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A study on the process design of prepreg compression forming using rapid heating and cooling system

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Abstract

Prepreg compression forming(PCF) is well known for the manufacturing process with high mechanical properties, low equipment cost and high surface quality. Generally, the temperature difference and rapid heat transfer between the tool and laminate can lead to some problems such as heat distortion, low formability and bad surface quality. Therefore, this paper attempts to solve these problems by using the rapid heating and cooling device, similarly to injection molding. It is possible to heat the tool above T_g and cool it down under T_g within few minutes. Also, the defect of distortion is prevented by rapid cooling system. In this study, the manufacturing process of CFRTP B-pillar reinforcement was designed based on structural analysis and thermal forming analysis. First, the thickness of laminate satisfying the energy absorption of conventional steel product was determined through structural analysis. Second, the thermal properties of the prepreg was evaluated for the thermal forming analysis. The thermal forming analysis of CFRTP laminate was carried out to determine the holding force. Finally, B-pillar reinforcements of CFRTP were fabricated and evaluated their dimensional accuracies and shear angle.

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Keywords: CFRTP; Prepreg compression forming(PCF); Rapid heating and cooling system; B-pillar reinforcement; Heat transfer; Thermal forming analysis;

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1. Introduce

Recently, due to steadily research and developments for manufacturing of low priced carbon fiber, CFRP is applied to mass production of automotive parts. Many researchers have been studying to develop the manufacturing process of CFRP products for short cycle time. PCF process with a high production rate and low cost is that the prepreg is laid on the mold and a shaped charge to facilitate rapid loading in heating tool. However, the temperature difference, rapid heat transfer between the tool and laminate, and cooling time of tools can lead to some problems such as heat distortion, low formability, bad surface quality and decreased production time[1]. Therefore, this paper attempts to solve these problems by using the rapid heating and cooling device, similarly to injection molding.

Generally, rapid heating and cooling system were developed to remove the defect of distortion and reduce the produce time injection molding process[2]. It is possible to heat the tool above T_g and cool it down under T_g within few minutes. Wang et al.[3] studied that the packing time and holding pressure reduced the defect of distortion in injection molding process. Also, Akopyan[4] and Santis[5] said that distortion was reduced by the rapid heating and cooling system. Therefore, the rapid heating and cooling system is applied to the PCF process to improve the conventional problems.

In order to apply the rapid heating and cooling system to PCF process, the automobile part of B-pillar reinforcement and tools were designed based on structural analysis, computation fluid dynamics(CFD) analysis and thermal forming analysis. First, the thickness of laminate satisfying the energy absorption(EA) of conventional steel product was determined through structural analysis. Secondly, CFD analysis were performed to evaluate the heating and cooling time of tools. Also, thermal mechanical properties of the shear and the heat transfer were measured by picture frame test and inverse analysis. The conditions of holding force and tool temperature were determined through the thermal forming analysis. Finally, CFRTP B-pillar reinforcements were fabricated and evaluated their dimensional accuracies and shear angle and compare with the product manufactured by conventional PCF process.

2. Thickness decision of B-pillar reinforcement

2.1. Material

The material used in the present study is a commercial twill weave prepreg provided by SK Chemicals. The carbon fiber (MRC PYROFILTM TR30S 3K) used in the prepreg was fabricated by MITSUBISHI RAYON. The resin used in the prepreg is a polyester-based thermoplastic polyurethane with a T_g of 110℃. The thickness of the prepreg is 0.3 mm and the carbon fiber volume fraction and the density of prepreg were evaluated as 39.64% and 1.52 g/cm^2, respectively. To conduct a structural analysis of the B-pillar reinforcement, the mechanical properties of SPFC590 and CFRTP were obtained from tensile tests[6]; they are summarized in Table 1.

Table 1. Mechanical properties of SPFC780 and CFRTP.

Material	Properties	Values	Material	Properties	Values
CFRTP	E_1	40.35GPa	SPFC590	Elastic modulus	206GPa
	E_2	40.35GPa		Yield stress	480MPa
	υ_{12}	0.13		Elongation	21%
	G_{12}	9.51GPa		UTS	610MPa
	G_{13}	1.95GPa		Poisson's ratio	0.3
	G_{23}	1.95GPa			

2.2. Thickness of B-pillar reinforcement with required energy absorption

The structural analysis of the CFRTP B-pillar reinforcement was performed to evaluate their EA. The EA of the CFRTP B-pillar reinforcement whose thickness had the greatest effect on the EA was determined to be similar with the required value of conventional reinforcement. Fig. 1(a) shows the FE-model of a B-pillar reinforcement. To model real products assembled with automotive parts more accurately, fixed boundary conditions were imposed