DEVELOPMENT OF THE UV-CURED RTM PROCESS

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Abstract

An unprecedented composite manufacturing technology that can provide as high productivity as metal parts manufacturing is being explored. This approach applies a novel resin curing technique what we call " the Chain-curing system [1]" to the cure of composites in a closed mold through the conventional resin transfer molding (RTM) process. The self-persistent polymerization of the matrix resin of carbon fiber reinforced composites in a RTM mold initiated by ultraviolet (UV) irradiation has been demonstrated to realize the UV-cured RTM composites in extremely short time. The thermally related processing factors that can significantly influence the continuity of the cure have been identified and experimentally examined. The improvement of mechanical properties of the chain-curable matrix resin has also been addressed conducting coupon and component tests for the application to the airframe structures in near future, and their results indicates the reasonable application potential of the UV-cured RTM composites.

1 Introduction

Replacement of metals by composites in commercial aircraft prime structures has been rapidly increasing to achieve further structural weight saving and reduce fuel consumption with a background of globally soaring oil prices. However, the mainstream of composites manufacturing technologies has still been using autoclaves for curing and their production costs have been higher relative to metal components manufacturing. Thus, more efficiency in composites manufacturing has been strongly needed as well as reliability and stability in their quality. One promising way to meet the cost reduction demand is to utilize radiation energy for curing instead of thermal energy. The most widely explored radiation energy source has been Electron beam although it demands highly expensive facility for radiation to say nothing of its risk to health hazards. UV-curing techniques have also attracted attention as an efficient and prompt polymer curing method. However, the application to composites has been limited to GFRP because there has been an essential problem that UV light does not penetrate into carbon fibers. In order to break through the barrier, this study has been conducted over three years. The unique approach to fabricate aerospace composites using minimal energy in extremely short cycle time is detailed.

2 Outline of the UV-cured RTM

The UV-cured RTM process is an especially novel manufacturing technology that can provide aerospace composites in extremely short cycle time. It incorporates a kind of UV-curable resin technique; what we call "the Chain-curing system " into the conventional resin transfer molding process. In the Chain-curing system, the reaction heat of the photo-polymerization occurred by UV irradiation drives to the following thermal-polymerization, which can reach the whole part of the material as shown in Fig.1. The whole cure of the resin poured into a container of 40 mm in diameter and 40 mm in depth was completed in 2 minutes after UV irradiation to the top surface.

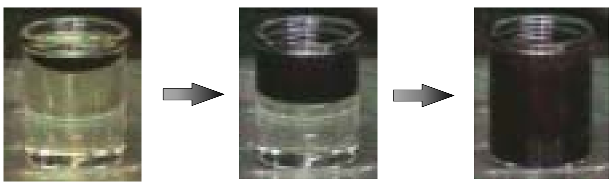

Fig. 1. The chain-curing behavior

This type of self-persistent cure is applicable for curing composites in a closed mold as in RTM process if it can continue under carbon fabric's presence. Fig.2. illustrates a schematic image of the

UV-cured RTM. Just with a few minutes of UV irradiation through a glass window at one side of the RTM mold, the cure continuously propagates toward the other side.

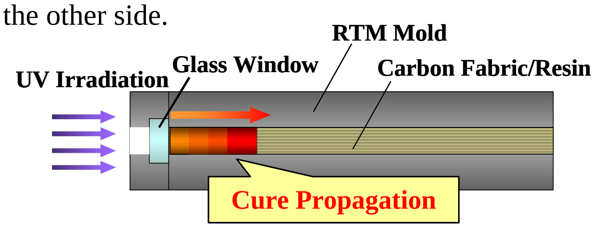

Fig. 2. Schematic image of the UV-cured RTM

3 Processing Conditions

Studies had been made on the Chain-curing continuity for a chain curable resin infused carbon fabric with several fiber volume fraction (Vf), and the results pointed out that it was significantly influenced by thermally related factors such as the resin exothermy of the polymerization reaction, the heat conductivity of the mold, and the heat dissipation into the reinforced fibers. So, their importance was examined more closely focusing on the exothermic reaction property of the resin, and heat transfer conditions between the resin and the mold.

3.1 Resin Exothermic Property

The three factors; (a) the exothermic speed (b) the amount of exothermic heat (c) the cure starting temperature, were considered for the exothermic reaction property of the chain curable resins based on their DSC measured curve. Preparing three levels of Resins for each factor, flat panel composite fabrication experiments for three different Vf values were conducted. The chain curing continuity was evaluated for each case by the changes in the temperature of thermocouples mounted in the fabric's interlayer. As a result, the exothermic speed was found to have greatest effect on the chain cure progress, while other two factors also considerably influence it.

3.2 Heat Transfer in the Curing System

Two ways of changing heat transfer conditions were attempted to assist the chain curing continuity. One was to sandwich a wood plate with significantly low heat conductivity between the carbon fabric/resin and the metal mold in order to mitigate heat dissipation. The other was preheating the mold so that the cure starting temperature could be easy to reach. Both approaches resulted in remarkably contributing to the cure progress.

3.3 Processing verification

Through a set of experimental examinations described above, it has been becoming clear that maintaining the heat balances in the mold in order that the heat generation speed at the front of the chain cure can be superior to the heat dissipation speed to the carbon fabric and the outer mold is necessary for the cure to stably propagate. Based on those findings, the processing conditions have been specified for continuously Chain-curing carbon/epoxy composites over 50% Vf. A z-section composite frame member was fabricated for the purpose of verifying processability and extracting problems. 1000 mm long composite with 50% Vf was cured in about 10 minutes by the UV-curing RTM technology As shown in Fig. 3.

Fig. 3. Z-section composite frame member fabricated by UV-cured RTM process

4 Structural Component Evaluation

4.1 Testing Specification

The application target of the UV-cured RTM has been considered to be such components as fuselage frames of commercial aircrafts in terms of the production volume and the dimensional accuracy demands that RTM process can meet. On the other hand, their shapes that have relatively constant cross section help to ensure the stable heat balance in the molds. Thus, composite frame members of a middle class commercial aircraft were chosen for component evaluation fabricated by the developing technology, and the critical mechanical properties were estimated. As shown in Fig.4, the frame members are mainly required to have enough stiffness to maintain the fuselage cross sectional shape. Therefore, flexural loading test were planned for the component evaluation.

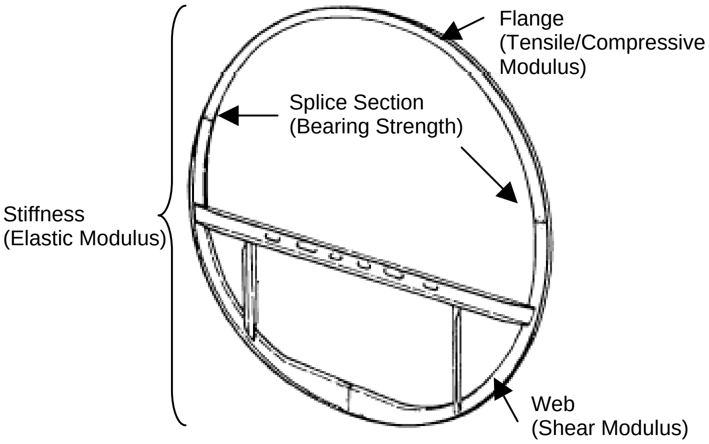

Fig.4 Critical mechanical properties for fuselage structure

4.2 Material Mechanical Properties

Mechanical properties improvement of the chain-curable matrix resin up to currently used epoxy resin systems for aerospace use is not easy to achieve because that might have a considerable effect on the processing parameters such as the chain curability and the resin viscosity. Our approach was to improve resin breaking strain while maintaining the heat resistance property in addition to those processing parameters described above. Then, the mechanical properties of the UV-cured RTM composites were obtained by the laminate coupon tests. The results in Table.1 indicated that further improvement of the resin flexibility and toughness are necessary.

Table 1. Laminate mechanical properties of UV-cured RTM composites

Mechanical Properties		Results
Tensile	Strength (MPa)	378.6
〃	Modulus (GPa)	46.0
Compressive	Strength (MPa)	402.4
〃	Modulus (GPa)	43.0
Bearing	Strength (MPa)	532.1
CAI *	Strength (MPa)	98.7

*Energy level: 6.7J/mm

4.3 Flexural Testing Results

Fig.6 shows a test specimen of frame members with 700 mm in length and 1.7 mm in thickness that have C-shaped cross section. Compressive force was loaded from the two points as shown in Fig.6 and Fig.7 and the relationship between the displacement and the force was measured. As a result, the both tensile and compressive modulus calculated from the measured data were in good accordance with the coupon test results, which demonstrated the process applicability.

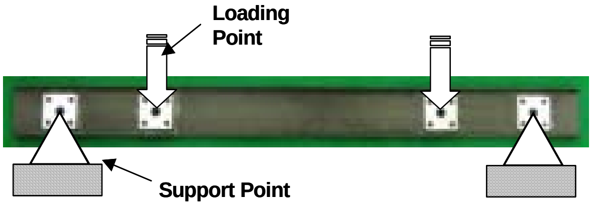

Fig.6 Testing specimen

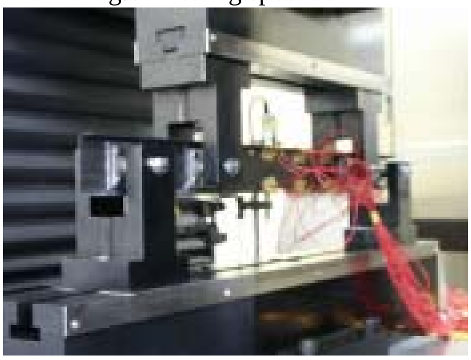

Fig.7 Flexural testing

Conclusion

An unprecedentedly high productive composite manufacturing technology has been under development by taking advantages of the Chain-curing system. After specification of the processing parameters, the technology has been advanced to structural component evaluation, while addressing the mechanical property improvement of the resin.

Acknowledgement

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References

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