RESEARCH ON THE DEFORMATION OF PREPREG TAPE INFLUENCED BY THE TEMPERATURE

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I. Introduction

Advanced composite material (ACM) is widely applied in areas of aeronautics, astronautics and national defense, due to its characters of low density, high strength-to-weight ratio and stiffness-to-weight ratio. To fulfill the requirement of higher product quality as well as the increasing demand, there is a growing trend in developing the low-cost and automatic ACM manufacturing technique [1-4]. The automated tape laying (ATL) technique is appropriate for the manufacturing of composite components in large size, for example, the structures of aircrafts [5]. The process of ATL is automatic and numerical controlled, as shown in Fig. 1[6]. This composites manufacturing method can greatly reduce the waste, lower the cost, raise the efficiency, and the most important of all, it can improve the properties of the product. For these reasons, nowadays, it is employed to produce composite components of airplanes in some developed western countries[5, 7-13].

Fig. 1: Automated tape laying head

The heating temperature of the prepreg tape is a key tape laying technic parameter, which affects the viscosity of the tape. Generally, the tape stickness becomes higher when the temperature increases, and it is easier to lay the tapes on the mold surface of different shapes. However, if the tape temperature is too high, the tape would be too sticky to dispatch the tape and backing paper. Besides, the resin fluidity in the tape becomes higher with the higher temperature. With the high tape laying press and high speed, the fluidal resin would be extruded out from prepreg tape. The higher preheating temperature would lead to poorer product quality undoubtedly. On the other hand, if the tape temperature is too low, the tape would be too dry for the resin to lay on the mould surface or the laid tape[14]. Therefore, the tape laying temperature is very important and need to be further studied.

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II. Theoretical analysis on tape deformation

The cross section of prepreg tape is shown in Figure 2, in which h is the tape-width and b is tape-thickness. It is assumed that the tape is in viscous state with the temperature in the ATL process. The pressure F from the roller was evenly distributed in the area of l in length and h in width. Formula (1) could be gotten from virtual work principal[15]. Formula(2) can be deduced from Formula (1) depending on the above assumption.

$$dW = \sum_{i=1}^{n} (F_{ix} d x_i + F_{iy} d y_i + F_{iz} d z_i) = 0 \quad (1)$$

$$F d b - 2 p S d h = 0 \quad (2)$$

Given $db << b$, then $S = lb$ and Formula (3) could be deduced from Formula(2).

$$p = \frac{F d b}{2 l b d h} \quad (3)$$

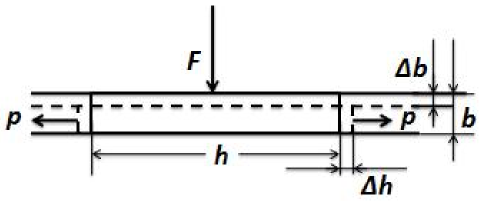

Fig. 2: Force analytical figure of the prepreg tape

Since the length is much longer than the width, we can consider the deformation in the direction of width alone. Assuming that the resin only flows from the center to the left and right sides equally, we can study the right side alone and regard laying tape as the flowing model between parallel plates (Fig. 3 and Fig.4) [16].

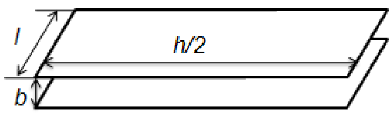

Fig. 3: Flowing Model between Parallel Plates

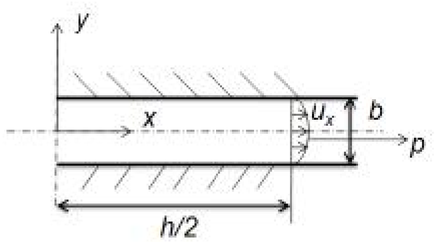

Fig. 4: Right section of the model

Assuming that $b<<h/2$, $b<<l$, i.e. the two plates are infinitely great.

The tape laying velocity could be gotten by formula(4).

$$u=[u_x(y),0,0] \qquad (4)$$

Formula(5) is boundary conditions.

$$u_x|_{y=\frac{b}{2}}=0,\quad \frac{du_x}{dy}|_{y=0}=0 \qquad (5)$$

The nontrivial component of the rate of strain tensor is described as formula(6).

$$\nabla_{xy}=\nabla_{yx}=\frac{\partial u_x}{\partial y} \qquad (6)$$

The nontrivial component of the rate of stress tensor is described as formula(7).

$$t_{xy}=t_{yx}=h\frac{\partial u_x}{\partial y} \qquad (7)$$

The X component of Simplified kinetic equations would be gotten as formula(8).

$$0=-\frac{\partial p}{\partial x}+\frac{\partial t_{yx}}{\partial y} \qquad (8)$$

The Y component of Simplified kinetic equations would be gotten as formula(9).

$$0=-\frac{\partial p}{\partial y} \qquad (9)$$

As to the flowing behavior in one dimension, constitutive relationship can be simplified as formula(10), if the fluid is power-law fluid [17]:

$$t=k\dot{g}^{n} \qquad (10)$$

k is consistency factor of the fluid and its dimension is $Pa\cdot s^n$, and n is non-Newtonian index. The larger k is, the higher the viscosity is. In this model, k and n can be considered as constants.

$$\dot{g}=\nabla_{yx}=\frac{\partial u_x}{\partial y} \qquad (11)$$

If $\frac{\partial p}{\partial x}=\frac{\Delta p}{h/2}$ and $\frac{\partial u_x}{\partial y}<0$, the result of Equation (4)-(11) would be:

$$u_x=\frac{nb}{2(1+n)}\left(\frac{pb}{kh}\right)^{\frac{1}{n}}\left(1-\left|\frac{2y}{b}\right|^{\frac{1}{n}+1}\right) \qquad (12)$$

Farther, volumetric flow would be gotten as formula(13).

$$Q=4\int_0^{\frac{b}{2}}\int_0^{\frac{l}{2}}u_x dzdy$$

$$Q=\frac{nb^2 l}{2(1+2n)}\left(\frac{pb}{kh}\right)^{\frac{1}{n}} \qquad (13)$$

Flow through per unit section could be described in formula(14).

$$\frac{Q}{l}=\frac{nb^2}{2(1+2n)}\left(\frac{pb}{kh}\right)^{\frac{1}{n}} \qquad (14)$$

Put equation (4) into equation (14), equation (15) would be gotten as follows.

$$\frac{Q}{l}=\frac{\mathrm{n}b^2}{2(1+2\mathrm{n})}\left(\frac{\mathrm{F}db}{2khld\,h}\right)^{\frac{1}{n}} \qquad (15)$$

Under the same tape laying pressure, F、l、db、dh remain constant. Without changing the type of the prepreg tape, b、h、n also remain the same. Therefore, the equation (15) implies that the flow through per unit section ($\frac{Q}{l}$) will increase if the temperature goes up, considering the consistency factor k decreases with the increasing temperature. In other words, higher temperature results lower resin viscosity and higher fluidity, and the tape-width deformation becomes larger with the tape laying pressure.

III. Experiment and discussion

To verify the theoretical analysis made before, the curve about tape-width and temperature should be studied by measuring tape-width with different temperatures. To get the curve, the prepreg tapes (bismaleimide resin, width: 150mm, thickness: 0.125mm) are laid down under a series of temperatures, without changing the tape laying pressure and velocity. The experiment is shown in Fig. 5. The result of the experiment is showed in Figure 6.

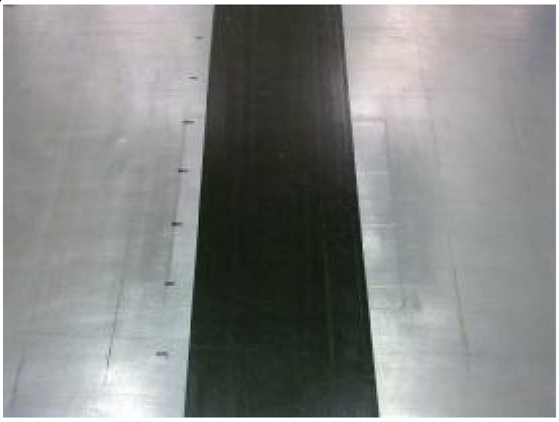

Fig. 5 The tape laying product

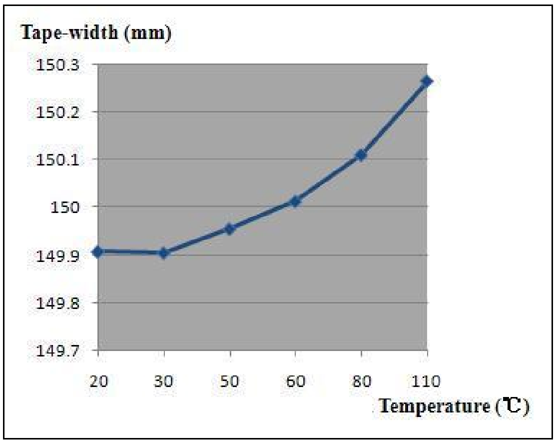

Fig.6 Prepreg tape-width under the influence of temperature

The change trend shown in Fig.7 agrees with the result from theoretical analysis. The tape width grows gradually with the ascending of the temperature.

There are two aspects of the prepreg tape performance, which outweigh the others in during the whole process of ATL. One is the laying situation, and the other is the covering situation. The laying situation means the adhesive situation between upper and under layer of prepreg tape, and between the tape and mold surface. It guarantees the interlaminar quality of the products. The covering situation means the situation of clearance or overlap between adjacent tapes. Fine covering situation indicates no clearance or overlap. It guarantees the layer quality of the final products.

The theoretical analysis and the experimental results both demonstrate that the tape-width would be influenced by temperature. To realize fine covering situation without clearance and overlap situation, different tape-width means different trajectory generation. Engineers can plan a better path for the tapes and achieve better products, by taking the tape deformation caused by temperature into consideration. On the premise of fine laying situation, composites supplier can manufacture better products if they would consider the deformation caused by temperature into manufacture process.

Therefore, the research on tape-width and temperature relationship is helpful for choosing moderate manufacturing temperature.

IV. Conclusions

The deformation of the prepreg tape influenced by the temperature is studied, especially the influence on tape width. It proved out that the width of the tape increased with the temperature, not only by theoretical analysis, but also by experiments. And the tape width affects the covering situation and the property of the products. Therefore, in order to manufacturing high-quality composite structures, it is necessary to find out the accurate relationship between the tape deformation and laying temperature, and in turn to optimize the laying path,.

With the achievements gained by now, the following work should be done as well: a. To Modify the model to predict the temperature to tape-width relationship more precisely; b. To test the mechanical performance of the products, which are laid up under different temperatures; c. To study the other factors which may influence the deformation of the prepreg tape, and then to optimize the ATL process and to improve the quality of composite structures.

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