres to the loading direction. Only single ply of the prepreg has been used for these testing. The test conditions of temperature used are: RT (room temperature), 40°C and 60°C. All prepregs studied for the temperature effects are tested at a strain rate of 60 mm per minute including the dry stitched fabrics. Figure 1 shows the images of deformed and undeformed states of bias extension tests performed for dry fabric (right-side) and the prepreg.

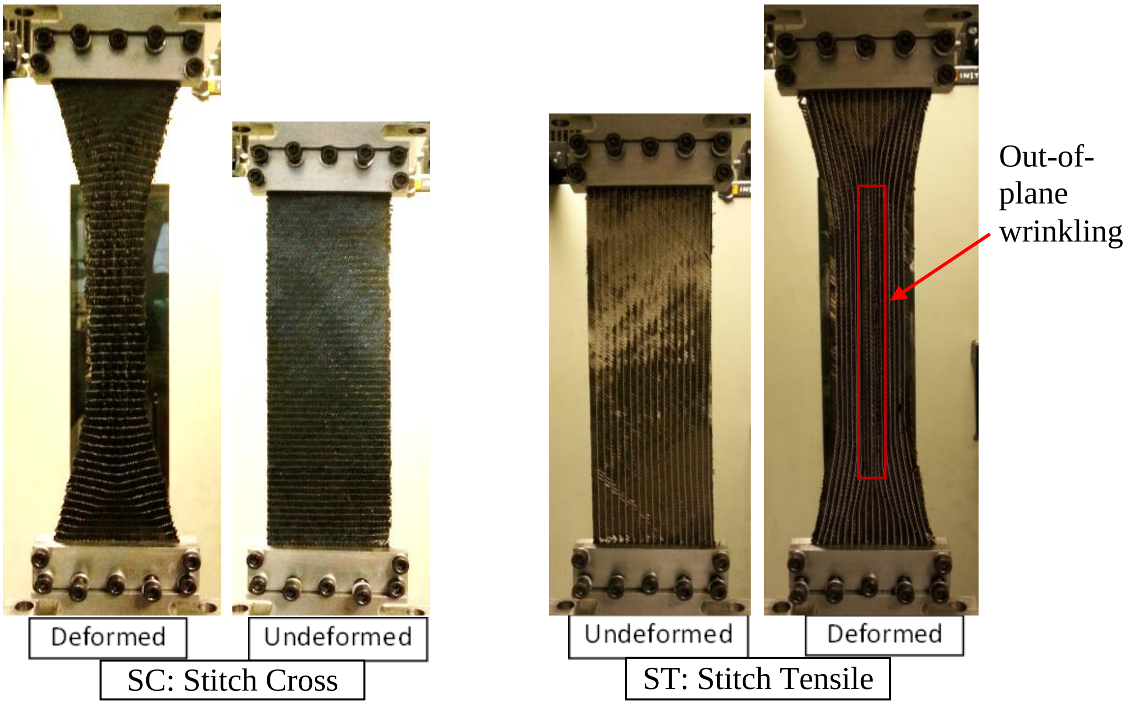

Figure 1 BE test images of biaxial Pillar Stitched (PS) dry NCF in the ST-direction and Prepreg in the SC-direction.

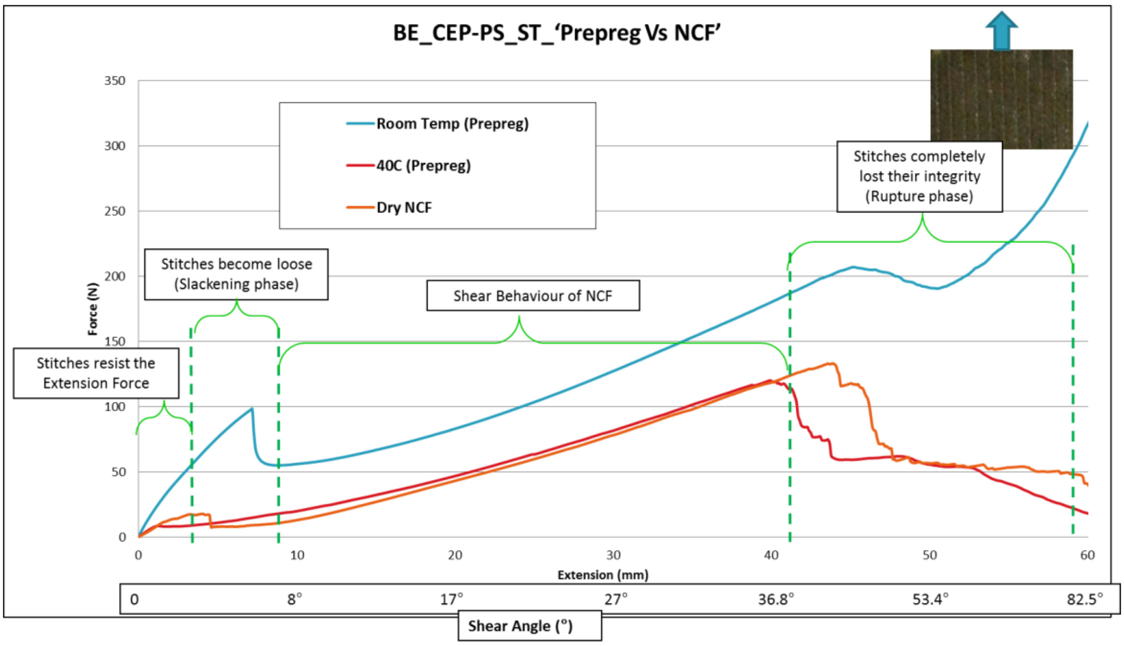

Figure 2 BE test results in the ST directions of biaxial Pillar Stitched (PS) NCF and Prepreg at RT and 40°C.

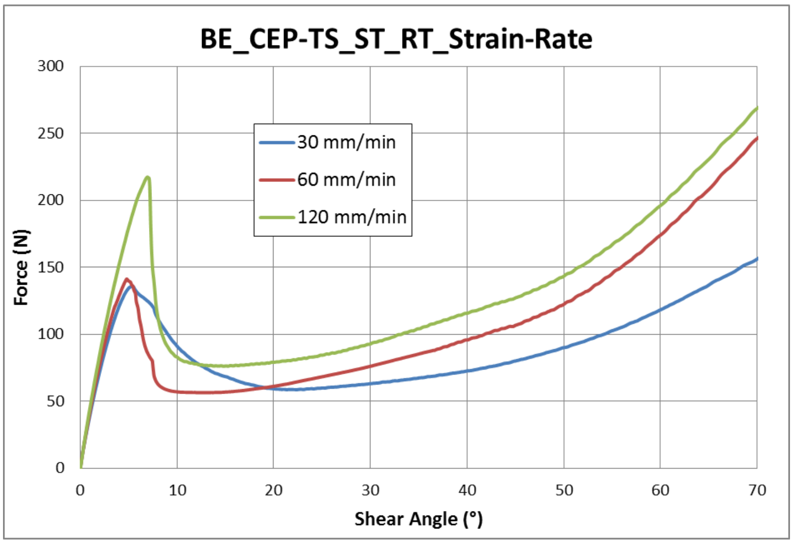

Figure 3 BE test results of biaxial Tricot Stitch (TS) Prepreg in the ST directions showing the strain rate effects.

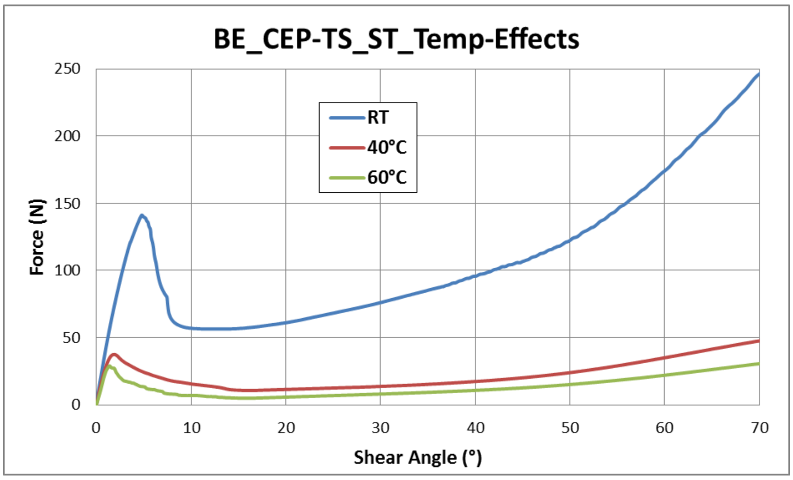

Figure 4 BE test results of biaxial TS Prepreg in the ST directions and the temperature effects.

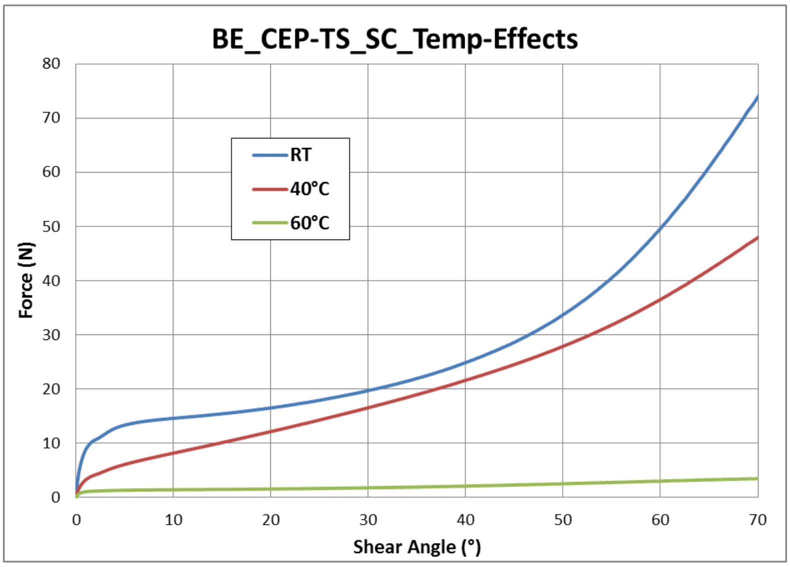

Figure 5 BE test results of biaxial Tricot Stitch (TS) Prepreg in the SC directions and the temperature effects.

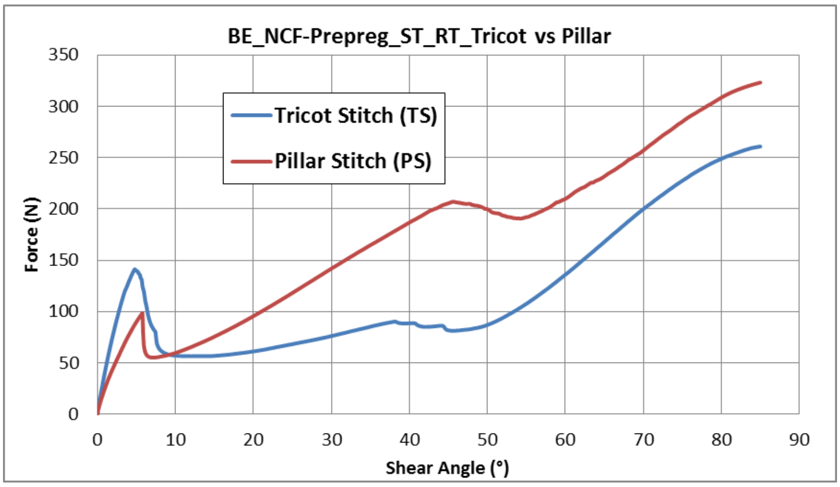

Figure 6 BE tests comparison of PS and TS Prepregs in the ST directions at room temperature (RT).

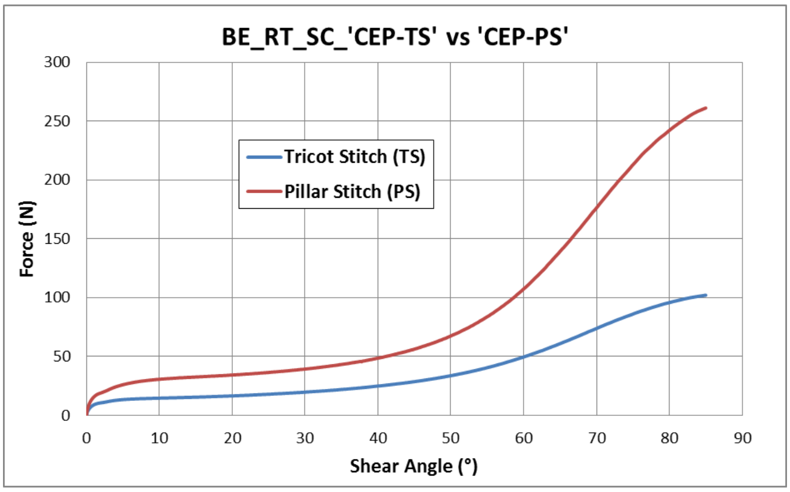

Figure 7 BE tests comparison of PS and TS Prepregs in the SC directions at room temperature (RT).

3.2 PICTURE FRAME (PF) TESTS

PF test can be used for characterisation of the shear resistance of composite reinforcements in a wide range of shear angles, up to 50°-60°, sometimes even up to 75°. The test-rig used to perform PF tests is shown in Figure 8. Four rigid links can deform the material in pure shear in the plane of the ply. Material is cut to the desired size and geometry to be clamped in the picture frame jig shown in Figure 8. The tows or yarns are parallel/perpendicular to the outer edges of the sample or clamping bars in the undeformed state. The effective specimen dimensions used for these tests are 110mm x 110mm.

The specimen should be fastened into the frame using clamps with a grooved or knurled surface to prevent any slip during testing especially at higher temperature. In order to test the composite prepregs at higher temperatures, there is a need to have a temperature controlled chamber in which the whole test-rig can be placed and testing should be done inside the chamber. Once prepreg samples were clamped within the frame, heating of the samples can be maintained at the requisite-level for 5-6 minutes to obtain uniform temperature distribution.

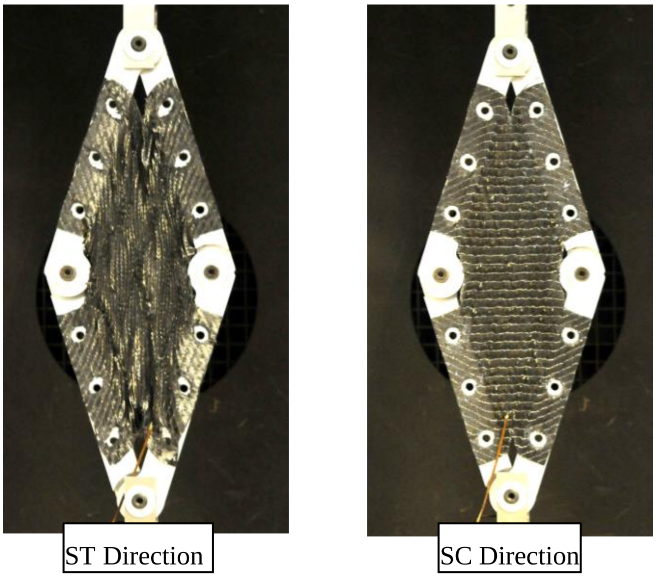

Figure 8 The images showing the influence of stitching direction during intraply shear tests of NCF reinforced prepregs determined with Picture Frame (PF) test.

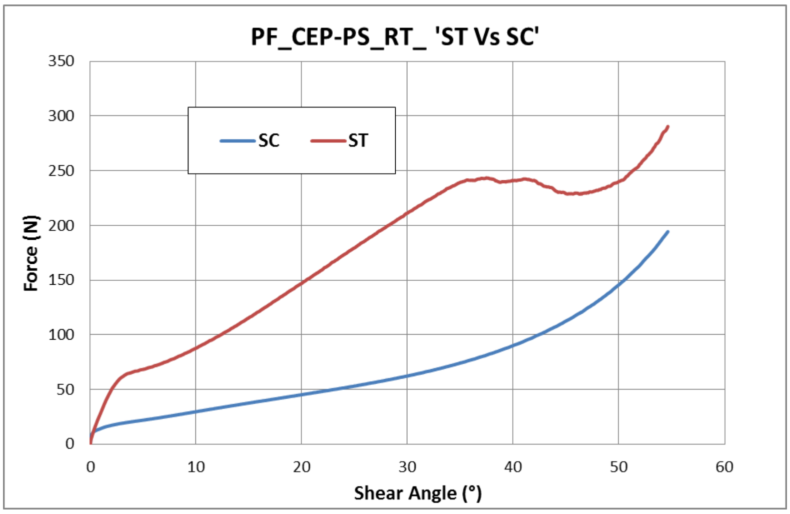

Figure 9 PF tests comparison of PS Prepreg in the SC and ST directions at room temperature (RT).

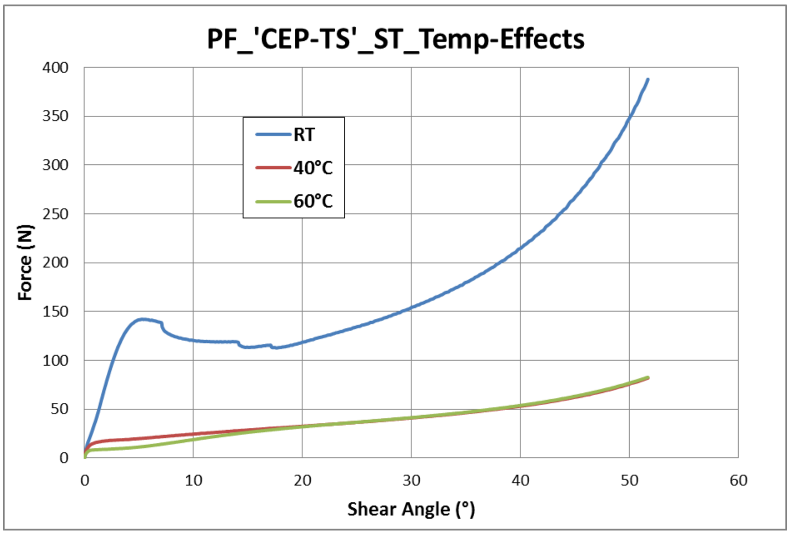

Figure 10 PF tests comparison of TS Prepreg in the ST directions at different temperatures.

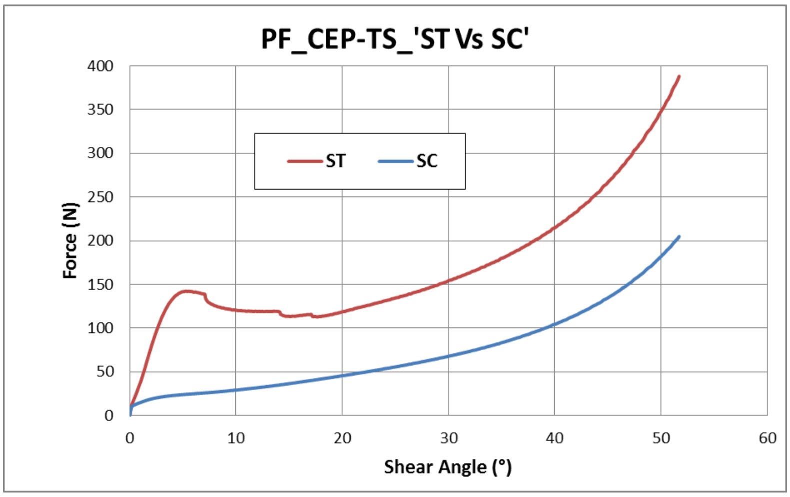

Figure 11 PF tests comparison of TS Prepreg in the SC and ST directions at room temperature (RT).

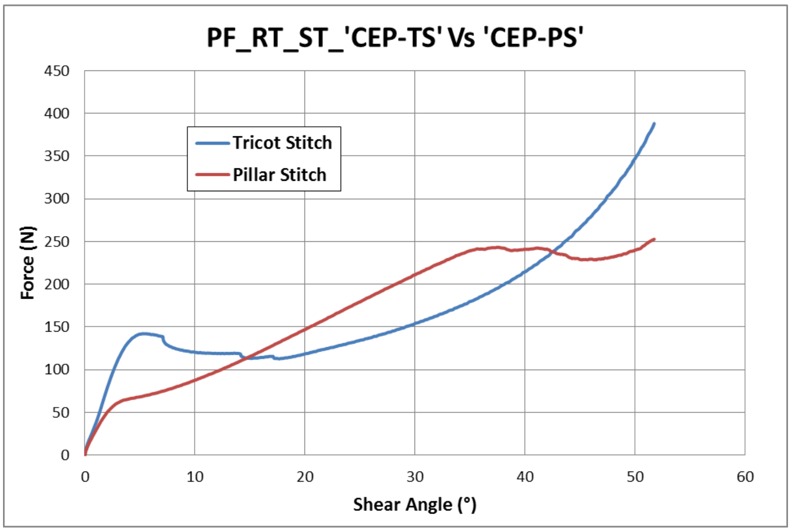

Figure 12 PF tests comparison of PS and TS Prepregs in the ST directions at room temperature (RT).

4. RESULTS AND CONCLUSIONS

Both, BE and PF, tests are performed to study the intraply shear behavior of the rapid cure thermoset prepregs. The tests are carried out on two different types of prepregs having the same resin system but they differ in the stitching pattern of the reinforcement. Therefore this study is mainly focused towards exploring the stitch pattern effects on the in-plane shear behavior of the prepreg materials. Further, these tests are aimed to explore the selected range of temperature and strain rate effects on the shearing behavior of the prepregs. However, it should be known that both PF and BE tests are isothermal.

Figure 2 shows the effects of temperature on the pillar stitch reinforced prepreg along with dry NCF used in the same prepreg. There is a drop in the force required to deform the material with the rise in temperature to just 40C°. This can simply be attributed to the drop in the viscosity of the resin at higher temperatures. Another important aspect of this study is that the shear behavior of the dry NCF is approximately overlapped with the shear behavior of the prepreg at 40C°. Figure 3 shows a comparison of force versus shear angle for the PS prepreg at different strain rates and that can again be mainly attributed to the nature of viscous resin. Figure 4 and 5 show the effects of temperature on TS prepregs in the SC and ST directions. This shows that the stitching direction greatly influences the in-plane shear behavior of the material. Therefore, the shear behavior of NCF materials is non-symmetric and dependent of the stitching directions. Figure 6 and 7 show the comparison of the two types of materials in the ST and SC direction respectively. These tests actually show the difference between the draping behaviour for of the two materials that can be compared on the basis of the force required to shear the material keeping all the test parameters constant.

The results achieved with PF tests are shown in Figure 9-12. The test parameters used are again similar to the ones used for BE tests. Generally the trends of force versus shear angles are similar with few discrepancies such as observed in Figure 10. There is almost the same amount of shear force required to deform the material at 40°C and 60°C. This could be attributed to the possible pre-extensional force effects to the in-plane shear of the material which is usually observed in woven reinforcements.

Following conclusions can be drawn from this study:

a) Intraply shear behavior of thermoset prepregs is strongly influenced by the change of temperature and it also depends on the shear strain rates to some extent.

b) Mainly the shear deformation behaviour of the prepreg is controlled by its reinforcement whereas the resin contributes to influence the magnitude of shear force.

c) The two stitching patterns investigated in this study induce non-symmetric shear response of thermoset prepregs.

d) Tricot stitch prepreg can offer better drapeability as compared to the pillar stitch prepreg under similar processing conditions.

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