Material Properties and Mold Folded Core Based on Ultra-violet Cured Resins

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Abstract: Ultra-violet(UV) curing is an efficient method for composite molding. Firstly, thermophysical properties of UV cured glass-fiber reinforced plastics are conducted. Material properties are studied for various kinds of post-curing modes. Then the UV curing method is suggested in manufacturing V-crimp folded core for sandwich panels. Two kinds of processing schemes for V-crimp folded core manufacturing using UV curing are presented. Finally, the effect of post-curing on the mechanical properties of folded core sandwiches is experimentally studied, and optimum modes of post-curing are determined. The experimental results show that the ultimate compressive strength of the folded sandwiches is increased by 60% after post-curing with the optimum post-curing mode.

Key words: glass-fiber reinforced plastic; composites; ultra-violet(UV) curing; V-crimp; strength of folded core

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0 Introduction

Pressure and temperature are two key processing parameters in most of composites molding methods. Application of these methods leads to several issues including large energy consumption, adoption of raw material intensive molding tools and expensive equipment. Besides, the duration of the processing cycle, which may take several hours, is another significant disadvantage. All these problems are associated with thermal compression molding methods (such as autoclave molding, press chamber molding, thermal expansion molding), as well as resin transfer methods (RTM). Therefore, efforts on seeking novel molding methods based on alternative physical principles are particularly imperative.

One concept for the composites molding that deserves attention is the method of ultra-violet (UV) curing, which is a chemical reaction induced by the energy of UV emission. There are two main kinds of photopolymerization, i. e., photochemical condensation reaction and polymerization induced by active center[1]. The essence of photopolymerization is the UV light-curing reaction and the consequent formation of the matrix which is cross-linked with polymer chains.

UV-cured compositions are widely applied in various industries. Application of UV-polymers for printing was explained by their ability to change their state from liquid into solid almost instantly[2]. In composite parts production, UV compositions were applied for rapid repair[3]. Application of these compositions in high efficient processes, e. g. pultrusion, was also studied[4]. Many researchers investigated combined UV curing and thermal curing as well as dark curing[5]. Application of UV-cured compositions with thermal accelerator provides higher degrees of conversion[6].

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This technology provides possibilities to implement new processing schemes for composite parts manufacturing, which are difficult to manufacture using conventional methods. One of such examples is synchronous production of folded core from reinforced composite materials. Advantages of UV curing application are the efficiency improvement due to high-velocity curing of the resin and the reduction of tool cost.

A possibility to manufacture lightweight folded cores using UV curing is studied in this research. This paper also dedicates to the selection of optimum post-curing mode to improve heat resistance property as well as compressive strength of sandwich panels with folded core. The work consists of three parts: Analysis of the properties of UV-cured materials to increase their strength, development of folded core manufacturing technology using UV curing and strength testing of folded core sandwich panels.

1 Material Properties at Various Curing Modes

In order to assess the applicability of UV-cured composites in aircraft structures, it is necessary to study the corresponding heat resistance property. Composite plates are manufactured using contact molding from biaxial fabric BX 450 and two types of UV curing resins (i. e. , Polylite PO-4761 and Norpol Dion 9300 UV) to determine the heat resistance property of UV-cured composites. Resins are cured using two methods: UV curing (UVC) and thermoset curing (TSC).

In the first case, composite is exposed in UV-cured unit (Fig. 1) for 3 min. The tooling is not heated.

In the second case, accelerator 9802 and catalyst MEK-11 are added to the resin in the amount which is recommended by the manufacturer. Samples are cured under the room temperature for 24 h.

Preliminary testing of UVC specimens demonstrates low mechanical properties of the composites. In order to produce specimens with higher quality, they are post-cured, i. e. , which are heated under various modes. The full list of modes of specimens manufacturing is presented in Table 1.

Fig. 1 UV-cured unit (General view)

Table 1 Modes of specimens manufacturing

No. of sample	Resin	Curing system	Post-curing
1	PO-4761	UVC	No post-curing
2		UVC	3 h at 80 ℃
3		UVC	1. 5 h at 130 ℃
4	9300UV	UVC	No post-curing
5		UVC	3 h at 80 ℃
6		UVC	1. 5 h at 130 ℃
7	PO-4761	TSC	No post-curing
8		TSC	3 h at 80℃
9		TSC	1. 5 h at 130℃
10	9300UV	TSC	No post-curing
11		TSC	3 h at 80℃
12		TSC	1. 5 h at 130℃

Testing of thermal mechanical properties of composite samples is performed using DMA Q800. The DMA method is proved to be suitable for the determination of heat resistance of UV compositions[7]. It is a sensitive method of interpenetrating networks analysis, which may appear when UVC and TSC are combined[8-9]. Heat resistance testing of composite samples is performed in compliance with ASTM D 4065. Elasticity modulus decrease, which corresponds to the glass transition temperature (T_g), is taken into consideration. Three specimens are considered for each series of testing. Due to the fact that the difference between the results within one certain series is less than 3%, the average values are used to create the diagrams below. Fig. 2 illustrates comparison of thermal mechanical graph of PO-4761 based composite cured in an UV unit and using a thermoset system. The elasticity modulus and the damping ratio of loss modulus to storage modulus tanδ are shown, respectively. From Fig. 2 to Fig. 5, the temperatures marked for elastic modulus curves means T_g determined at the beginning of elastic modulus decrease, while the temperatures marked for tanδ curves means T_g at the tanδ curves' peaks.

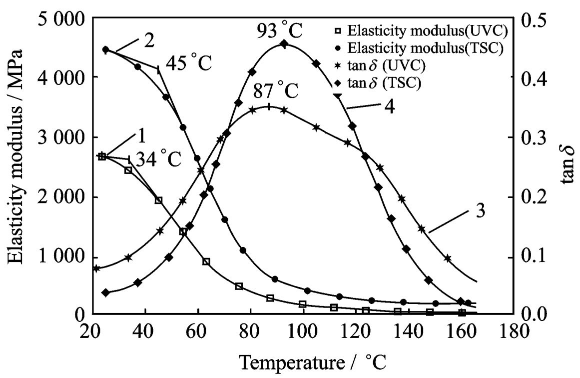


Fig. 2 Thermal-mechanical curves of PO-4761 based composite

Fig. 3 illustrates comparison of thermal mechanical graph of 9300UV based composite, cured in a UV unit and using a thermoset system.

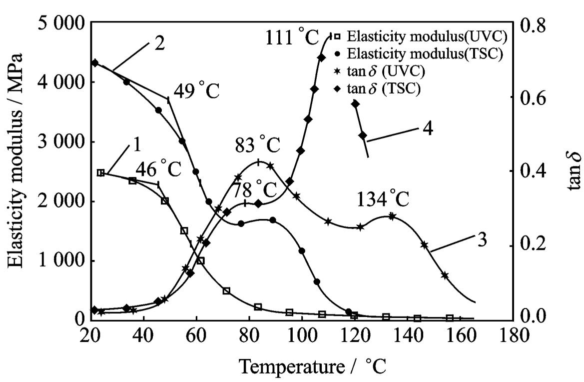


Fig. 3 Thermal- mechanical curves of 9300UV based composite

In compliance with ASTM D 4065, glass transition temperature is determined based on the intersection of tangents at the moment of elasticity modulus decrease onset (Curves 1, 2). As shown in Figs. 2, 3, the elasticity modulus and glass transition temperature under UV curing (Curve 1) are lower compared with those cured with thermoset system (Curve 2). It should also be noted that the presence of multiple peaks in the curves of tanδ (Curves 3, 4) indicates the heterogeneity of physico-chemical property of the obtained composite samples. This phenomenon might be related to the incomplete curing of the resin.

To improve the physics mechanics property of composites, post-curing at 80 ℃ for 3 h are recommended by the resin manufacturer.

Analysis of tanδ curves of studied composite samples demonstrates that, at the recommended curing modes (Figs. 4, 5), the resin properties are not fully realized. It is found that the recommended curing modes cannot provide virtual heat resistance. At the same time, Ref. [10] explains that it is necessary to heat polymer to the temper-

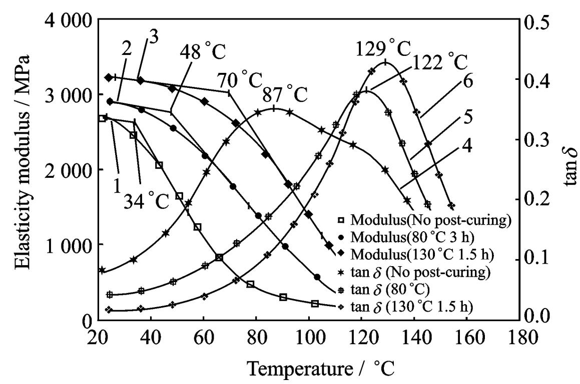


Fig. 4 Thermal mechanical curves of UVC PO-4761 based composites with various modes of post-curing

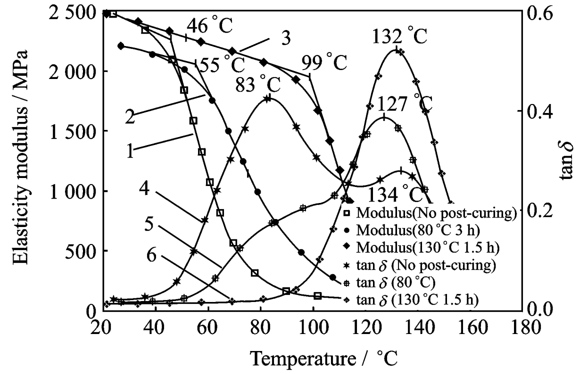


Fig. 5 Thermal mechanical curves of UVC 9300UV based composites with various modes of post-curing

atures higher than the end point of its glass transition temperature in order to be fully cured. That is why post-curing temperature of 130 ℃ is chosen for both types of resins. Experiments are carried out to determine the post-curing time. Samples are post-cured at 130 ℃ for 0.5, 1, 1.5, 2 and 2.5 h, respectively. According to the previous experiment results, the heat resistance does not change significantly after 1.5 h. Therefore, the mode of post-curing at 130 ℃ for 1.5 h is chosen for the following study. Fig. 4 demonstrates thermal mechanical curves of composites based on UVC resin PO-4761 with various modes of post-curing.

Fig. 5 shows thermal mechanical curves of 9300UV based composites, cured in an UV unit with various modes of post-curing.

Comparisons of the glass transition temperatures for composites molded at various modes are presented in the form of histograms, as shown in Fig. 6. It shows that the heat resistance of the GFRP composites post-cured at the 130 ℃/1.5 h mode is nearly doubled compared with those without post-curing for both kinds of resins. It can be concluded that post-curing is a must in order to achieve complete polymerization during UV curing reaction.

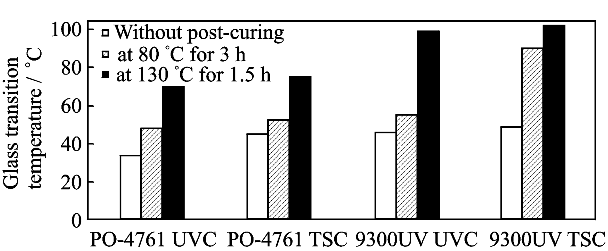


Fig. 6 Glass transition temperature comparison diagram for PO-4761 and 9300UV based composites at various post-curing modes

2 Development of Technology for V-crimp Production Using UV Curing

It is possible to switch to the research in the domain of folded cores manufacturing technology once physics mechanics properties of these materials are obtained. Compared with the classical curing scheme, the physics mechanics properties of these materials are improved via post-curing mode optimization.

Elementary V-crimp based folded structure is considered at this preliminary stage[11]. However, the technology described in this paper can be applied to the whole variety of folded core structures[12-13].

A scheme of synchronous prepreg folding is selected for research purposes[14-15]. A blank of material is folded along all marking lines at the same time. The process scheme is shown in Fig. 7.

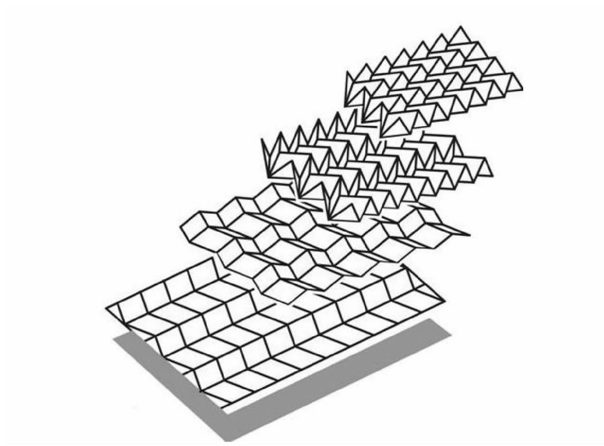


Fig. 7 Transformation of a plain prepreg into a relief structure via synchronous folding

Considering the features of UV curing, two methods of synchronous folding are developed.

The first method supposes to produce the V-crimp from prepreg using transformable matrices[15]. The scheme is demonstrated in Fig. 8. Firstly, prepreg is placed between two transformable Matrices 1, 2. Matrices are then folded and exposed to UV emission. After curing, the finished V-crimp folded core is extracted. To perform UV curing, matrices have to be UV transparent. Such material is found experimentally. Faces of matrices used in the experiment are made of this material.

The other method is illustrated in Fig. 9. A template is placed on prepreg. The template consists of narrow strips, which are aligned with marking lines. Then the prepreg is exposed to UV light. Faces become hard while the prepreg under the template strips stays uncured, so that it

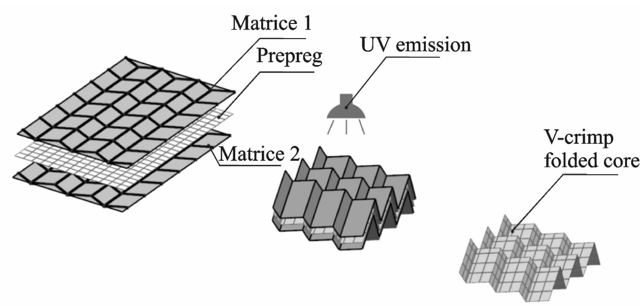


Fig. 8 Scheme of V-crimp manufacturing using transformable matrices

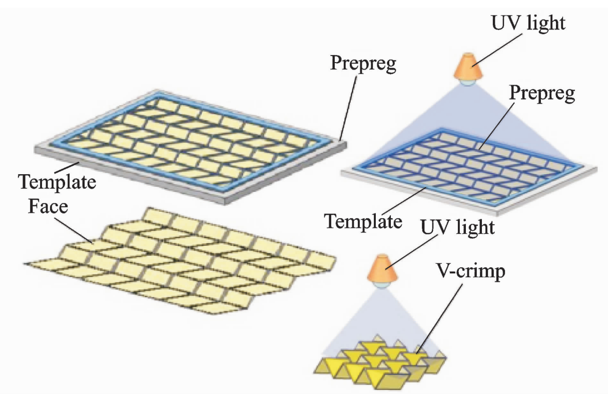


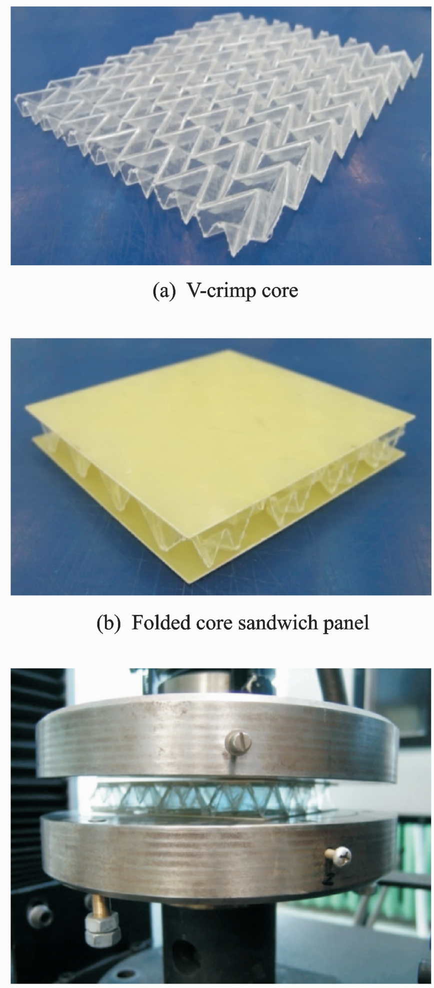
Fig. 9 Scheme of V-crimp manufacturing using UV curing and template

can be folded into a V-crimp with given dimensions along soft marking lines. Finally, the ribs are cured with UV light 4.

Comparing these two methods, we may assume that the second scheme is preferable, since faces are cured in a planar state orthogonally by UV light. Thus, the structure is cured better. Besides, the second scheme can be applied in cyclic folded core manufacturing[16], where the prepreg is fed continuously.

3 Evaluation of Mechanical Strength of V-crimp Folded Core Based Panels

Samples of V-crimp are produced using two translucent matrices at this stage, as shown in Fig. 10(a). To confirm results obtained earlier and determine the relation between the mechanical strength of a folded core and post-curing, four samples of sandwich panels are manufactured for each type of post-curing mode, i. e., without post-curing and post-curing at 130 ℃ for 1.5 h. A typical panel sample is shown in Fig. 10(b). Samples dimensions are 130 mm × 140 mm × 20 mm. V-crimp density is 70 kg/m^3. Flatwise compression test of a folded sandwich sample is shown in Fig. 10(c).



(a) V-crimp core

(b) Folded core sandwich panel

(c) Testing of sample sandwich panel

Fig. 10 Samples testing

The compressive failure load for these four folded sandwich samples are illustrated in Figs. 11(a,b), respectively. Fig. 11(b) shows the mean values for these two different modes of post-curing. It can be seen that the ultimate compressive strength is increased by 60% after post-curing.

4 Conclusions

Technological experiments demonstrate that the concept of V-crimp folded core manufacturing using two translucent matrices and UV-cured prepreg makes it possible to manufacture V-crimp

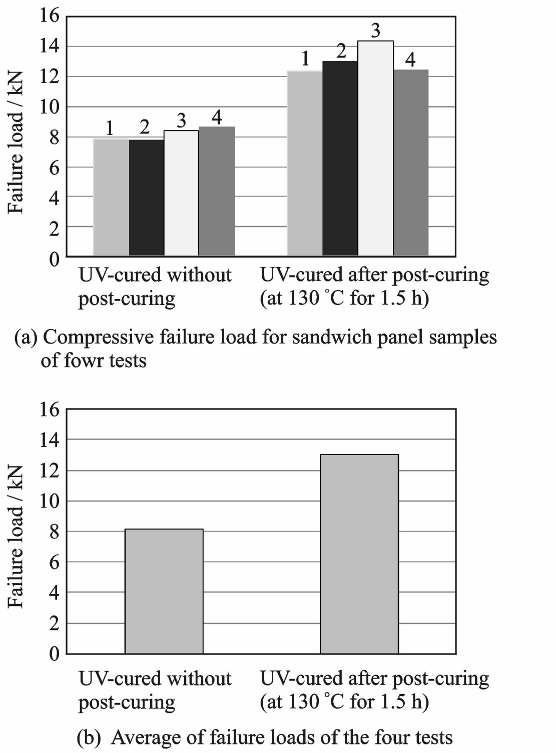


Fig. 11 Compressive failure load for sandwich panel samples and mean value in one post-curing mode

folded core from reinforced composites. It is found that these V-crimp samples have relatively poor mechanical properties according to earlier tests. Post-curing is performed to further improve the performance. The post-curing mode selected in this study can increase the compressive breaking load of folded core sandwiches by more than 60%.

The disadvantage is that the materials used in UV curing are limited. This method is suitable for molding of glass fiber reinforced plastic and basalt fiber reinforced plastic, but it cannot be applied to carbon fiber reinforced plastic.

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