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Influence of the Process Parameters on Shear Cutting of UD Prepregs

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Abstract **- The quality of edges formed during cutting and slitting of thin polymer webs is important for many industrial applications. To control the edge quality of the separated material, it is necessary to understand cutting. Experiments were conducted on UD thermoplastic and thermosetting prepregs. The slitting speed, tension in the web and angle of cut were varied during tests. This allowed a quantitative understanding of the cutting mechanisms to be established.**
Next, the prepreg was shear cut by two rotating circular knives. In the first part of this paper, a microscopic evaluation of the sheared edges of prepregs, cut under a variety of parameters. A particular cutting defect, namely the formation of different defect, is discussed. In the second part, a theory for the shear cutting process of prepreg and the related fiber formation is presented. Special attention is paid to the influence of the prepreg manufacturing parameters (applied in this study) on the behavior of the material during shear cutting.

Keywords— Slitting; shear cutting, UD prepreg;

I. INTRODUCTION

The use of prepregs has increased significantly in the last few decades. Thermoset prepregs with desirable tack and drape properties enable manufacturers to produce composites with complex shapes [1-20]. Even though the cutting is a common practice in processing the polymer prepreg, it is not that well known in the literature. Many standard tests are available to determine physical properties of polymers, and relatively few tests are available into the investigation of the slitting process.

The choice of the variables that affects the quality of the cut into the slitting technology is the most important into the process especially when it is needed for the tolerance of the width, especially when the slitted tapes is carried out in an automatic process of laying of each complex- constructive and expensive composite part for the aerospace or aviation industry. If the slitting and rewinding, and also the tolerance of the cutted tapes are with poor quality, which are the input parameters into the process of laying of some complex composite part it can cause defects into the process of the production. These defects into the AFP/ATL technology caused by input material can lead to big material and quality losses [21-26].

For that purpose, in this master thesis are explained, selected and defined all defects that can occur in the technology of slitting process. There are final conclusions which should be applied for quality cut into the technology of the slitting. At the end it is explained what defects can occur if the slitting is not good and with good quality into the AFP/ALT processes.

II. EKSPERIMENT

A. Materials and equipment

In order to determine the impact of the parameters on the quality of the cut of the unidirectional material were used following materials:

- Type 1 UD thermoplastic prepreg-type Barrdey PEKK- TU0300-145-AS4D-34-12.00 (Weight 145gsm, thickness 0.15mm),
- Type 2 UD thermoplastic prepreg-type Toray PAEK- T700GC 12K 91N, 34% RC (Weight 194gsm, thickness 0.2mm),
- Type 3 UD thermoset prepreg-type, TCR-T700SC-12K-50C (weight 186gsm, thickness 0.22mm) and
- Type 4 UD thermoset prepreg-type, Hexcel M21 / 34% / UD194 / IMA-12K / 300ATL (weight 294gsm, thickness 0.2mm).

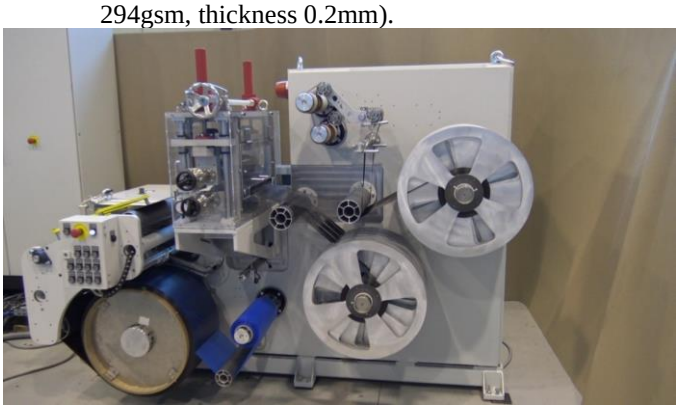

Fig. 1 Machine for shear slitting of UD prepreg tapes (Mikrosam D.O.O.)

UD prepregs has been provided by the laboratories of IACR - Prilep, R.N. Macedonia. In this study, samples were slit by using an equipment for slitting of prepreg, manufactured from Mikrosam.D.O.O., R.N.Macedonia. The basic image of the process is presented on the following Fig 1 and Fig 2.

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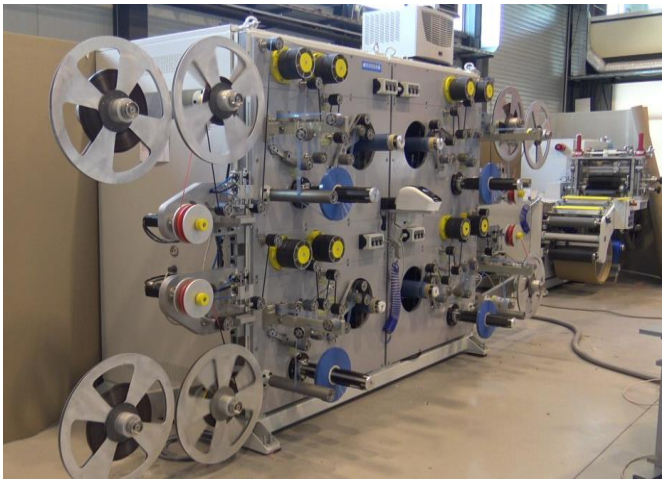

Fig.2 Machine for parallel rewinding of slit tape UD prepreg (Mikrosam D.O.O)

B. Shear cutting and working

This slitting method uses two rotary knives to produce the same cutting effect as obtained by pushing a pair of opened scissors through a sheet of paper. It is used for slitting heavier gauge material such as thicker film/sheet, paper, foil, prepreg and most laminates.

The benefits of this method include accurate slit widths and close tolerances. The setup for this method needs to be extremely precise and requires achieving an ideal angle at the junction of the blades.

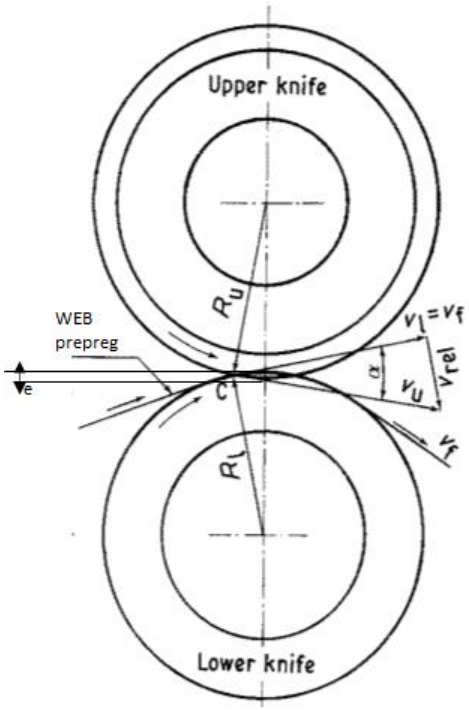

Fig. 3 Set up for the shear cutting of Prepref (web) **Ru** and **Ri** are the diameters of upper and lower knife, respectively, **Vu** and **Vi** are the respective peripheral velocities at the intersection of the knife edges (point C) and **Vrel** is the relative velocity of the upper knife vf is the prepreg velocity , **α** is cutting angle and **e** is overlape distance

The prepreg was shear cut in longitudinal direction by two rotating circular knives (Fig. 3). The lower knife has a cylindrical shape and carries the prepreg during the cutting process. The upper knife has a dish-like shape. The two knives have a minimum overlap distance to avoid damage while rotating [12]. Overlap distance and knife diameters determine the cutting angle (Figs 3 and 4). Continuous but elastic contact between the knives was realized with a compressive spring mounted on the upper knife axis: a clearance [13] between the upper and lower knives must be avoided [12], to prevent the highly compressible prepreg from being pinched between the knives instead of being cut by them. A rounding off at the right part of the lower knife, called the shoulder, avoids damage to the prepreg caused by folding. The upper knife is characterized by a knife angle at its tip. It rotates at a higher peripheral velocity than the lower one, to obtain a relatively vertical penetration into the prepreg (Fig. 3) [12].

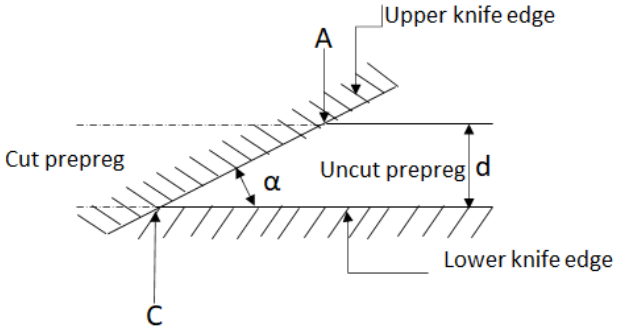

Fig. 4 Detailed shematic view at point C of Fig 3; d is the prepreg thickness

C. Various defects in shear cutting.

As one of the factors that affect the quality of the cut strips for UD thermoset dressing is the room temperature which should be maintained from 18 °C to 23 °C degrees to reduce the adhesion of the resin from the dressing on the blades and thus after a certain period lead to poor quality of the material and even the material cannot be cut at all. For this purpose, when cutting thermosetting prepregs, it is recommended to maintain a lower temperature in the room where the machine is located.

Fig. 5 shows various defects in shear cutting Fig. 5 a) shows a cut band of 6.35 mm. From the picture it can be seen that the cut ends are not flat. The reason for this defect can be the high tension when winding the cassettes, as well as the high temperature of about 30 °C when cutting the material. Figure 3b) shows that some of the strips are not cut at all. This is due to the fact that the overlap between the blades was about 0.4 mm, which is not enough to cut this type of material. Fig. 5 c) shows that the cut strips are not flat along the entire length but are cut like a snake. This is due to the very low tension in the system leading to axial displacement of the material in this system. Fig.5 d) shows a badly cut tape, which is due to a damaged knife that repeatedly led to the same tape not being well cut. Fig.5 e) shows twisted cut strips resulting from a large cutting angle of 1 °. Fig. 5 f) shows uncut foil during the sliding process. From the picture it cannot be noticed that in this case the UD preform is cut but the foil remains uncut which leads to a halt in production. To solve this problem the lateral side pressure was increased from 0.7mm to 0.9mm, after this problem was completely solved.

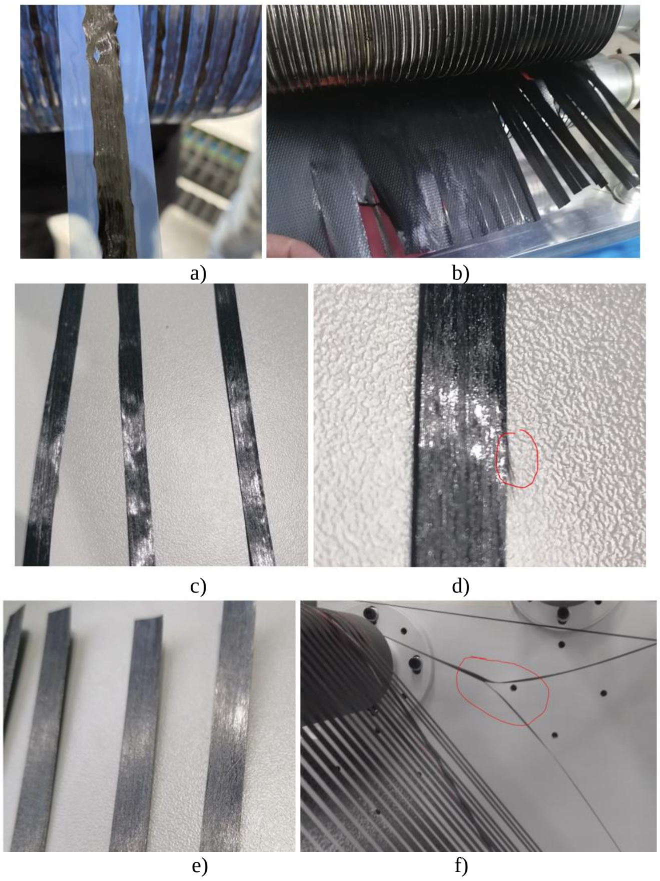

Fig.5 Different types of defects with shear cutting

D. Several factors

The quality of the cut strips for UD thermoset and thermoplastic dressing is influenced by several factors, and the most important can be singled out:
- cutting angle,
- determining the overlap of the blades,
- determination of lateral pressure,
- the sharpness of the knives,
- the material and shape of the knives, as well as voltage control tension the system and
- line speed control.

The standard width tolerance for cut strips commonly used in automatic fiber laying technology is from +/- 0.125mm to +/- 0.127mm.

III. RESULTS AND DISSCUSION

A. The overlap between the upper and lower blades

One of the many factors that are crucial for the good quality of the cut strips, and as mentioned several times in the previous chapters, is the determination of the overlap between the upper and lower blades.

TABLE I. SHEAR SLITTING EXPERIMENT ON UD THERMOPLASTIC PREPREGS WITH DIFFERENT OVERLAP.

	Factors			
Material	**overlap (mm)**	**Angle between the knives (°)**	**Lateral pressure (mm)**	**wide of tape (mm)**
Type 1	0.6	0.3	0.9	6,4
	0.6	0.3	0.9	6,45
	0.6	0.3	0.9	6,45
	0.8	0.3	0.9	6,45
	0.8	0.3	0.9	6,5
	0.8	0.3	0.9	6,45
	1	0.3	0.9	6,45
	1	0.3	0.9	6,47
	1	0.3	0.9	6,47
Type 2	0.6	0.3	0.9	6,47
	0.6	0.3	0.9	6,48
	0.6	0.3	0.9	6,48
	0.8	0.3	0.9	6,46
	0.8	0.3	0.9	6,45
	0.8	0.3	0.9	6,45
	1	0.3	0.9	6,46
	1	0.3	0.9	6,45
	1	0.3	0.9	6,48

TABLE II. SHEAR SLITTING EXPERIMENT ON UD THERMOSET PREPREGS WITH DIFFERENT OVERLAP.

	Factors			
Material	**overlap (mm)**	**Angle between the knives (°)**	**Lateral pressure (mm)**	**wide of tape (mm)**
Type 3	0.6	0.3	0.9	/
	0.6	0.3	0.9	6.4
	0.6	0.3	0.9	6.42
	0.6	0.3	0.9	6.34
	0.6	0.3	0.9	6.4
	0.8	0.3	0.9	6.45
	0.8	0.3	0.9	6.42
	0.8	0.3	0.9	6.42
	1	0.3	0.9	6.4
	1	0.3	0.9	6.4
	1	0.3	0.9	6.45
Type 4	0.6	0.3	0.9	6.45
	0.6	0.3	0.9	6.45
	0.6	0.3	0.9	6.45
	0.8	0.3	0.9	6.45
	0.8	0.3	0.9	6.45
	0.8	0.3	0.9	6.45
	1	0.3	0.9	6.45
	1	0.3	0.9	6.45
	1	0.3	0.9	6.45

B. Choice of lateral side pressure between upper and lower blades

As standard parameters for the entire duration of this experiment were taken angle of 0.3°, overlap between the blades of 0.8 mm and tension winding from 3 to 5 N/cm. This material was cut with lateral pressure of 0.5mm, 0.7mm and 1mm. The results of the tape width measurements are given in tables III and IV.

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TABLE III. SHEAR SLITTING EXPERIMENT ON UD THERMOPLASTIC PREPREGS WITH DIFFERENT SIDE LOAD FORCE

Factors				
Material	**Lateral pressure (mm)**	**Overlap (mm)**	**Angle between the knives (°)**	**wide of tape (mm)**
Type 1	0.5	0.8	0.3	6.45
	0.7	0.8	0.3	6.47
	0.7	0.8	0.3	6.45
	0.7	0.8	0.3	6.47
	1	0.8	0.3	6.47
	1	0.8	0.3	6.48
	1	0.8	0.3	6.47
	1	0.8	0.3	6.47
	1	0.8	0.3	6.47
Type 2	1	0.8	0.3	6.45
	0.7	0.8	0.3	6.45
	0.7	0.8	0.3	6.47
	0.7	0.8	0.3	6.47
	0.5	0.8	0.3	6.43
	0.5	0.8	0.3	6.45
	0.5	0.8	0.3	6.4
	1	0.8	0.3	6.47
	1	0.8	0.3	6.47

TABLE IV. SHEAR SLITTING EXPERIMENT ON UD THERMSET PREPREGS WITH DIFFERENT SIDE LOAD FORCE

Factors				
Material	**Lateral pressure (mm)**	**Overlap (mm)**	**Angle between the knives (°)**	**wide of tape (mm)**
Type 3	0.5	0.8	0.3	6.45
	0.5	0.8	0.3	6.45
	0.5	0.8	0.3	6.47
	0.7	0.8	0.3	6.45
	0.7	0.8	0.3	6.45
	0.7	0.8	0.3	6.42
	1	0.8	0.3	6.45
	1	0.8	0.3	6.45
	1	0.8	0.3	6.48
Type 4	1	0.8	0.3	6.45
	1	0.8	0.3	6.48
	1	0.8	0.3	6.45
	0.7	0.8	0.3	6.47
	0.7	0.8	0.3	6.47
	0.7	0.8	0.3	6.45
	0.5	0.8	0.3	6.45
	0.5	0.8	0.3	6.45
	0.5	0.8	0.3	6.48

C. Choice of angle between the knives

The angle of grip of the blades does not affect the quality of the cut strips but has a great impact on the wear and damage of the blades. It is recommended that the grip angle should not be greater than 1° if we want to increase the lifespan of the blades. The recommended cutting angle is given in the table V.

TABLE V. DIFFERENT VALUE FOR CAN'T ANGLE BETWEEN THE KNIVES FOR DIFFERENT TYPES OF UD PREPREG

Type material	**PAW (gsm)**	**thickness**	**Angle between the knives**
Thermoset prepreg	100-150gsm	0.1 – 0.15mm	0.1° - 0.3°
	150-250gsm	0.15 – 0.25mm	0.3 ° - 0.4°
	250-300gsm	0.25 – 0.3mm	0.3 ° - 0.5°
Thermoplastic prepreg	100-150gsm	0.1 – 0.15mm	0.1° - 0.3°
	150-250gsm	0.15 – 0.25mm	0.3 ° - 0.4°
	250-300gsm	0.25 – 0.3mm	0.3 ° - 0.5°

D. Choice of linear speed

An experiment was made with different line speeds and cutting of different materials and the results are given in a table VI.

TABLE VI. EXPERIMENT FOR SHEAR SLITTING OF UD PREPREG WITH DIFFERENT LINEAR SPEED

No.	**Type material**	**speed m/min**	**results**
1.1	Type 3	5	Clean and quality cut
1.2	Type 3	15	Clean and quality cut
1.3	Type 3	40	Clean and quality cut
2.1	Type 1	5	Clean and quality cut
2.2	Type 1	15	Clean and quality cut
2.3	Type 1	40	Clean and quality cut

From the experiments performed with different line speeds and cutting of different materials, it can be noticed that the line speed has no role in the quality of the cut. With all speeds from 5m/min to 40m/min, you get well-cut strips and quality sec. However, it should be taken into account that the determination of the line speed depends on the type of material (whether it is sticky, whether there are frequent defects in the input material, whether there has already been experience with cutting that type of material, etc.).

V CONCLUSION

From the performed experiments for different types of materials with different parameters during cutting, the following conclusions were made:

- The most important factor in determining the parameters for cutting UD prepreg is the type of material to be cut
- The overlap of the blades (Overlap) should not change much for different thickness of the material. For almost all material thicknesses the overlap ranges from 0.6 to 0.8 mm. An overlap of less than 0.4mm can lead to poor material cut, even is not cut at all.
- The lateral pressure should increase with increasing material thickness and ranges from 0.6mm to 1.2mm.
- The grip angle between the knives is always the same and is about 0.3 ° regardless of the thickness of

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the material. In some of the experiments, an attempt was made to increase the grip angle from 0.3 ° to 1 °, but there was no difference in the quality of the cut. It is recommended that the grip angle should not be greater than 1 ° if we want to increase the lifespan of the knives.

- From the performed experiments it can be noticed that the line speed has no role in the quality of the cut. With all speeds from 5m / min to 40m / min, you get well-cut strips and quality sec.

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