INVESTIGATION OF PREFORM MANUFACTURING TECHNIQUES USING NOVEL BINDER COATED CARBON FIBRE TOWS

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1. INTRODUCTION

In the aerospace industry, Resin Transfer Moulding (RTM) and vacuum infusion processing are replacing pre-preg autoclaving moulding to reduce manufacturing costs. These processes require the assembly of dry preforms.

Depending on the nature of the fabric, handling these preforms poses difficulties, cutting and draping are a challenge and without the use of binder to rigidify the fabric, preforms may be damaged during movement and handling from the assembly/cutting area to the infusion tool.

Fabrics are cut and draped and after sprinkling or spraying epoxy powder binder, they become compacted and adhered. The EU funded PreCarBi project is investigating the use of preform assembly using binder coated carbon fibre tows which are being developed as part of the project [1]. Preforms are either laminated using a tow placement system or assembled from fabrics manufactured from binder coated tows.

Since the binder coated tows are not tacky at room temperature, they may be used in conventional textile machinery for production of woven or warp knitted (NCF) fabrics. The fabrics can then be draped or formed to near net shape of the component, then heated to achieve adhesion between tows and layers; after cooling the preform becomes rigid. This process is referred to as activation. The aim of this study is to determine the optimum processing parameters, such as temperature, compaction force, and heating intensity for different activation techniques.

2. Material and methods

The material used in this project is a 12k, 800 Tex HTS based bindered tow supplied by TOHO TENAX. As mentioned before, during manufacturing, the preforms are assembled then, a heat and pressure cycle is applied to activate the binder.

Several heat input methods were investigated. These are electric oven, hot plate, microwave oven, ultrasonic UAZ™ Z-fiber® insertion gantry [2], CO_2 laser and Argon Laser. Nd:Yag and Ti-Sapphire diode laser were also trialled.

Depending on the heat input method used, various techniques were used to apply known compaction force. Clamps of known spring force were used in the electric oven. The compaction force on the hot plate was provided either by vacuum bagging (Fig. 1) or by placing masses on the sample. Stacking of glass plates was used in the microwave oven. The pressure force was measured using the ultrasonic Z-pinning gantry (Fig. 2). Finally, when using laser the samples were maintained in place and compacted by either using a suction table or by clamping of glass plates (Fig. 3).

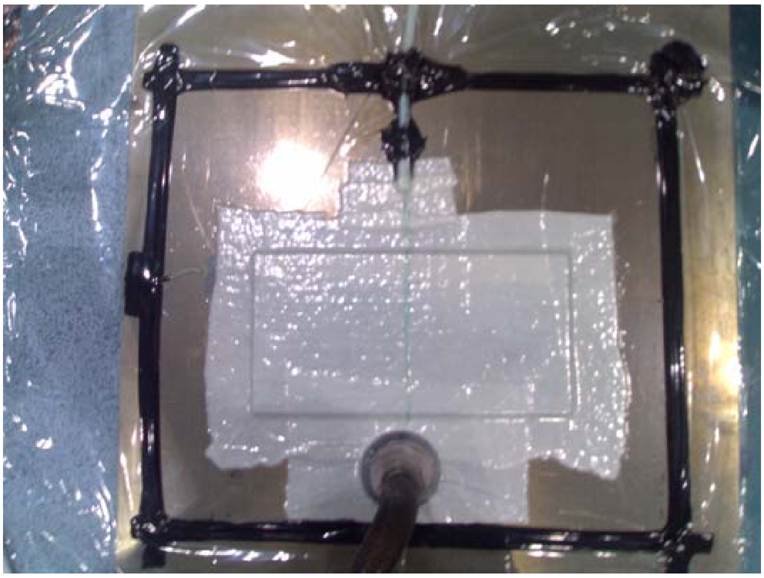

Figure 1: Activation using Vacuum bagging on Hot plate

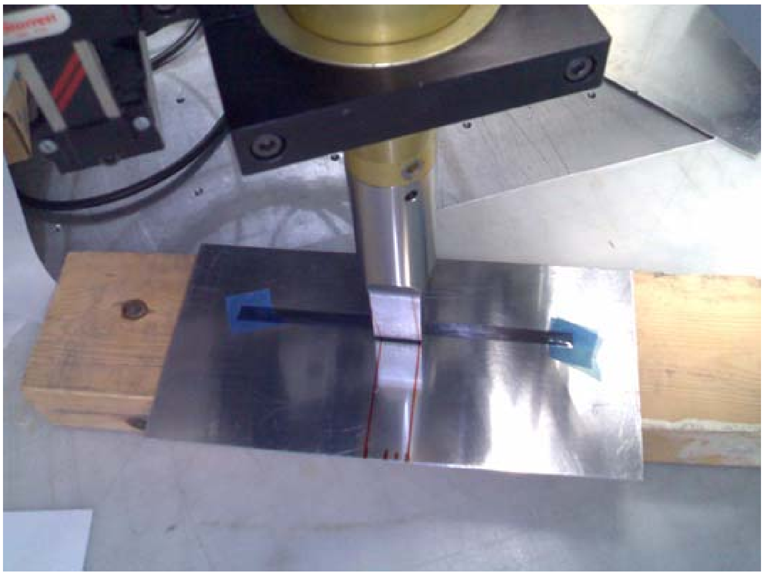

Figure 2: Activation using ultrasonic UAZ™ Z-fiber® insertion gantry

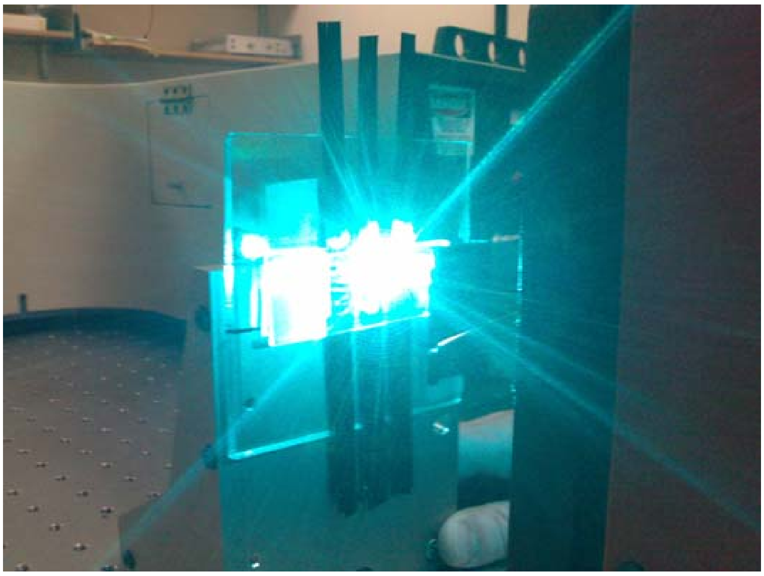

Figure 3: Activation with a 3W Argon Laser, specimen clamped under a glass plate

In order to assess the quality of the activation, a simple double lap shear test was selected. The geometry of the sample is shown in Fig. 4. For processes where the activation is local, only the overlapping area was activated.

The samples were tabbed using flash tape or 120grid sand paper when high failure loads were expected. The results are plotted in terms of ultimate strength.

For manufacturing efficiency reasons, electric oven was the activation technique selected for determination of the minimum activation temperature and similarly, the minimum compaction force was determined using the hot-plate-vacuum bag process.

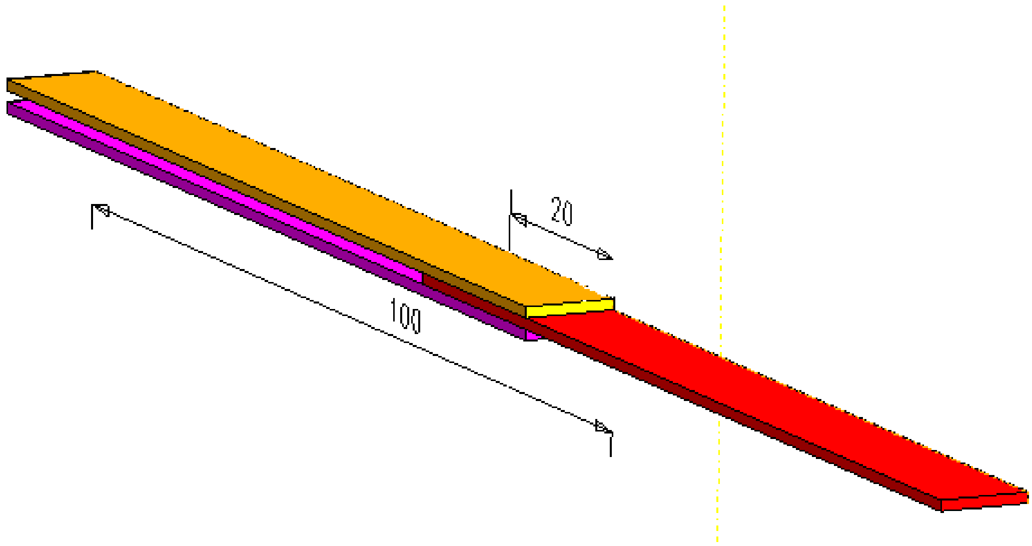

Figure 4: Double lap-shear configuration for testing of preform tackiness

3. RESULTS

All the results for the experiments performed are summarised in the table on page 5. Each value is an average of 10 tests performed for the given activation conditions.

In order to evaluate the effect of temperature on the activation, samples were manufactured in an oven, compacted using the same compaction force of 15.6N and heated at different temperature. The results of this experiment are presented in Fig. 5. A threshold of temperature at 110°C to reach a strength level of 1MPa is visible. It is also argued that when heated above 190°C, the strength of the activated specimen is slightly higher than below 180°C. The error bars show the standard deviation. It is visible that the results from this type of experiments are variable. The variability is believed to be due to the low content of binder in the yarn, such that the coverage of the binder is uneven.

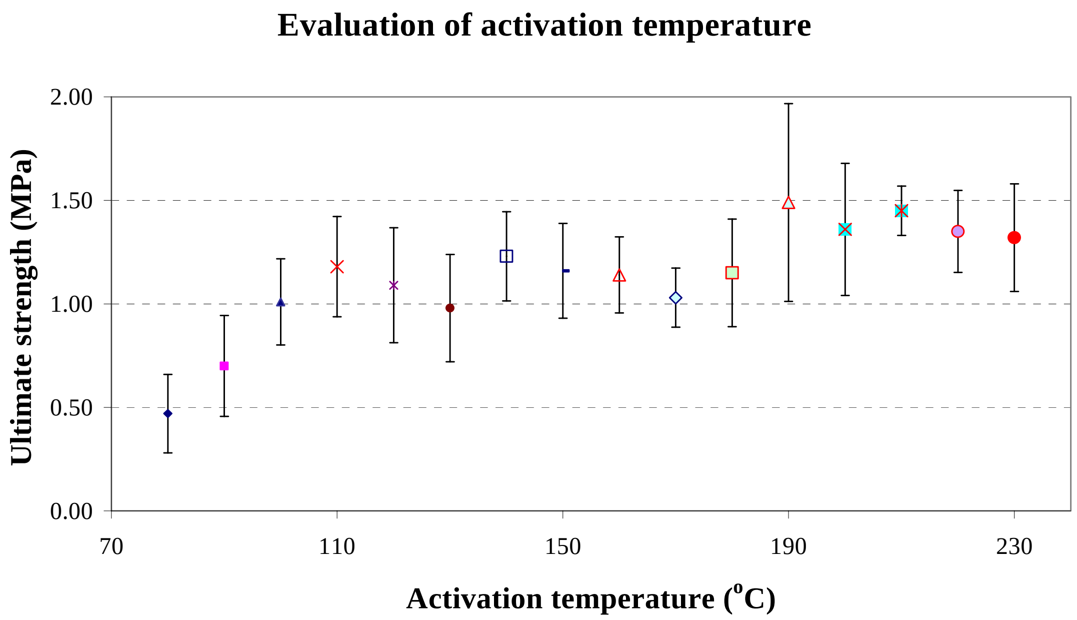

Figure 5: Evaluation of activation parameters- temperatures

The effect of the compaction pressure has been studied using a hot plate and a vacuum table. Specimens were heated at 140°C and various levels of vacuum were applied. The compaction pressure was maintained until complete cooling of the materials. The results shown in Fig.6 tend to suggest that a minimum pressure of 0.25MPa is necessary to obtain a plateau strength level of 1.5MPa. As for the samples made in the oven, the results of testing specimens made under vacuum/hot plate show relatively large scatter.

The results from the various other activation techniques are presented in Table 1. The pros and cons of each method will be discussed in the next section.

Activation technique	Activation temperature (^oC)	Activation compaction force (N)	Time at prescribed temperature (s)	Activated sides	Ultimate strength (MPa)	Ult. strength standard deviation	comments
Electric oven	80	15.6	300	both	0.47	0.19	Reliable temp. and CF control Rapid manufacturing No damage to the tow system Long cooling period (15-30 min) Not suitable for ATP
	90	15.6	300	both	0.70	0.24	
	100	15.6	300	both	1.01	0.21	
	110	15.6	300	both	1.18	0.24	
	120	15.6	300	both	1.09	0.28	
	130	15.6	300	both	0.98	0.26	
	140	15.6	300	both	1.23	0.22	
	150	15.6	300	both	1.16	0.23	
	160	15.6	300	both	1.14	0.18	
	170	15.6	300	both	1.03	0.14	
	180	15.6	300	both	1.15	0.26	
	190	15.6	300	both	1.49	0.48	
	200	15.6	300	both	1.36	0.32	
	210	15.6	300	both	1.45	0.12	
	220	15.6	300	both	1.35	0.20	
	230	15.6	300	both	1.32	0.26	
Hot plate	140	2	300	both	0.88	0.23	As for electric oven Variable CF
	140	15.6	300	both	0.94	0.21	
	140	45	300	both	1.52	0.19	
	140	90	300	both	1.37	0.27	
	140	135	300	both	1.44	0.32	
Microwave	123	2	4	1	0.04	0.02	Sparks and fumes produced
	123	2	8	2	0.18	0.04	
	125	2	5	1	0.21	0.16	
Ultrasound	182	2	5	1	0.21	0.03	Damage to tow structure
	182	2	10	both	0.24	0.06	
	182	15.6	5	1	0.35	0.12	
CO_2 Laser	93	3	400mm/s; 3passes	both	0.04	0.02	Damage to Binder
	134	3	300mm/s; 3passes	both	0.05	0.02	
Argon Laser	?	15	1mm/s; 3passes	1	“1.33”	0.53	ATP ✓

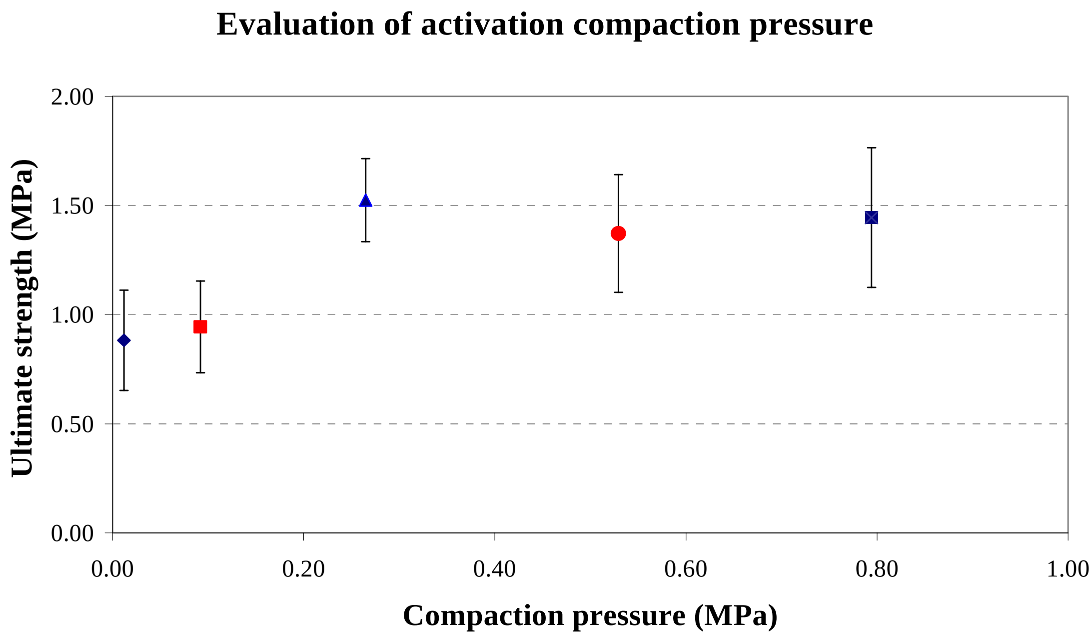

Figure 6: Evaluation of activation parameters- compaction force

4. DISCUSSION

Without undertaking a full characterisation of parameters such as temperature, pressure and laser power, it is very difficult to compare the different activation techniques against each other. However, the observations made during the preform manufacture using the various techniques and the testing of the double lap shear sample are discussed.

Various manufacturing requirements need to be considered. Firstly, the material needs to be laminated using an automated tow placement machine, therefore the activation method must be suitable for an ATP or robot head. Secondly, the material needs to be capable of being woven or knitted using weaving or NCF machines to create larger preforms to be cut, placed and formed at a later stage. Thirdly, preforms need to be shaped and adhered together using the binder to fix the shape and bond preform components.

The use of a conventional microwave oven was not shown to be effective, both in terms of ultimate strength, which may result from binder/fibre surface damage from overheating and the risk of combustion with the inherent health and safety issues.

The electrically heated table/vacuum bag and electric oven are considered to be the most appropriate activation techniques for the fabric manufacturing processes (alongside others such as infra red heating) and the laser and ultrasonic processes are considered to be more suitable for the tow laminating processes.

The vacuum based techniques are also considered for post lay-up forming of the material. The preforms made using vacuum and hot plate are considered as very effective since they provide the greatest adhesion strength and control of temperature and pressure is relatively easy. The activation is uniform and the binder particles are diffused between the fibres as shown by scanning electron micrograph (Fig. 7.)

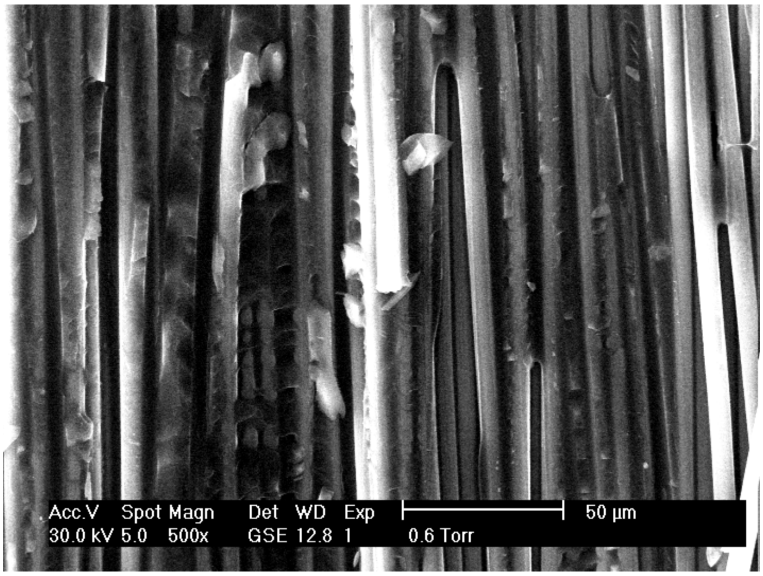

Figure 7: micrograph showing homogenous activation- (Vac table specimen)

The laser techniques are effective for heating the tows. The preliminary results presented here show that the choice of laser type and its specifications (e.g. wavelength, intensity) are important. Damage to the binder and/or carbon fibres may occur. In figure 8 it is visible that the CO_2 laser has oxidised most of the binder particles from the fibre surfaces.

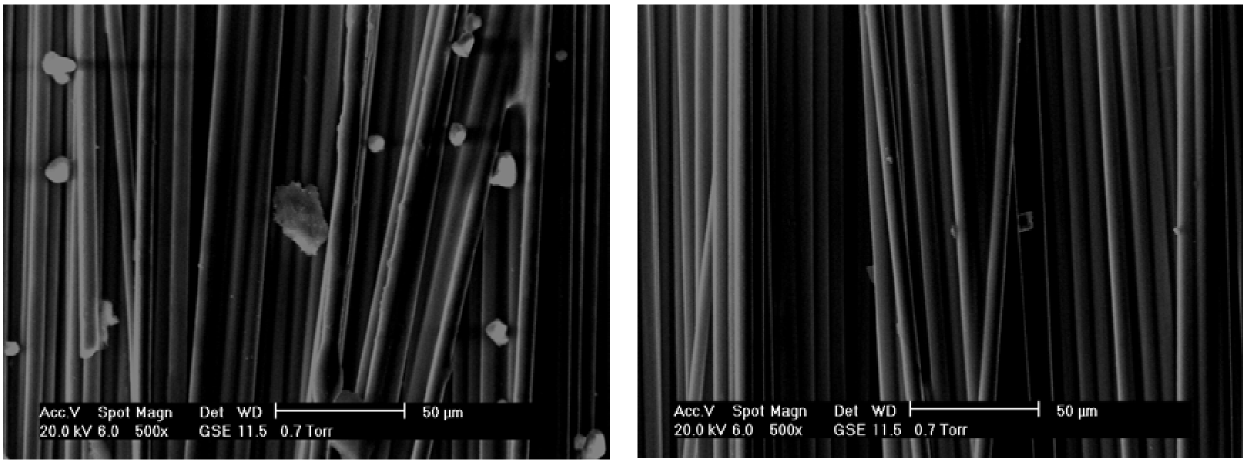

Figure 8: Difference in binder count, non-activated region (left) and activated region (right) of specimen activated with CO_2 laser.

The Nd:Yag laser used in these trials resulted in some damage to both binder and carbon fibres as shown in figure 9.

The samples activated using an Argon laser show the greatest potential. The activated area is visible in Fig. 10 (darker area). A higher magnification micrograph (Fig. 11) shows that the binder has started to diffuse within the fibres.

It is thought that further investigation of laser heating parameters may overcome the binder and fibre damage issues.

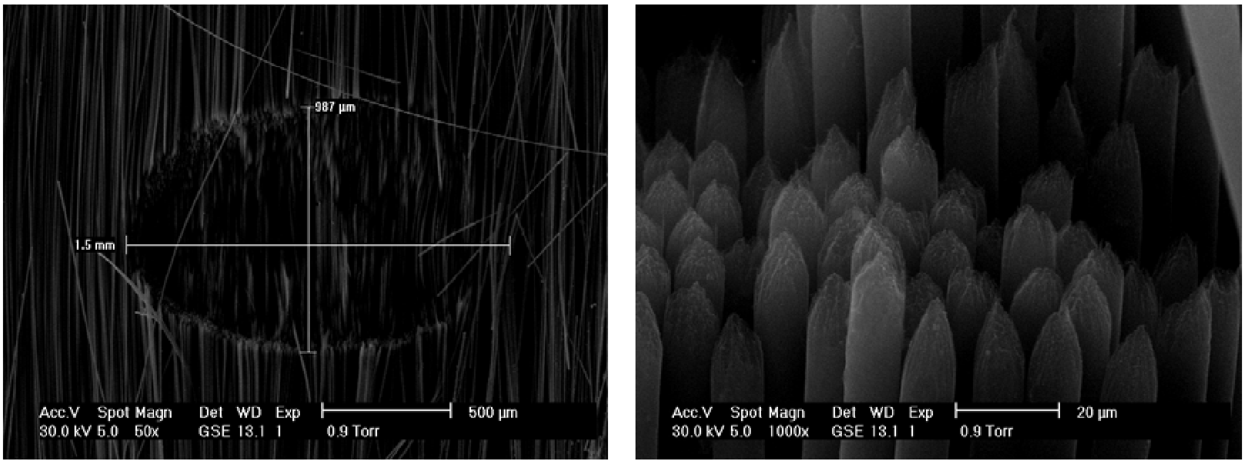

Figure 9: Damage introduced by the Nd:YAG laser.

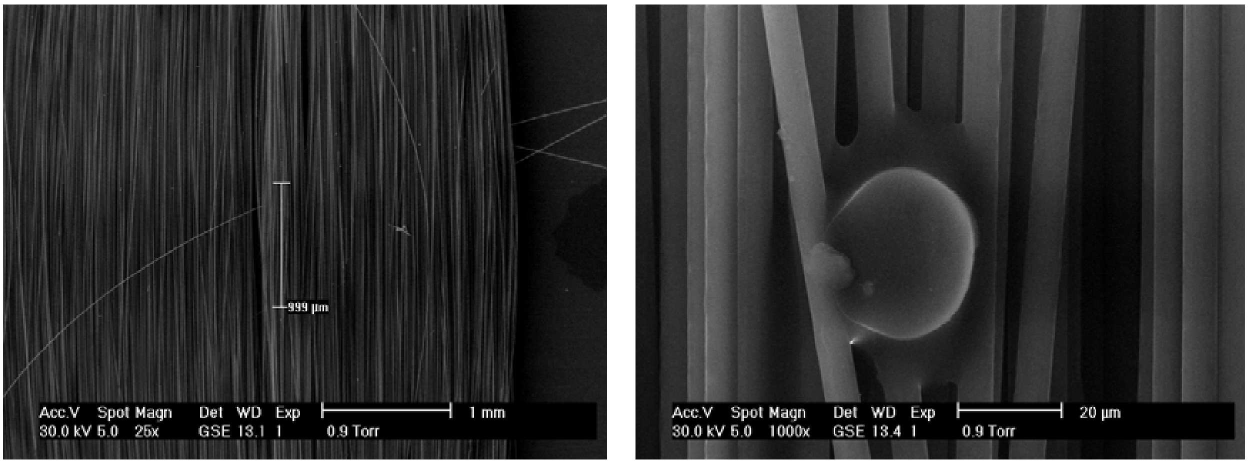

Figure 10 and 11: Activation using an Argon laser.

The use of ultrasonic equipment showed considerable fibre damage. Figure 12 And 13 show the damage introduced to the sample when using the ultrasonic horn available at Cranfield. It is possible that a modified design of head would reduce the damage, but the UAZ™ ultrasonic generator in its current format is not considered as effective as direct heating methods.

Figure 12: damage by US visible as widened tow structure.

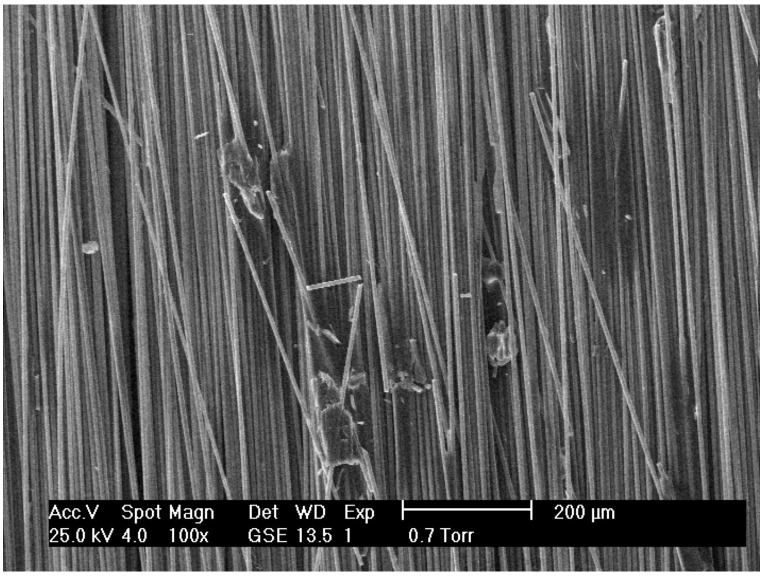

Figure 13: SEM from top tow of a US made specimen, broken filaments visible

5. CONCLUSIONS

A wide range of preform heating and compaction techniques were set up and evaluated.

The most effective technique for fabric heating is considered to be an electrically heated vacuum table.

Laser heating has the potential to damage binder coated carbon fibre tow through vaporising either the binder or fibres or both.

For tow fixing with robot deposition as for ATP, argon laser heating is shown to be an effective technique. Further technique development and assessment is required.

Ultrasonic techniques have the tendency to damage fibres since they rely on vibration and hence friction to generate heat and are therefore unsuitable for preform compaction.

Activation using conventional microwave ovens poses health and safety concerns.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. PreCarBi Proposal No. 30848; April 2006.
2. Partridge, I.K. and Cartié, D.D.R., "Delamination resistant laminates by Z-Fiber® pinning: Part I manufacture and fracture performance", C*omposites: Part A*, 2005;36:55-64.