RESIN IMPREGNATION OF CFRTP PREFORM BY USING ULTRASONIC WAVE

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Abstract
CFRTP (carbon fiber reinforced thermoplastics) is promising material for reducing the weight of automobile. However, it has not been applied to structural material of mass production automobile because impregnation and molding processes take long time and are expensive. Ultrasonic heating was proposed as a new method to heat material to high temperature in a short time and that makes it possible to perform impregnation of CFRTP preforms using ultrasonic heating. Then, we measured the temperature of CFRTP preform and performed three-point bending test to make clear the possibility. From experimental results, we indicated the potential of impregnation of CFRTP preform by using ultrasonic heating.

1. Introduction

In recent years, environmental and energy issues resulting from increase of the energy consumption become serious problems over the world. Especially, about a half of annual world oil products is consumed by automobiles. Since weight reduction of automobile is effective for not only improving fuel efficiency but also early spread of electric vehicles, CFRP (carbon fiber reinforced plastics) has recently been expected to be applied. CFRP can be divided into two types, CFRTP and CFRTS (carbon fiber reinforced thermosetting resin). Now, most of CFRP which is applied to structural material is CFRTS. But from a view point of application to mass production automobile, CFRTP has some advantages over conventional CFRTS such as excellent energy absorption capacity, short molding cycle and high recyclability. However most of these CFRTP technologies are derived from aerospace field, so they have not fully developed yet for mass production automotive application.

In this study, we focused on the resin impregnation of CFRTP preform because the resin impregnation before molding was necessary to realize both high cycle molding and superior mechanical properties. However, it takes long time to produce CFRTP preform by conventional methods, so the price of the preform is expensive like CFRTS. In order to solve this problem, we proposed ultrasonic heating as an efficient heating method of CFRTP preform because ultrasonic welding is well known as very fast heating [1].

In order to make clear the potential of ultrasonic impregnation, we measured the temperature of preforms during ultrasonic heating and performed three-point bending test with specimens which were molded by ultrasonic heating.

2. Material preparation and experimental methods

2.1. Material preparation

UD75A and UD75C are UD (uni-directional) pre-preg sheets produced by MITSUBISHI RAYON Co., Ltd. Matrix resin of those pre-preg sheets is polypropylene. Specification of those pre-preg sheets is shown in Table 1. Impregnation rate of UD75A was known to be enough, hence production speed for UD75A is sufficient. On the other hand, production speed of UD75C was 4 times faster than that of UD75A as a trial material. So, impregnation rate of UD75C is assumed to be insufficient. In this study, CFRTP specimens are made by UD75C.

By cutting UD75C semi-preg sheet in the direction of 0° and 90°, we made 0° UD semi-preg tape and 90° UD semi-preg tape. In this study, three types of CFRTP preform are prepared for experimental study, which are 10-ply UD preform, 2-ply UD preform, and 10-ply CP (cross-ply) preform. 10-ply UD preform is prepared by laminating 10 plies of 0° UD semi-preg tapes, while 2-ply UD preform is composed of 2 plies of 0° UD semi-preg tapes. 10-ply CP preform is prepared by laminating UD semi-preg tapes in the direction of $[0°/90°/0°/90°/0°]_2$. Laminate configurations of each three types of preform are shown in Fig. 1.

Name	Type	FAW [g/m²]	V_f [%]	Thickness [μm]	Processing（production）speed
UD75A	UD	75	45	93	Normal speed for fully impregnated pre-preg
UD75C	UD	75	Depends on impregnation degree		4 times faster than UD75A

Table 1 Specification of two types of pre-preg.

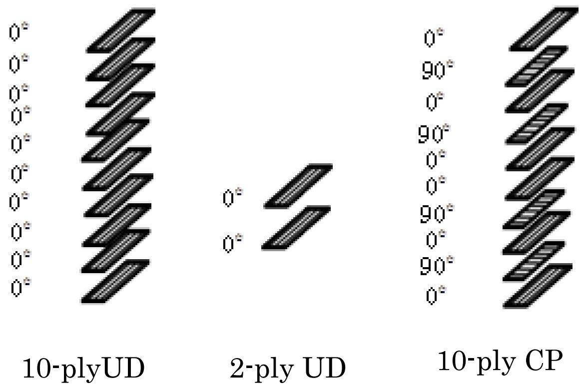

Fig. 1 Laminate configurations of three types of preforms.

2.2. Experimental methods

2.2.1 Temperature measurement of the preforms

In order to perform the impregnation of CFRTP, it is necessary to heat the resin up to its melting point and to keep a certain time under an appropriate pressure, which is usually called T-P-t relationship [2]. Higher temperature causes lower pressure and shorter time for impregnation, hence lower process cost. Therefore the heating condition should be investigated to impregnate as quick as possible under the precondition that the deterioration of the resin does not occur. IR heater is commonly used for preheating of high cycle molding since it is flexible for blank (preform) size and shape, and temperature control is easy. However it is too slow (more energy consuming) and has a demerit of resin deterioration due to an oxygen attack. And above all, pressure is not applied at the same time, so it is not possible to perform the impregnation. Compared to IR heating which takes a few minutes, ultrasonic heating applies pressure simultaneously and is capable of heating in seconds. On the contrary, ultrasonic heating has some restrictions such as maximum pressure and heating area, but the mentioned feature above is very attractive for the resin impregnation.
Temperatures of three types of CFRTP preform were measured with three changing parameters; heating time, amplitude and pressure as shown in Table 2. That is, we measured temperature of each preform in 18 heating conditions. The temperature of CFRTP preforms are measured by thermocouple. The thermocouple used in this study is type K thermocouple (Chromel-Alumel). Measurement point is shown in Fig. 2.

Pressure [MPa]	0.7・1.2
Amplitude [%]	50・75・100
Heating Time [sec]	1.0・3.0・5.0

Table 2 Numerical values of each parameter at ultrasonic heating.

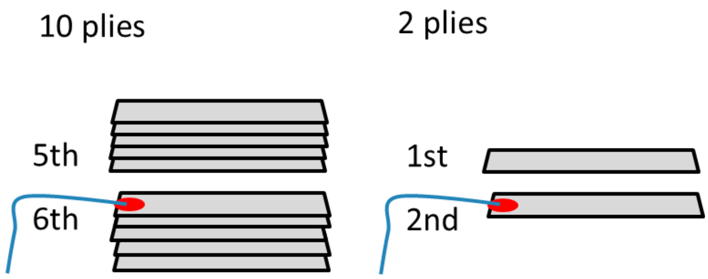

Fig. 2 Measurement point of temperature.

2.2.2 Three-point bending test

If the resin impregnation is not sufficient before stamp forming (i.e. preform is heated outside of the mold before iterative compression molding with a constant mold temperature), CFRTP products with enough mechanical properties cannot be obtained [3]. In order to evaluate the impregnation rate of three types of CFRTP preforms, three-point bending test were performed.

3. RESULTS AND DISCUSSIONS

3.1 Measurement of temperature

Maximum temperature of 10-ply UD, 10-ply CP and 2-ply UD preforms under various conditions are shown in Fig. 3-5. We couldn't measure the temperature under some conditions. One reason is that it is estimated that preform gasified strongly in some particular heating conditions and another reason is that ultrasonic welding machine couldn't be applied to other particular heating conditions.

Fig. 3 and Fig. 4 show that maximum temperatures of 10-ply UD and 10-ply CP preforms increased according to the amplitude and heating time. On the other hand, pressure had little influence on maximum temperature of those preforms. In addition, Fig. 3 and Fig. 4 show that the maximum temperature of 10-ply UD preform was higher than that of 10-ply CP preform under heating conditions that maximum temperature was higher than approximate 200°C (near the melting point of polypropylene: 170-180°C). This is because heat of 10-ply CP preform, which was generated during ultrasonic heating, diffused more rapidly than 10-ply UD preform.

On the other hand, Fig. 5 shows that maximum temperature of 2-ply UD preform had different tendency from that of 10-ply UD and CP preforms. The maximum temperature of 2-ply UD preform was lower than approximate 300°C. Therefore, it is supposed that heat of 2-ply UD preform is distributed and it is cooled better than that of 10-ply UD and CP preforms. This is probably because 2-ply UD preform is more influenced than 10-ply UD and CP preforms by high thermal conductivity of jig and horn around preforms.

In turn, concerning time variations of temperature of preform, temperature of 2-ply UD preform, is kept near maximum temperature longer than 10-ply UD and CP preforms. It is also because 2-ply UD preform is more influenced by high thermal conductivity of which jig and horn around preforms.

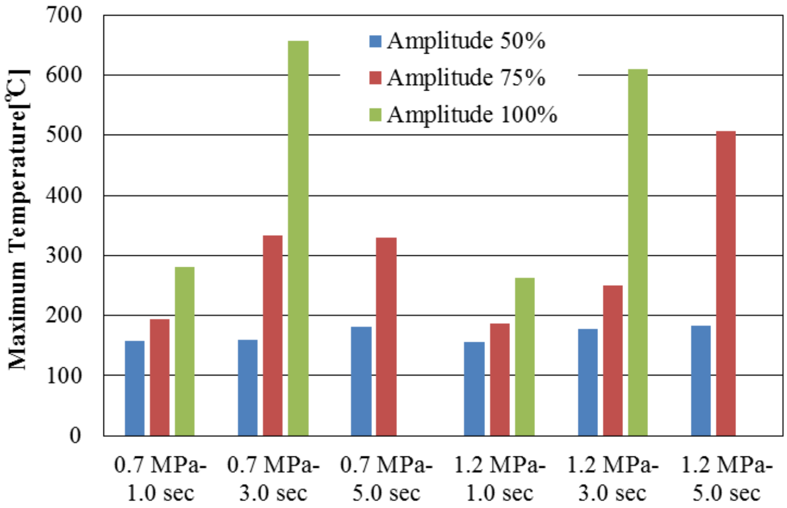

Fig. 3 Maximum temperature of 10-ply UD preform during ultrasonic heating.

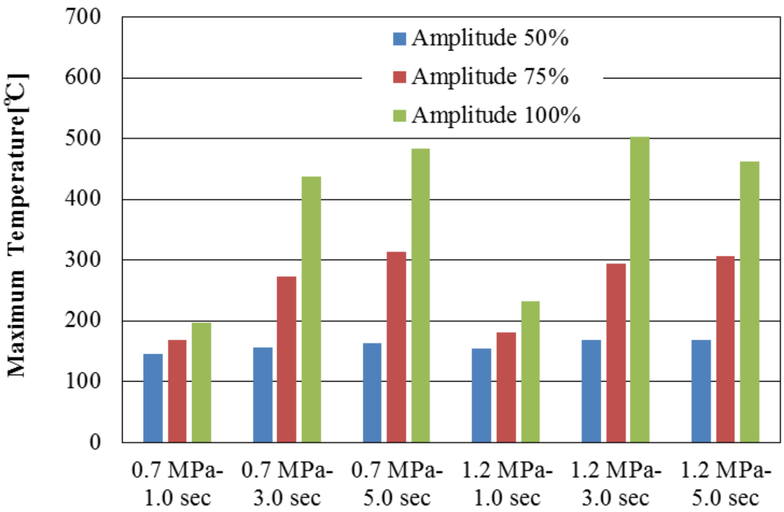

Fig. 4 Maximum temperature of 10-ply CP preform during ultrasonic heating.

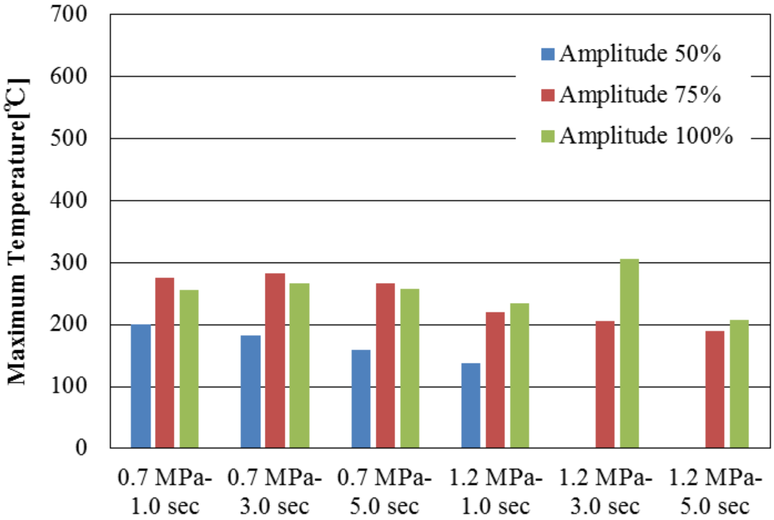

Fig. 5 Maximum temperature of 2-ply UD preform during ultrasonic heating.

3.2 Three-point bending test

We performed three-point bending test to evaluate the impregnation rate of CFRTP preforms. **Table 3** Table 3 shows the number of specimens and a number of each heating conditions under which 10-ply UD preforms were heated by ultrasonic. Fig. 6 shows relationships between flexural strength and maximum temperature of 10-ply UD preforms. Considering Fig. 6, it is proposed that all heating conditions are classified into three groups: Group 1, 2 and 3. Group 1 includes heating conditions under which maximum temperature of preform is less than 200°C. Group 2 includes conditions under which maximum temperature of preform is from about 250°C to about 350°C. Group 3 includes conditions under which maximum temperature of preform is higher than 500°C.

Specimens which were heated under conditions included in Group 1 had low flexural strength because maximum temperature was not high enough for impregnation. Specimens which were heated under conditions included in Group 2 had the best flexural strength among the three groups. Flexural strength of specimens which were heated under conditions included in Group 3 had larger scatter in the group. The reason is that degree of impregnation and degradation of the resin became different from each specimens. The reason of higher flexural strength of Group 3 is that V_f (fiber volume fraction) of some preforms are increased because of resin evaporation.

From this experiment, it was found Group 2 is the most appropriate heating conditions for impregnation, and consequently that appropriate T-P-t for resin impregnation can be achieved by ultrasonic heating.

		Welding Time [sec]		
Pressure [MPa]	Amplitude [%]	1.0	3.0	5.0
0.7	50	Unmelted	Unmelted	Condition 1 n = 3
	75	Unmelted	Condition 2 n = 5	Condition 3 n = 5
	100	Condition 4 n = 5	Condition 5 n = 5	Dangerous
1.2	50	Unmelted	Condition 6 n = 4	Condition 7 n = 5
	75	Condition 8 n = 5	Condition 9 n = 5	Condition 10 n = 5
	100	Condition 11 n = 5	Condition 12 n = 3	Dangerous

Table 3 The number of specimens and a number of each heating conditions under which 10-ply UD preforms were heated by ultrasonic.

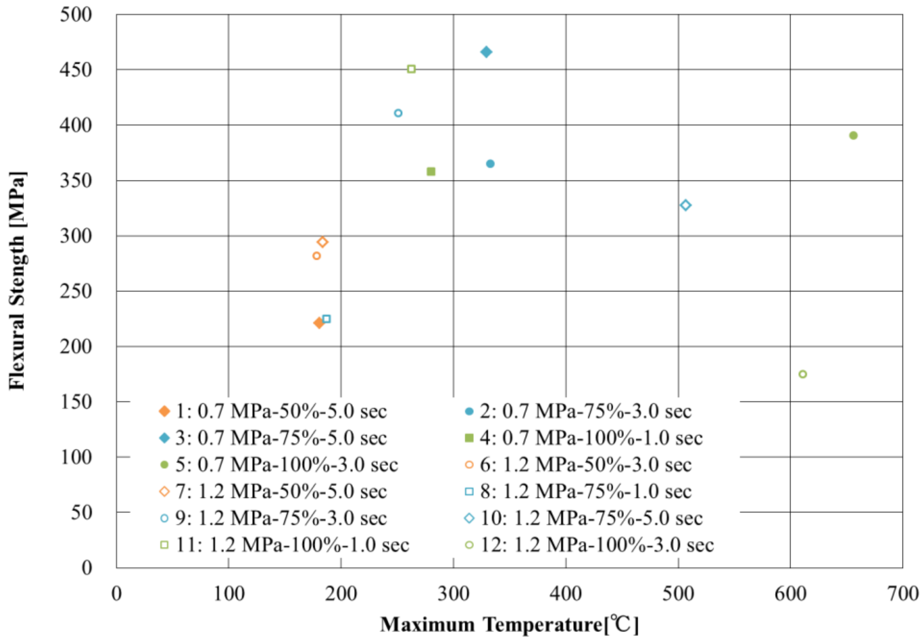

Fig. 6 Relationship between flexural strength and maximum temperature.

4. Conclusions

In this study, in order to make clear the possibility of the application of ultrasonic heating on resin impregnation of CFRTP semi-preg, we measured the temperature of CFRTP preforms during ultrasonic heating, and performed three-point bending test with specimens which were molded by ultrasonic heating. Then, from the results of the experiments, following conclusions can be obtained.

1. Preforms can be heated up to the melting point of polypropylene by ultrasonic heating in a very short time.
2. Necessary pressure for resin impregnation is successfully kept during heating.
3. Consequently, ultrasonic heating has a potential to perform a very efficient impregnation of CFRTP semi-preg and to make drastic cost-down of CFRTP parts than now.
4. In the case of thinner preform, temperature may be easily controlled, but in the case of thicker preform, temperature control is very sensitive to material.

Acknowledgement

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