Rapid pipe moulding process of Carbon Fibre Reinforced Thermoplastics by high-frequency direct resistance heating

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Abstract

Carbon Fibre Reinforced Plastics (CFRP) with thermo-setting resin are usually used in aerospace applications and racing cars. However, considering moulding time and recyclability, it is desirable to use thermoplastics resin for the matrix. In our previous study, Non-woven Stitched Multi-axial Cloth (NSMC) was developed as moulding semi-product of Carbon Fibre Reinforced Thermoplastics (CFRTP). In this study, the rapid pipe moulding process of CFRTP components by means of high-frequency direct resistance heating, in combination with NSMC, was invented. This method allows heating of the mould surface rapidly by using high-frequency direct resistance heating. NSMC makes the lamination process easy, due to the fact that the non-crimp fabric of carbon fibre and the non-woven fabric of thermoplastics resin are stitched to one sheet, so production cycle time can be reduced. The invented high-speed moulding technique is expected to apply to CFRTP pipes. This moulding method can also reduce production cycle times, and therefore the cost to manufacture composite parts can also be reduced. CFRTP pipe had been successfully moulded in the size of 300 mm in length, 47 mm in diameter and 3 mm in thickness by this moulding method.

Keywords: carbon fibres, thermoplastic resin, pipe moulding, non-woven fabric, non-woven stitched multi-axial cloth (NSMC), high-frequency direct resistance heating.

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1 Introduction

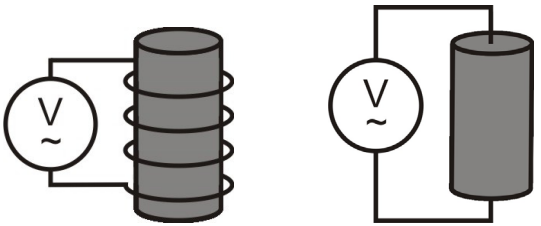
Carbon Fibre Reinforced Plastics (CFRP) have many superior mechanical properties, such as high-specific strength and high-specific stiffness. Within the automobile industry, in order to improve gasoline mileage, reduction of vehicle weight by using CFRP is expected [1]. Pipe-shape component parts are commonly used in vehicle structural component parts, such as the suspension arm, torsion beam, door guard bar and impact beam [2, 3]. Therefore, the reduction of vehicle weight is expected by using CFRP for these parts, and the development of a low-cost moulding method is needed. In addition, considering moulding time and recyclability, it is desirable to use thermoplastics resin for the matrix [4]. In this study, we focus on the Carbon Fibre Reinforced Thermoplastics (CFRTP). For the pipe moulding process, rapid processing using the electromagnetic induction was developed by Roctool Co. (Fast Tube®) [5]. However, this system needs a coil for electromagnetic induction. To reduce the cost of production, another system without complicated equipment is expected to be developed.

For a heating technique that is to be applied for metal heating, metal treating and welding, one can use induction heating (IH system) or high-frequency direct resistance heating [6–10]. These heating methods are ways of heating by Joule heat using the skin effect of high-frequency currents. Fig.1 is a schematic drawing of these heating methods. In induction heating, alternating current within the coil produces a magnetic field, and an eddy current is induced to the mould inside the coil. However, the cost of equipment was increased due to the fact that a large coil was needed in the IH system. On the other hand, the high-frequency direct resistance heating is desirable to reduce cost, because this method can heat moulds directly without coils. In this study, the rapid pipe moulding process of CFRTP by high-frequency direct resistance heating was developed.

2 Materials and moulding procedure

2.1 Non-woven Stitched Multi-axial Cloth (NSMC)

Non-woven Stitched Multi-axial Cloth (NSMC) was used as the moulding material. As shown in fig.2, polyamide 6 non-woven fabric was stitched to carbon fabric in the processing of creating non-crimp stitched fabric (NCF, or MMF: Multi-axial Multi-ply fabric). This NSMC consists of non-crimp stitched carbon fabric of [0°/+45°/90°/-45°] in the weight per unit area of 240g/m^2 and polyamide 6 non-woven fabric in the weight per unit area of 50g/m^2. NSMC is one sheet by combination of matrix resin and reinforcing fibre. One of its advantages is that it allows the winding process to be carried out easily. In addition, the fibre orientation is adaptable; therefore, it can form CFRTP pipes with certain orientation for designed purposes.



(a) Induction heating. (b) Direct resistance heating.

Figure 1: Schematic drawing of heating methods.

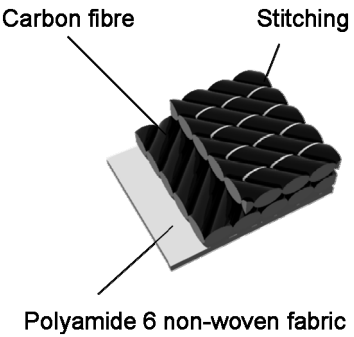


Figure 2: Schematic drawing of Non-woven Stitched Multi-axial Cloth (NSMC).

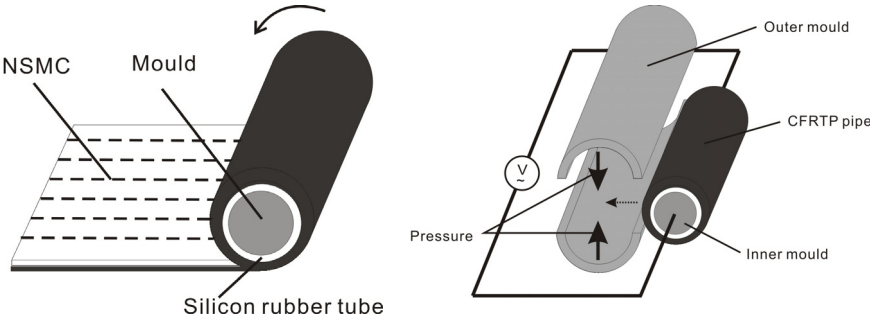


Figure 3: Process of CFRTP pipe moulding.

2.2 CFRTP pipe moulding procedure

Fig.3 is a schematic drawing of the pipe moulding process for CFRTP. A carbon steel round bar in the size of 315 mm in length and 32 mm in diameter was used as the material for the inner mould. At first, a silicon rubber tube was winded to the inner mould. NSMC was cut in the width of 300 mm, and winded fourfold to the mould. After that it is clamped by the outer mould. The silicon rubber tube was inserted between the NSMC and the inner mould to apply inner pressure to the NSMC.

Fig.4 is an overview of the pipe moulding device for CFRTP using high-frequency direct resistance heating. The vacuum-tube oscillator with 30 kW maximum output and 185 kHz current frequency was used as the high-frequency oscillator. In this study, the mould was heated by 3 kW output of the oscillator. This device passes an electric current by a contacting electrode to both ends of the mould. Fig.5 is a cross section view of the mould after set up. The temperature between the material and the outer mould in heating and cooling was measured by thermocouple.

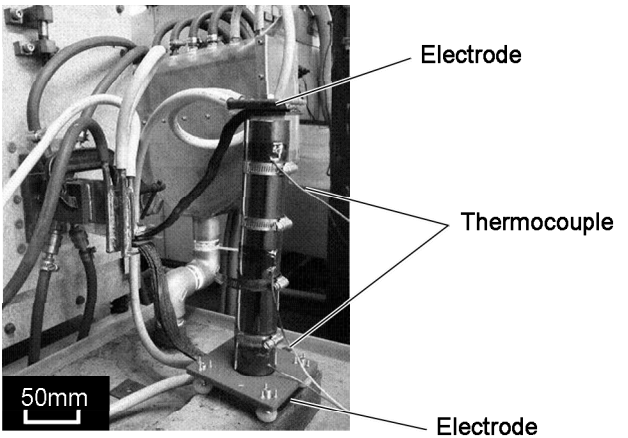


Figure 4: Mould with high-frequency direct resistance heating system.

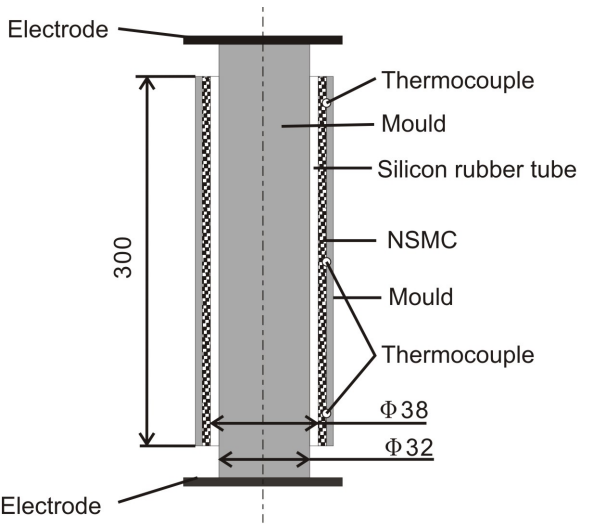


Figure 5: Cross section view of the mould.

3 Results and discussion

Fig.6 is a temperature history measured by thermocouple. As a result of heating the mould by 3 kW output of the oscillator, it enables the temperature to rise from room temperature to 230 °C at a constant rate in about 200 seconds. In this study, the mould was cooled by natural cooling due to this device not having any cooling pipe. As a result, it took about 50 minutes for cooling from about 250 °C to room temperature.

Fig.7 is an overview of the moulded pipe. CFRTP was successfully moulded into a pipe shape without any remaining resin residues.

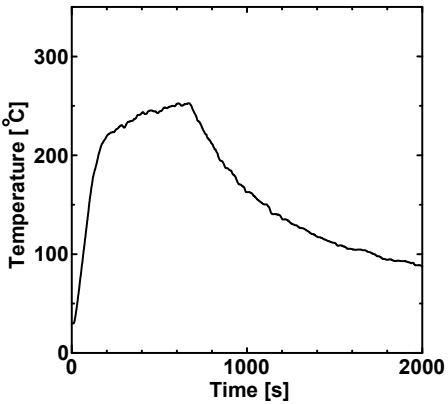
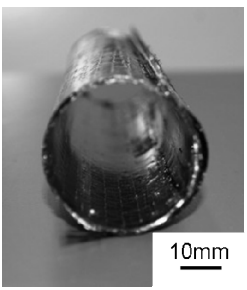
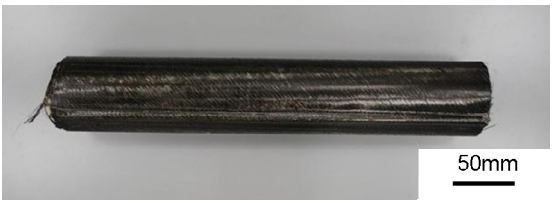


Figure 6: Temperature history.



(a) Cross section view.



(b) Outer appearance.

Figure 7: CFRTP pipe moulded by high-frequency direct resistance heating.

4 Conclusions

In this study, a CFRTP pipe moulding process using high-frequency direct resistance heating in combination with NSMC was developed. The investigation yields the following conclusions:

1. As NSMC containing non-crimp carbon fabric and non-woven matrix resin, it can make the laminating process easy and is suitable for moulding material of CFRTP.
2. High-frequency direct resistance heating enables the heating of the mould from room temperature to 230°C in 200 seconds.
3. The moulding process, in combination with NSMC and high-frequency direct resistance heating, enables the moulding of the CFRTP pipe in a short time.

Acknowledgement

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