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メタデータ	言語: eng
	出版者:
	公開日: 2017-10-03
	キーワード (Ja):
	キーワード (En):
	作成者:
	メールアドレス:
	所属:
URL	https://doi.org/10.24517/00009552

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[Au10-3-7929, 5227wds]

Effect of Press Slide Speed and Stroke on Cup Forming using a Plain-Woven Carbon Fiber Thermoplastic Composite Sheet

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Carbon-fiber-reinforced thermoplastic (CFRTP) is viewed as a prospective material for high-cycle production of CFRP parts. This paper deals with a process whereby a preheated thermoplastic plain-woven carbon fiber fabric sheet is formed into a circular cup by a mechanical servo-press. The effects of press parameters, specifically the bottom dead center and slide speed in the forming of CFRTP cup, on the press load, pressure, internal temperature, shape accuracy, and internal structure have been investigated. A plain-woven carbon-fiber-reinforced PA6 thermoplastic sheet was used. The sheet consisted of four layers of woven 3K carbon and had a thickness of 1 mm. The sheet was heated to 320 °C under a halogen heater so that it would be around the recommended temperature for forming 260 °C after transfer to the mold. The sheet was pressed into a circular cup shape by a cold mold while the periphery was cramped by a heated holder so as not to cool the sheet before it was pulled into the mold cave. Die clearance was designed considering the thickness increase due to the fiber concentration during the forming. By increasing the slide stroke to the bottom dead center, the applied press load was increased and the internal structure was improved, showing no voids. By increasing the slide speed, the final press load was reduced and shape accuracy was improved through a good pressure distribution on the mold. Measurement of the surface temperature of the sheet during the forming revealed that it remained in the melting region of the resin in the case of fast slide speed, but dropped below the melting temperature in the case of low slide speed. This difference apparently led to spring-in or spring-back after the forming. The experimental results indicate that appropriate balance among press speed, bottom dead center, and sheet temperature is important in the high-cycle forming of CFRTP.

Keywords: CFRP; Carbon-fiber-reinforced thermoplastic; Composite material; Press-forming; Mechanical servo-press

1. INTRODUCTION

Carbon-fiber-reinforced thermoplastic (CFRTP) is expected to be amenable to future mass production with short manufacturing times by virtue of the fact that the resin can be re-melted by heating and fixed by cooling. CFRTP is also expected to show superior shock absorption performance compared with thermoset CFRP.

Among many processes considered for the production of CFRTP parts, the most prominent involves the formation of so-called stampable or organo CFRTP sheets from carbon fiber and thermoplastic, subsequent press-forming at high temperature, and finally cooling. In fact, this process has similarities to sheet metal forming. This paper deals with the press-forming process used with woven carbon fiber fabric reinforced polyamide. Although press-forming of CFRTP sheet may resemble the usual sheet metal forming process, there are some notable differences. First, a CFRTP sheet of woven carbon fiber has strongly anisotropic deformation properties. Second, the sheet needs to be kept in the region of the melting temperature during press-forming and then cooled in the mold before taking out the product. Third, the deformation resistance is quite low because the resin is molten but the final material needs to be pressed to maintain good contact between the carbon fiber surface and the consolidated resin.

Previous research has provided much background knowledge on deformation during the forming of unidirectional carbon fiber thermoplastic composites. Zahlan and O'Neill presented an equation for the spring-forward effect of a continuous carbon-fiber-reinforced composite[1]. Hou and Friedrich revealed that the spring-forward effect increases with increasing stamping pressure and stamping velocity in the bending of unidirectional continuous fiber-reinforced thermoplastic laminates[2]. Hou et al. further investigated the influences of laminate thickness and stamper radius on the final part angle in V-shaped bending[3]. They also simulated the relative slip between the layers during bending. Friedrich and Hou investigated the effects of die geometry and original laminate dimensions on shear-buckling[4]. Krebs et al. were able to improve material deformation by using double diaphragm forming compared with matched-die forming although surface roughness was better in matched-die forming in the forming of unidirectional reinforced laminates[5]. Sadighi et al. investigated the influence of laminate sequencing of unidirectional grass fiber reinforced polypropylene on the compressive strain in the thermoforming of a hemispherical cup[6].

Concerning the effect of press conditions during forming, Chen et al. found that temperature variations have the greatest effect on the material deformation of co-mingled glass/polypropylene fabric[7].

Concerning the deformation of plain woven-fabric composite, the main deformation of a cross-ply sheet is the change of cross angle by shearing deformation during press-forming. Another factor is the sliding between the plies. Severe deformation occurs at a double-dome corner. Harrison et al. revealed that wrinkling can be restricted by the tension of a spring attached at the periphery of the sheet as compared to when the sheet is held by a blank holder[8]. Nezami et al. developed a new testing machine capable of applying a tensile force during a picture-frame test to investigate the shearing behavior of woven fabrics under the influence of tensile stress[9]. They also demonstrated that the shearing angle could be changed by means of divided blank holders in the forming of a spherical cup.

Simulation work has also been carried out on deformation during press-forming of thermoplastic composites. Lee et al. characterized woven fabric composites and numerically analyzed double-dome stretch-forming[10]. Wang et al. simulated the thermo-forming of multilayer composites with continuous fibers and a thermoplastic matrix[11]. They analyzed forming into a square cup by using a semi-discrete shell and considered the deformation property in the sheet and the friction between the laminates, and thereby predicted the fiber orientation and wrinkle initiation. Zhang et al. simulated deformation in the thermal deep-drawing of woven carbon fiber composites based on the mechanical properties obtained from picture-frame tests[12].

With regard to the mechanical properties after press-forming, Vieille et al. presented stamping effects in the mechanical behavior of woven carbon fiber ply laminates by thermo-compression but stamping conditions were not discussed[13]. Miyake and Seki found that fracture strength is reduced where large shearing deformation occurs in press-formed spherical cups of CFRTP[14].

Considering the forming tool in press-forming, stamping with an upper die and punch is referred to as matched die-forming. Yoneyama et al. proposed the press-forming of unidirectional carbon fiber laminated sheet sandwiched by rubber sheets[15]. Antonelli et al. proposed a forming method by using rubber particles in a mold half to obtain a uniform pressure distribution[16].

Although such new forming technologies improve uniformity of pressure distribution during press-forming, this paper deals with matched die-forming because a metal die has good toughness and dimensional accuracy, which are necessary for a precise mass production process.

There has been a great deal of research on deformation behavior in press-forming, but there have been few studies on the effects of press parameters on the actual forming situation. A hydraulic press is typically used for the press-forming of a thermoplastic composite because it is considered that the main task is applying pressure during cooling of the composite. Conversely, a mechanical servo-press is widely used in the field of sheet metal forming for the mass production of automobile parts because it offers high-speed motion and flexible, precise slide motion[17-19]. For the future high-cycle production of CFRTP parts, the applicability of a mechanical servo-press for the press-forming of CFTP should be investigated. Therefore, this paper is focused on the effect of press conditions by using a mechanical servo-press on the forming of CFRTP parts. As the basic forming shape, a cup comprised of a spherical top and a lower conical section has been examined. Yoneyama et al. introduced the design of die clearance and deformation of plain-woven fabric thermoplastic sheet in the cup forming[20]. This paper deals with the influences of press speed and the position of the bottom dead center on the forming accuracy and pressure distribution in the cup forming.

2. PRESS EQUIPMENT AND PRESS PROCEDURE

2.1. Press procedure and press mold

This paper deals with the press-forming process using a thermoplastic sheet reinforced with carbon fiber fabric. The process is divided into two steps: preheating of the CFRTP sheet and forming by a mechanical servo-press, as shown in Fig. 1. The method for fabricating the initial CFRTP sheet is not dealt with in this paper. Good consolidation of the CFRTP sheet before preheating is assumed. The interior of the material, i.e., whether or not voids appear, has been assessed. The forming process includes deformation of the sheet and cooling prior to removal of the product.

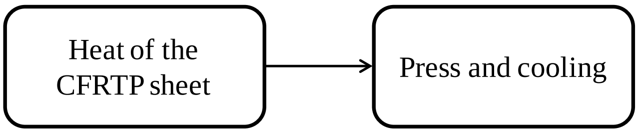
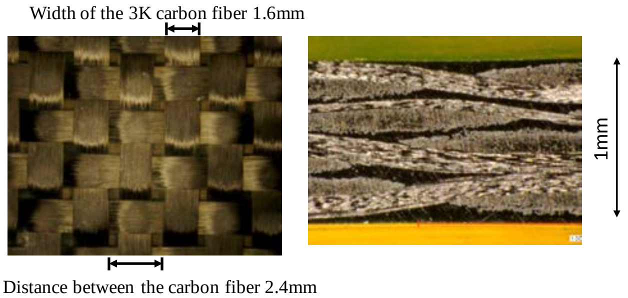


Fig. 1 Press forming process using carbon fiber reinforced plastic sheet

The specimen used was a thermoplastic sheet reinforced with plain-weave carbon fiber. Yarn of three thousand (3K) carbon fibers (T300) made by Toray Co. Ltd. was woven and four layers of the carbon cross were laminated with thermoplastic PA6 films. The laminated sheet was heated and pressed to a thickness of 1 mm. The surface of the fabric and cross-section of the sheet were observed, as shown in Fig. 2. The volume percentage of carbon was 40%. The recommended forming temperature was 260 °C. The sheet was produced by Ichimura Co. Ltd.



(a) Surface of the plain-woven fiber sheet (b) Cross section of the sheet

Fig.2 Plain-woven CFRTP sheet[17]

The structure of the press-forming mold is shown in Fig. 3. In this research, so-called "matched die-forming" was adopted to obtain a precise form and smooth surface. The mold consists of an upper mold, a lower mold, and a sheet holder. The lower sheet holder is supported by a die cushion, which applies constant force by air pressure independent of the press load. A spacer ring is placed between the upper and lower holders to keep the clearance at the sheet holder at 1 mm. When the upper mold slides down, the peripheral part of the sheet is first held by the sheet holder and then the sheet is drawn into the space between the upper and lower molds. The expected shape of the formed cup consists of a spherical section at the top, a conical side section, and a bottom flat flange. Outside of the flat flange of 90 mm diameter is considered as a blank holder part, which will be trimmed after the press-forming.

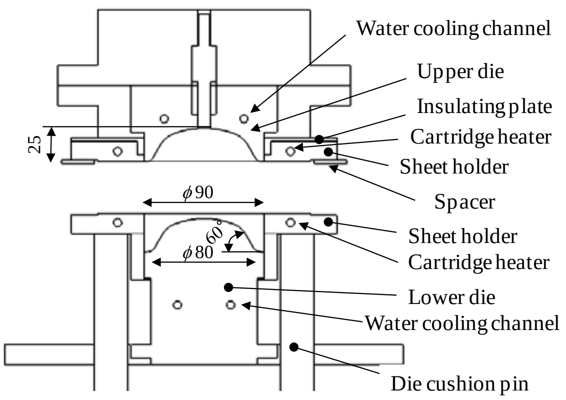


Fig.3 Structure of the press mold[17]

Pressure sensors were embedded in the mold, as shown in Fig. 4. Ejector pin type sensors (EPS) made by Futaba Electric Co. Ltd. were used, which are commonly used for pressure measurement in injection molding. The diameter of the detection pin was 3 mm and strain gauges were fitted on the bottom plate that supported the pressure pin. The pressure measurement range was up to 200 MPa.

Although carbon fiber is not susceptible to plastic deformation in the longitudinal direction, the crossing angle of the fabric can be changed by a shearing force or by forces in the direction 45° to the fiber orientation. Owing to elongation and contraction in the 45° direction, as shown in Fig. 5, as well as the elastic bending of the fibers, the sheet can be deformed into a three-dimensional cup shape, as illustrated in Fig. 6.

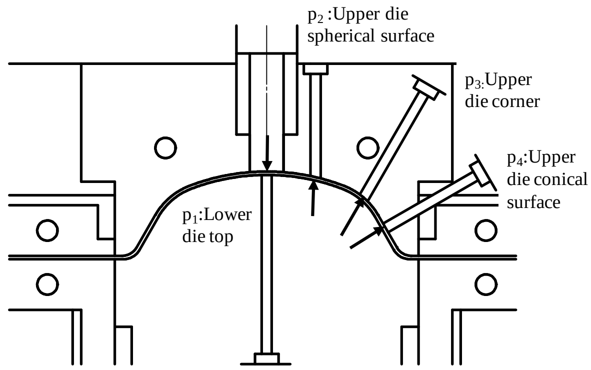


Fig.4 Pressure sensors equipped in the mold

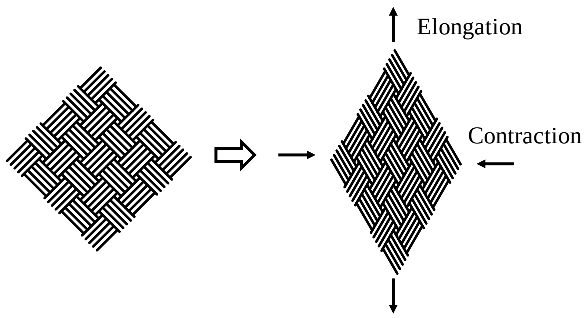


Fig.5 Main deformation of woven carbon fiber

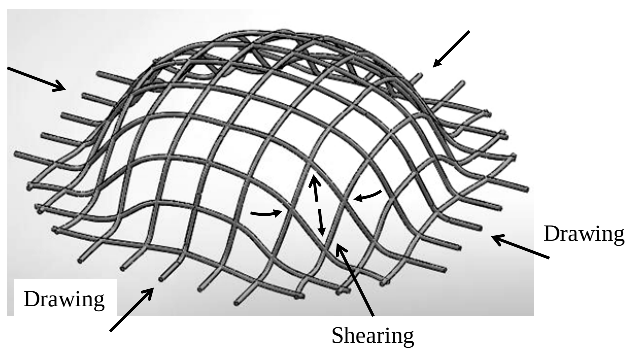


Fig.6 Drawing and shearing of fibers during cup forming

2.2. Press parameters

Press parameters, the resulting press condition, and output characteristics are illustrated in Fig. 7. The press parameters are divided into three groups. The first set of parameters relate to sheet condition such as preheating temperature, sheet dimension, and fiber orientation. The second set of parameters relates to press conditions such as slide speed, bottom dead center, and sheet hold condition. In this research, a mechanical servo-press was used with a view to future mass production. In the mass production of automobiles, mechanical servo-presses are now widely used for sheet metal forming because of their precise positional control and excellent press speed. In a mechanical servo-press, slide speed and slide position control are the main parameters. Therefore, slide speed and the bottom dead center were selected as the main parameters of the press condition in this work. The third set of parameters relate to the mold condition such as mold surface profile, mold clearance, and mold temperature. Through the combination of these parameters, pressing conditions such as material deformation, sheet temperature during forming, and applied pressure could be regulated. According to the press conditions, output characteristics such as fiber orientation in the formed material, surface roughness, dimensions and thickness of the formed product, and internal structure could be controlled.

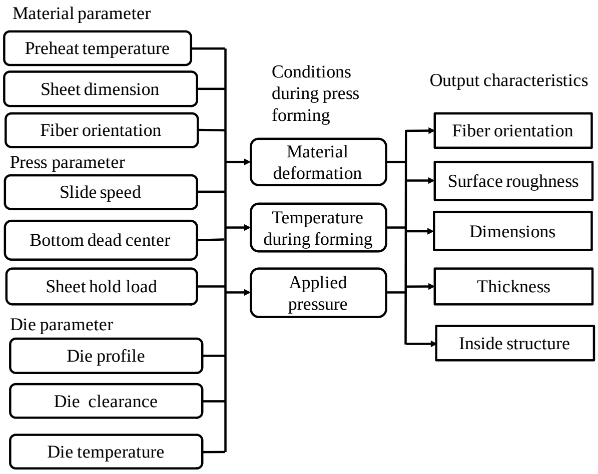


Fig.7 Press parameters and output characteristics

To obtain a formed material with no voids and no internal delamination, the following parameters are important. First, the temperature of the sheet during forming should be in the range of melting or low deformation resistance. If the material temperature falls below the melting temperature region, the carbon fibers cannot move easily and wrinkles occur during forming. A desirable temperature profile during the forming is shown in Fig. 8. Second, the pressure applied on the material at the end of forming through the mold is a key factor in order to ensure close contact between the carbon fibers and resin with no voids.

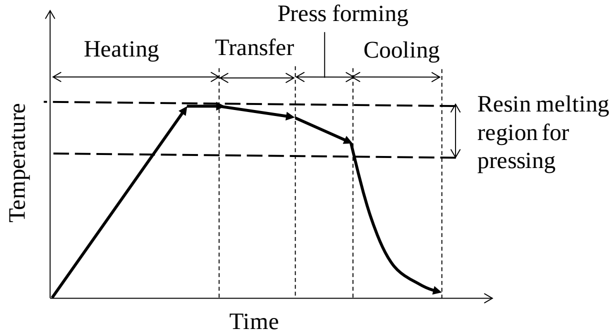


Fig.8 Desirable temperature process during the press forming

For the first issue, the time required to transfer the sheet from the heater to the hold plate, the pressing speed, and the mold temperature are the salient parameters. In this experiment, the sheet was transferred from the heater to the top surface of the sheet hold plate by manual handling by using an original gripper, as shown in Fig. 9. Approximately 10 s were required to transfer the sheet and set it on the sheet hold plate. The sheet was heated to 320 °C between infrared heaters so that its temperature would remain above 260 °C during transfer to the mold. The temperature of the sheet holder was kept at 260 °C during the forming. The mold temperature was kept at 20 °C by cooling with water. Once the upper mold reached the bottom dead center, the hold plate heater was switched off to allow cooling by the mold.

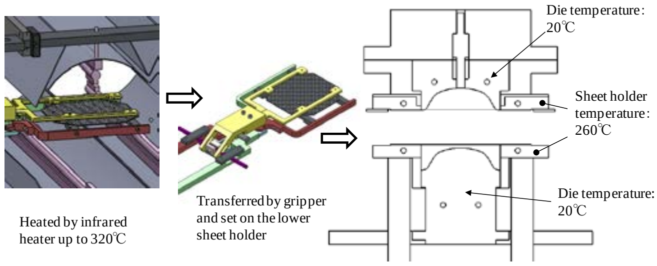
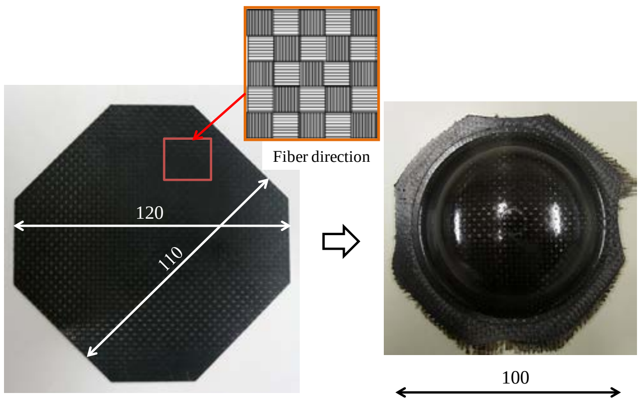


Fig.9 Heating of the sheet and transfer to the mold

Sheet dimensions and fiber orientation in the sheet are shown in Fig. 10 (a), along with the formed shape. Considering the fiber length drawn along each mold surface profile, the sheet was cut as an octagon of 120 mm in the fiber direction and 110 mm in the 45° direction. An example of the formed cup is shown in Fig. 10 (b) as a top view and in Fig. 11 as bird's-eye view.



(a) Sheet before pressing (b) Pressed sheet

Fig.10 Sheet dimensions and fiber orientation

(a) Upper die side (b) Lower die side

Fig.11 Example of formed material

Die clearance is shown in Fig. 12 at a distance where the top of the spherical surface becomes 1 mm. The thickness in the circular cross-section will increase as the circumference of the flat sheet before forming is decreased to that in the horizontal conic circle in the conical surface, as shown in Fig. 12 (a). Consequently, clearance gradually increased along the lateral line from the top to the bottom part, as shown in Fig. 12 (b).

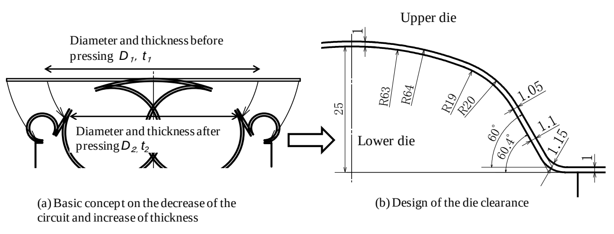


Fig.12 Die clearance[17]

Press speed is defined as a percentage of the maximum speed of the link motion. The press-forming stroke is 25 mm, from the point at which the upper die holder touches the sheet on the lower sheet holder to the bottom dead center, where the clearance between the upper and lower molds represents the desired distance. In this experiment, the press speed during the stroke of 25 mm was varied from 20 to 60 mm/s.

The position of the bottom dead center affects the forming pressure at the final point. In the forming process, the upper mold stays at the bottom dead center until the temperature of the formed material decreases to such a level that the formed cup can be taken out without additional deformation. Assignment of the bottom dead center is explained in Fig. 13. The position of the bottom dead center is based on the position for the desired forming thickness with no load condition. Additional stroke is set from this position. The press slide moves to this set point in the case of no load. However, elastic deformation of the press frame occurs due to the press load. The real bottom dead center corresponds to the assigned bottom dead center reduced by the elastic compliance of the press frame. The actual bottom dead center is detected by a displacement meter connected to the press machine. Additional stroke leads to increased press load.

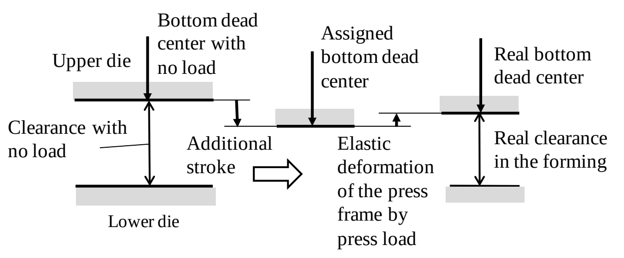


Fig.13 Position of the bottom dead center and additional stroke

The sheet holding load was fixed at 5 kN in this experiment. Excessive load leads to compression and expansion of the held sheet. Insufficient load leads to wrinkles in the held sheet. A spacer was inserted between the upper holding and lower plates in order not to compress the held sheet to less than 1 mm.

3. EXPERIMENTAL RESULTS

3.1. General behavior

An example of a press load-time diagram is shown in Fig. 14. Slide refers to the upper mold position from the position of bottom dead center assigned with no load condition. The initial low press load from 0.7 to 1.8 s was the sheet holding load. The press load increased sharply near the bottom dead center. The slide did not reach the assigned position owing to the elastic deformation of the press frame during the press load. Therefore, the real bottom dead center was defined as the position of the upper mold when the press load reached its maximum value. After the peak, the press load gradually decreased over several seconds and then remained constant. During the decrease of press load after the peak, the slide position also changed by approximately 0.03 mm, as shown in Fig. 15. This change in slide position must be due to the shrinkage of the thermoplastic in the formed material with the decrease of temperature. The factor of visco-plastic deformation must be very small, since the amount of the slide displacement after the bottom dead center is the same for both slide speed 20 mm/s and 60 mm/s. The slide movement is caused by reversal of the elastic deformation of the press frame. The decrease in the press load after the peak is due to the reduction in elastic deformation of the press frame. Because the

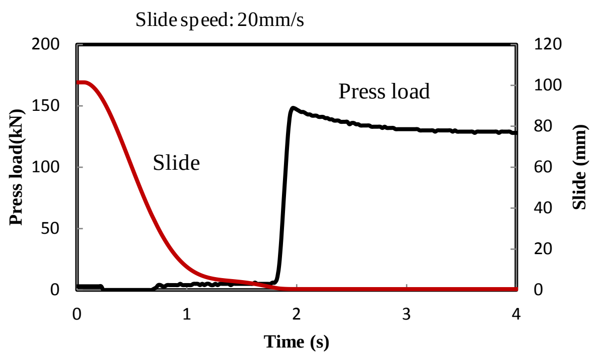


Fig.14 Press load and slide diagram

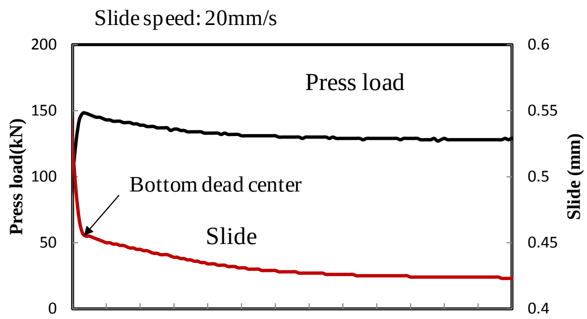


Fig.15 Press load and slide change after the stop of upper mold (Detail figure in Fig.14)

period of position decrease and press load decrease finishes approximately 2 to 3 s after the load peak, the formed material must be suitably cooled within this time.

The detailed relationship between the press load and the slide obtained from Fig. 14 is shown in Fig. 16. In this figure, the position at the maximum load is set as the last zero point. The press load only increased in the last 0.5 mm of the slide. From the fact that the press load did not increase during the drawing into the mold clearance between the upper and lower molds in a slide of 25 mm, except in the last 0.5 mm, it is clear that the deformation resistance during the forming was quite low. The last 0.5 mm of slide must be a compression stage to fit the material to the mold surface. Especially in the last 0.2 mm, the press load increased linearly with slide. In order to get good adhesion between the carbon fiber surface and the consolidated resin, it is thought that the material must be compressed with appropriate pressure by the press load. An example of the variation in pressure applied to the mold surface is shown in Fig. 17. It can be seen that the pressure on the conical surface gradually decreased after cessation of the slide. Conversely, the pressure at the spherical surface of the upper mold increased slightly with the decrease of pressure at the conical surface. It is surmised that the pressure at the conical surface decreased because of the thermal shrinkage of the resin material of the CFRTP. Although the pressure at the top was maintained or increased slightly by the slide downward with the reverse of press frame, the decrease of the distance at the conical surface is not sufficient to keep the pressure because the

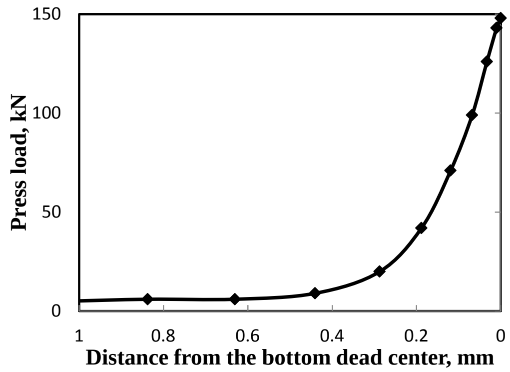


Fig.16 Relation between press load and slide obtained from Fig.14

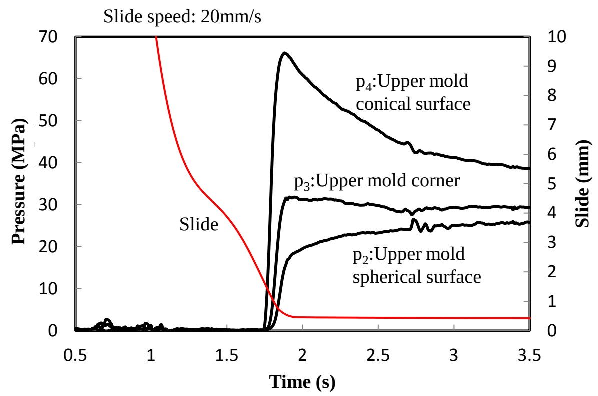


Fig.17 Example of pressure on the mold surface during the press forming

displacement normal to the conical surface is smaller than that in the downward direction.

3.2. Effect of slide stroke

As described in Section 2.2, the bottom dead center is changed from that with no load by adding the additional stroke. The relationship between the maximum press load and the additional stroke at a press speed of 20 mm/s is shown in Fig. 18. With the increase of additional stroke, peak load increases. Therefore, peak press load can be controlled by changing the additional stroke.

The effect of additional stroke on the internal structure is shown in Fig. 19. There are several voids in the cross-section of the top spherical part in the case of no additional stroke.

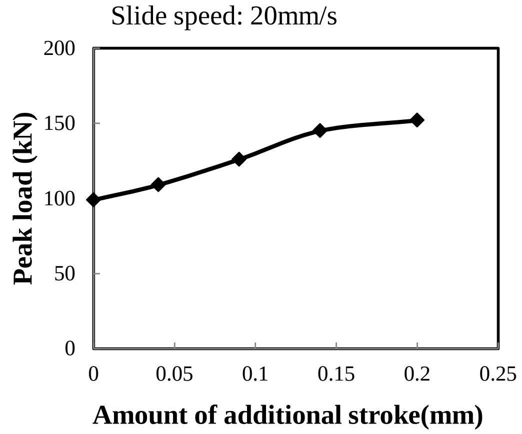


Fig.18 Influence of additional stroke on the press load

(a) Top part with voids in case of no additional stroke

(b) Top part with no voids in case of 0.2mm additional stroke

Fig.19 Effect of additional stroke on the inside structure

Conversely, there are no voids in the same cross-section in the case of 0.2 mm additional stroke. This implies that despite the same press load applied, no effective pressure was applied on the top area in the case of no additional stroke. It is surmised that in the case of no additional stroke, pressure was mainly applied on the peripheral part and little pressure was applied on the top area. Therefore, additional stroke is necessary to apply pressure on the top part.

The influence of additional stroke on the formed profile is shown in Fig. 20. Deviation of the formed profile from the mold profile is magnified five times in the illustration of this figure. There are no great differences in the deviation between the cases with and without additional stroke. Additional stroke does not greatly improve the profile.

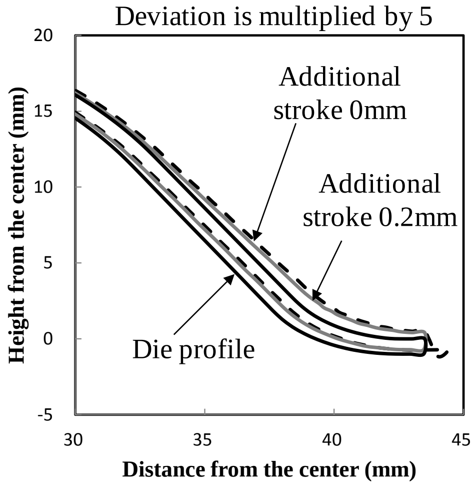
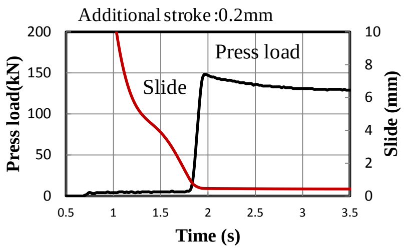


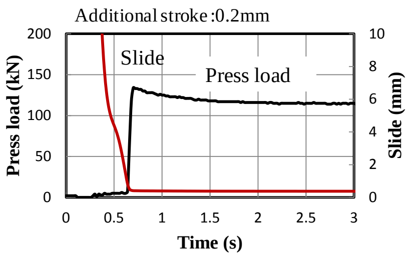
Fig.20 Influence of additional stroke on the formed profile

3.3. Effect of slide speed

The effect of slide speed on the peak press load is shown in Fig. 21. By increasing the press speed from 20 to 60 mm/s, the peak press load decreased from 150 to 130 kN with the same additional stroke of 0.2 mm. This must have been because of the reduction of the press time. The temperature of the sheet material will be kept higher by reducing the press time so that the resin remains softer. According to the pressure distribution shown below (Fig. 23), material flow during the slide must change according to the hardness of the resin.



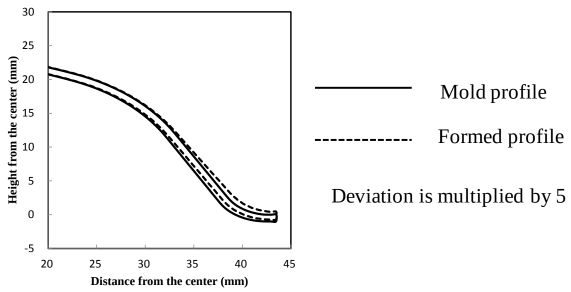
(a) Slide speed 20mm/s



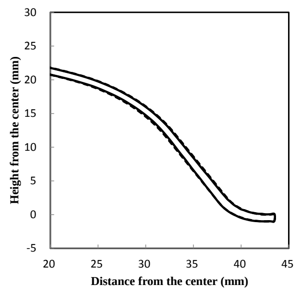
(b) Slide speed 60mm/s

Fig.21 Influence of slide speed on the press load

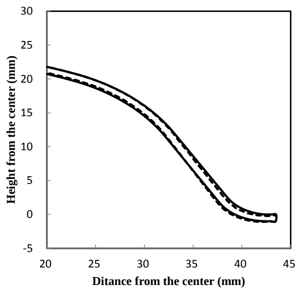
The influence of slide speed on the formed profile is shown in Fig. 22. Deviation is again multiplied five times in this figure. When the slide speed was 20 mm/s, the formed profile was displaced from the mold profile. This resembles spring-back in metal forming. When the slide speed was 40 mm/s, the formed profile matched well with the mold profile. When the slide speed was 60 mm/s, the formed profile was somewhat within the mold profile. It is often noted that warp or spring-in occurs in injection molding. It is estimated that in-plane thermal shrinkage is quite low because of the low thermal shrinkage of carbon fiber. Conversely, thermal shrinkage in the thickness direction is large because of the large thermal shrinkage of the resin. At a corner, owing to the difference in thermal shrinkage between the plane and thickness directions, the bending angle increases with decreasing temperature. In the case of 60 mm/s press speed, such deformation may occur without elastic spring-back. In the case of a press speed of 20 mm/s, elastic spring-back is larger than the thermal shrinkage deformation. At 40 mm/s, elastic spring-back is almost the same as the thermal shrinkage deformation. These combinations will change with the press speed and the rate of temperature decrease during the forming.



(a) Slide speed 20mm/s



(b) Slide speed 40mm/s



(c) Slide speed 60mm/s

Fig.22 Influence of slide speed on the formed profile

The variation in the pressure applied on the mold surface with press speed is shown in Fig. 23. These are measurements from pressure sensors at the time of the press load peak. In the case of a press speed of 20 mm/s, the pressure on the conical surface is larger than that on the top spherical surface. With increasing press speed, the pressure on the top surface increases and that on the conical surface decreases. At 60 mm/s, the pressure on the top spherical surface is larger than that on the conical surface. It is likely that contact of the top part of the upper mold to the sheet material becomes easier to achieve as the press speed is increased because the material temperature during the forming is kept higher and the material remains softer. It should be mentioned that the measured pressure does not show same value even under the same press conditions. It may have been influenced by the contact situation between the sensor position and woven fiber because the diameter of the pressure sensor pin was only 3 mm and the carbon fibers were intertwined with the other fibers in the fabric. Therefore, at this moment, the measured pressure distribution is considered merely as a basis for comparison of the press parameters. Precise pressure measurement in the mold will be important for the further development of press-forming of CFRTP.

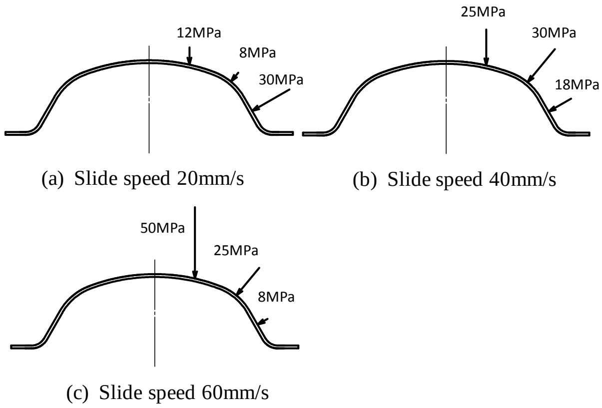


Fig.23 Influence of slide speed on the pressure applied on the upper die surface

To investigate the influence of slide speed on the internal temperature change during the forming, thin thermocouples were inserted into the sheet. In this experiment, thin thermocouples of diameter 0.25 mm were inserted into a laminated plain-woven sheet of thickness 0.2 mm. One thermocouple was inserted in the first layer and another one was inserted in the middle sheet of five layers, as shown in Fig. 24. Temperature change was compared for the cases of slide speeds 20 and 60 mm/s. The results are shown in Fig. 25. The internal temperature suddenly decreased immediately after contact between the sheet and mold. The temperature of the first layer decreased faster than the middle layer. The rate of temperature decrease was almost the same under both slide speed conditions. However, the times from the initial contact to the bottom dead center were different. In the case of slide speed of 20 mm/s, the temperature of the first layer decreased to below the melting temperature of PA6 of 230 °C at the time of bottom dead center. The temperature beneath the sheet surface decreased to below the melting temperature during the forming. In the case of slide speed of 60 mm/s, the temperature of the first layer remained at above the melting temperature at the time of bottom dead center. Therefore, the temperature beneath the surface remained in the melting region during the forming.

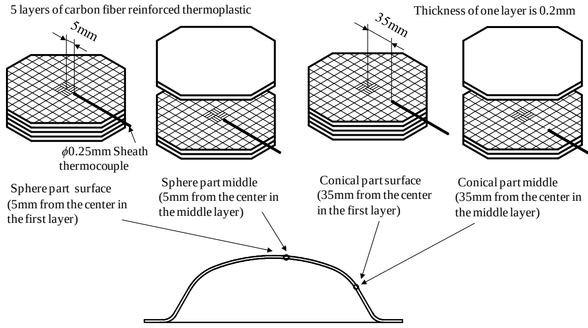


Fig.24 Temperature measurement during the press forming

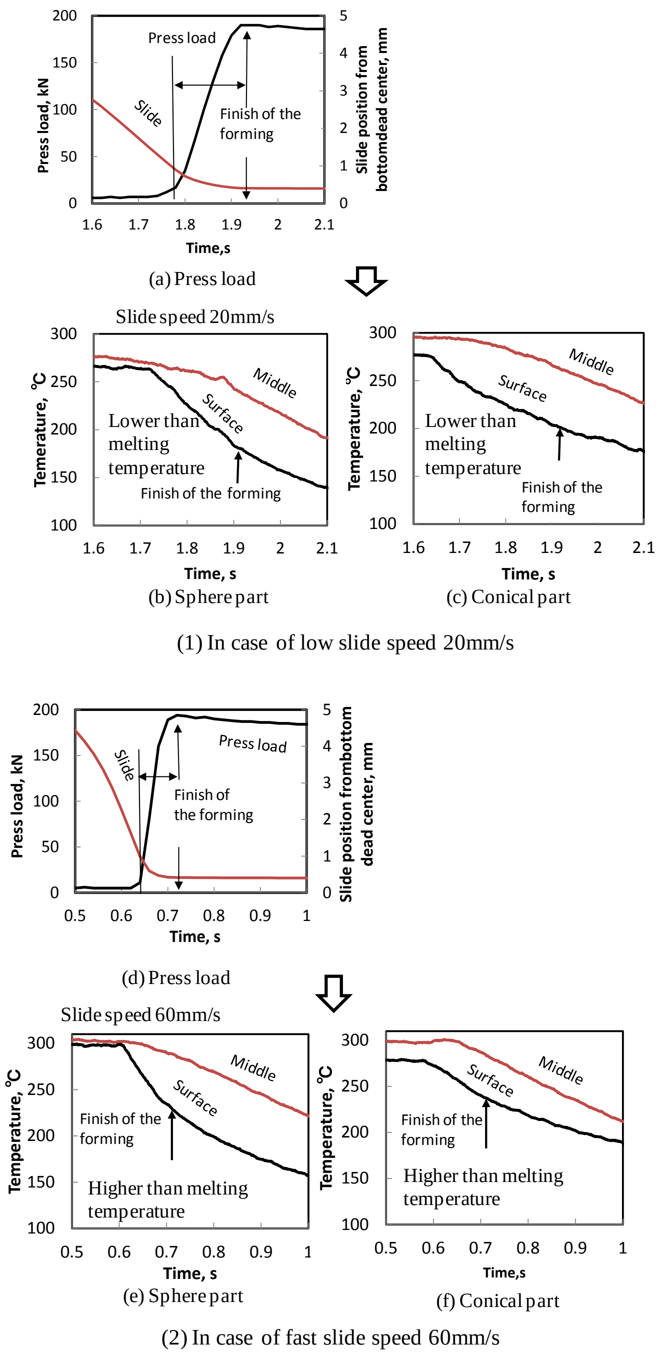


Fig.25 Influence of slide speed on the material temperature during forming

4. DISCUSSION

In the use of a mechanical servo-press, control of the slide position is the main factor in metal forming. In the case of metal forming, the material has deformation resistance during the plastic deformation process. Therefore, the press load during the plastic deformation is important. In the forming of a CFRTP sheet, however, the deformation resistance during the forming process is quite low. The press load only increases in the final stage of the slide. The bottom dead center affects the final press load, which in turn has a large effect on the internal structure of the material. The final pressure applied to the material is clearly important to obtain an internal structure free from voids. Increase of the additional stroke, which means the downward position of the bottom dead center, has an enhancing effect on the final press load. A final pressure of 10 MPa is nearly sufficient to avoid voids. It is often noted that a hydraulic press is necessary to apply a constant load during the final stage of the pressing. A mechanical servo-press can also apply an almost constant load by appropriate setting of the bottom dead center. The press load is maintained nearly constant after cessation of the slide with compensation for the elastic deformation of the frame of the press machine. However, the reduction of the press load after cessation of the slide depends on the displacement caused by thermal shrinkage of the formed material; control of the slide position according to the load change or pressure change is essential to control the pressure.

Advantageous features of the mechanical servo-press are rapid motion and precise positioning of the slide. Precise positioning is essential to obtain shape accuracy. By controlling the press load through control of the slide, adequate press-forming with sufficient pressure applied to the material will be realized. Even if this press load control is realized, though, there still remains the issue that pressure on the side-wall decreases during cooling in the mold. A new approach is needed to address this issue.

A fast slide speed has the advantage of a smaller decrease in sheet temperature during the forming. In this experiment, slide speed more than 40 mm/s was necessary to keep the material at melting temperature during forming. Sheet temperature is one of the most significant factors. The most precise method for controlling the sheet temperature involves heating the mold to the melting temperature of the resin in the CFRP during the forming and then cooling to room temperature after the forming. However, this method requires long heating and cooling stages of the mold as well as complicated mold design and structure. For high-cycle production and simple mold design, time control of the forming process is the simplest method. One of the authors is conducting research on a rapid heat and cool system for a mold. Such technology will be important for future high cycle and precise production [21-22]. In this experiment, although the time for press-forming could be reduced by increasing the slide speed, the time required to transfer the sheet from the heating furnace to the mold in the press could not be reduced owing to the manual handling employed. Temperature regulation prior to press-forming is also an important issue to be addressed. Direct temperature measurement of the forming material in the mold has indicated the significance of a fast slide speed to keep the sheet temperature in the resin melting region during the forming.

5. CONCLUSION

The effects of press parameters, specifically the bottom dead center and slide speed, in the forming of CFRTP by using a mechanical servo-press have been investigated. By applying additional slide displacement from the bottom dead center with no load, the applied press load was increased and the internal structure of the product was improved such that it was free from voids. By increasing the slide speed, the final press load was reduced and the product shape accuracy was improved through good pressure distribution on the mold. The described forming process that involves preheating of the CFRTP sheet followed by press-forming by a cold mold is a simple and quick process for realizing high-cycle production.

Acknowledgements

This study was supported by the Adaptable and Seamless Technology Transfer Program through target-driven R&D of the Japan Science and Technology Agency.

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