논 문

The Effect of Compression Ratio on the Fiber Orientation During Compression Molding of Short-fiber Reinforced Composites

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Abstract

단섬유강화 고분자 복합재료의 고온압축 프레스 성형 시 유리섬유의 유동을 지배하는 인자인 유리섬유와 모재의 유동성에 관하여 연구하기 위하여 춉트 스트랜드의 교차각도를 30°, 45°, 60° 로 배향하여 모재와 적층시킨 다음 열압축프레스를 사용하여 1 차로 시트를 제작하고, 이 제작된 시트를 가열로로 가열하여 열압축프레스로 2 차 고온압축 프레스 성형한다. 여기서, 압축속도와 압축비를 변화시켰을 때 발생되는 유리섬유의 배향에 관한 실험결과를 고찰한다.

Key words : Fiber Orientation, Closure Speed, Compression Ratio, Orientation Angle, Compression Molding

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1. Introduction

It has revealed that in case of orientation of long fiber, it did not depend on flow filed but it depended on the displacement. At this time, a yardstick of separation used the degree of heterogeneity and orientation used orientation function and the orientation function was obtained by image processing. In case of high temperature compression molding (Secondary process) of fiber reinforcement composites, the biggest problem is that molding product becomes heterogeneously and anisotropy due to the generation of fiber orientation by the difference of flow velocity of material when carrying out compression molding and therefore, strength or the characteristics of molding products become changed. Accordingly, excellent molding products were obtained as fiber orientation is made clear in connection with molding condition or material and also as optimum molding condition is determined, if fiber orientation is controlled. Separation coefficient was proposed and measured by inducing separation equation that can express the separation of fiber and fiber orientation was measured by using image processing. Manufactured sheet was molded secondarily at high temperature compression press using 25 tons hydraulic thermo-press after heating the sheets at heating furnace. This research project indicates that the results of experiments regarding orientation of glass fiber were generated according to the changes of closure speed and compression ratio[1-8].

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2. Experiments

2.1 Equation of Fiber Separation

In high temperature compression press molding of fiber reinforced composites, flow was considered as one flow with two statues of solid (fiber) and liquid (polymer) and fiber was presumed as a globe. At this time, one fiber movement equation with velocity of fiber V_f and velocity of matrix V_m is like the Eq. (1) based on the flow theory of two statues [1].

$$\frac{W_f}{g}\frac{dW}{dt} = C_D\frac{r_m}{2g}(V_m - V_f)^2 a_f + W_f\frac{r_f - r_m}{r_m}\cos\theta - f_f \quad (1)$$

where W_f is the weight of fiber, C_D is drag coefficient, r_m is specific weight of matrix, r_f is specific weight of fiber, and a_f is a projection area of the direction of a right angle at the direction of flow. The first term in the right side of Eq. (1) indicates the drag by the difference of velocity between fiber and matrix and the second term indicates the gravity and buoyancy of fiber and θ is the angle formed between gravity and the direction of flow. Also, the third term indicates shape of fiber, fiber content, and molding condition affected by friction of fiber or tangled power that receives interaction force of constraint.

In case of Newton fluid, drag coefficient can be expressed in $\alpha Re_f^{-\beta}$ (In case of globe $\alpha = 24$, $\beta = 1$and in case of cylinder $\alpha = 6.474$, $\beta = 0.883$). Actual drag coefficient C_D of fiber during flow molding by calibration coefficient j is

$$C_D = j\alpha Re_f^{-\beta} \tag{2}$$

and Reynolds number Re_f is

$$Re_f = (V_m - V_f) d_f \rho_m \mu_n \tag{3}$$

where ρ_m, μ_m are density and viscosity of matrix and d_f is a diameter of fiber in case of a cylinder. Diameter in case a globe d_{fs} is

$$d_{fs} = \sqrt[3]{1.5 d_f^2 \overline{1}_f} \tag{4}$$

where $\overline{1}_f$ is average length of fiber.

As velocities V_c, V_f, V_m are changing in the process of separation between matrix and fiber, it is presumed that V_m and V_c are the same. In addition, by ignoring the terms of gravity and buoyancy, it is presumed as a steady status as Reynolds number (Re_f<0.1) is small. Using the above assumption, fiber is presumed as a globe and if it obtains velocity V_f of fiber from the formula (1), (2), (3) and (4), fiber is

$$V_f = V_c - \frac{f_f}{18 j_{sp} w_f} \frac{r_f d_{fs}^2}{\mu_m} = V_c - K_{sp} \frac{r_f d_{fs}^2}{\mu_m} \tag{5}$$

where V_c is the velocity of composites and K_{sp} is the separation coefficient.

In Fig. 1, when compression flow (z direction velocity is ignored as thickness of z direction is small compared to the length and width of x, y direction) of one dimensional rectangle plates, the relationship between separation coefficient and average velocity of x direction is investigated. If it calculates average velocity $\tilde{V}_m$ (Eq. (6)) of x direction assuming that velocity of composites and velocity of matrix are the same.

$$\tilde{V}_m = \frac{2}{h}\int_0^{\frac{h}{2}} V_m dz \frac{\dot{h}}{h} x \tag{6}$$

where $\dot{h}$ is the closure speed of press and h is the thickness after molding.

Average velocity incline is

$$\bar{\gamma}\frac{2}{h}\int_0^{\frac{h}{2}} \gamma dz = 2C\frac{\dot{h}}{h^2}x \tag{7}$$

where γ is velocity incline and C = (2 nm + 1)/(n_m + 1), n_m is structural viscosity index of polymer.

Since composites are pseudo-plastic fluids, viscosity μ_m expresses as pseudo-plastic model by Eq. (7)

$$\mu_m K_m \bar{\gamma}^{\frac{n-1}{m}} = K_m\left(2C\frac{\dot{h}}{h^2}x\right)^{\frac{n-1}{m}} \tag{8}$$

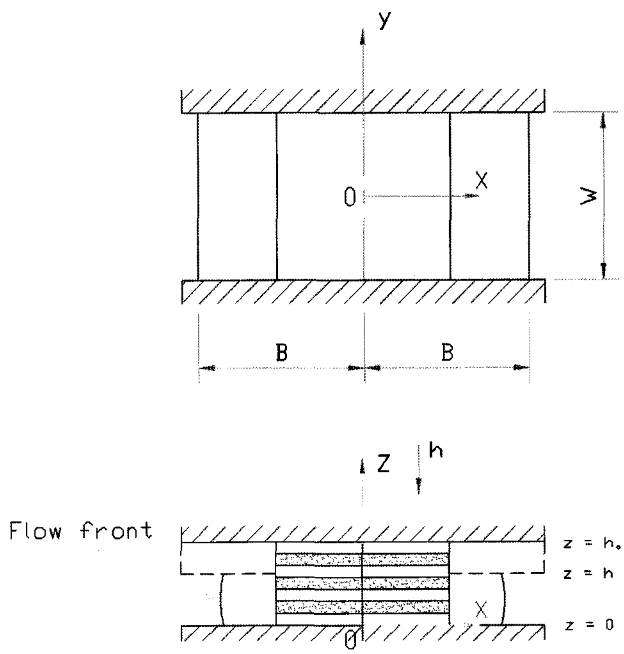


Fig. 1. Nomenclature for slab-shaped part compression molding.

where K_m is structural viscosity of polymer.

Velocity V_f of fiber among high temperature compression molding from the Eq. (5), (6), and (8) is

$$V_f = \frac{\dot{h}}{h}x - K_{sp}\gamma_f d_{fs}^2\left(2C\frac{\dot{h}}{h^2}\right)^{1-n_m} \tag{9}$$

2.2 Equation of Fiber Orientation

It only considers velocity incline in the direction of x axis because of suppression the flow of y direction in the Fig. 1.

In the Fig. 2, fiber with length L positioned in the middle of the flow rotates by the difference of velocity in the direction of x axis. Angular velocity of fiber is Eq. (10).

$$\dot{\theta} = \left[\frac{V_{fa} - V_{fb}}{L} L\right] sin\theta \tag{10}$$

where V_{fa} and V_{fb} are the velocity at both ends of fiber.

$$V_{fa} = \frac{dV_f}{dx}\left(x + \frac{1}{2}cos\theta\right) \quad V_{fb} = \frac{dVf}{dx}\left(x - \frac{L}{2}cos\theta\right) \tag{11}$$

where dV_f/dx is velocity incline in the direction of x axis. Velocity difference at the both ends of fiber is

$$V_{fa} - V_{fb} = \frac{dV_f}{dx} L cos\theta \tag{12}$$

Angular velocity of fiber θ from the Eq. (10) and (12) is

$$\dot{\theta} = \frac{dV_f}{dx} cos\theta sin\theta \tag{13}$$

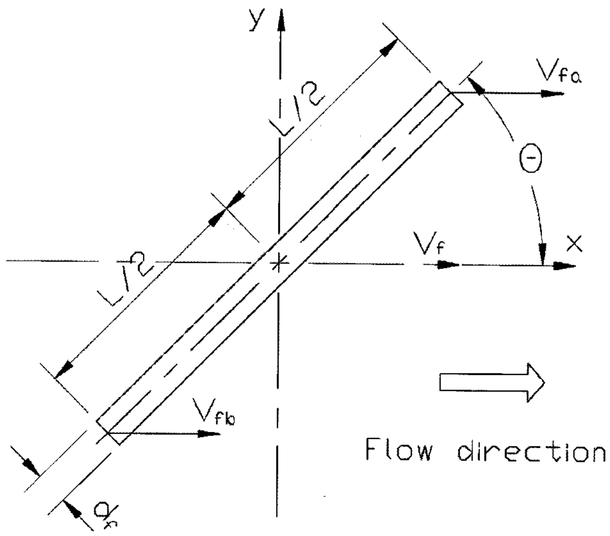


Fig. 2. Flow direction of fiber.

In addition, in case separation of fiber positioned at the distance x from the center of molding product occurs, if differentiated by x in Eq. (9) velocity incline is

$$\frac{dV_f}{dx} = \frac{h}{h} - \frac{K_{sp}\gamma_f d_{fs}^2}{K_m}(1-n_m)\left(2C\frac{h}{h^2}x\right)^{-n_m} \quad (14)$$

When substituting Eq. (14) with Eq. (13), angular velocity of fiber is

$$\theta = \left[\frac{h}{h} - \frac{K_{sp}\gamma_f d_{fs}^2}{K_m}(1 = n_m)\left(2C\frac{h}{h^2}x\right)^{-n_m}\right]\cos\theta\sin\theta \quad (15)$$

3. Experimental procedure

Matrix and glass fiber were laminated by intersecting angle θ° of chopped strand that was oriented at 30°, 45°, and 60° into the direction of x axis in the Fig. 3. To

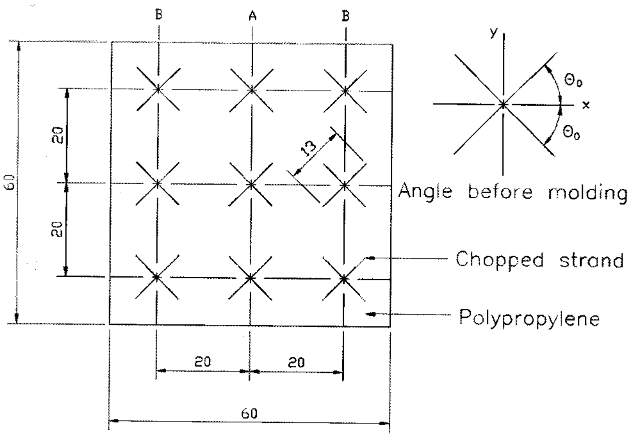


Fig. 3. Specimen for one-dimensional square shaped.

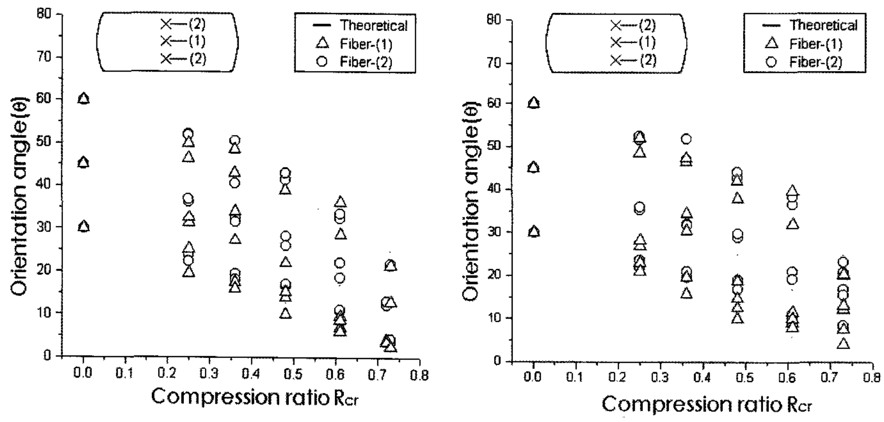
manufacture primarily sheet, polypropylene sheet with the thickness of 0.25 mm was cut into the size of 60 mm (width)×60 mm (length) and have laminated 18 sheets and then manufactured specimens using thermo compression press. At this time, mold temperature and material temperature were all set at 200°C, when specimens laminate in the 9 locations of middle layers in Fig. 3, fibers with the length of 13 mm (strand Tex: 75, filament diameter: 14 μm) were stacked in intersection mode.

Closure speed used in high temperature compression press molding was 1 mm/s, 10 mm/s, 18 mm/s, and 25 mm/s and compression ratio (R_{cr} = 1-h/h_o, h: thickness after molding, h_o: thickness before molding) was 0.25, 0.36, 0.48, 0.61, and 0.73. At this time, dimension of mold cavity was 60 mm×240 mm and temperature of blank was 200°C and temperature of mold was maintained at 200°C. As a compression device, 25 tons hydraulic thermo-press (CARVER, MODEL: 2518) was used. In high temperature compression press molding of a specimen with intersection angle θ° of chopped strand, flow of material has bound the direction of width like the Fig. 1 to make it only in the direction of length and it was set at θ by measuring the angle of fiber orientation of molding product after high temperature compression molding of primary dimensional plate.

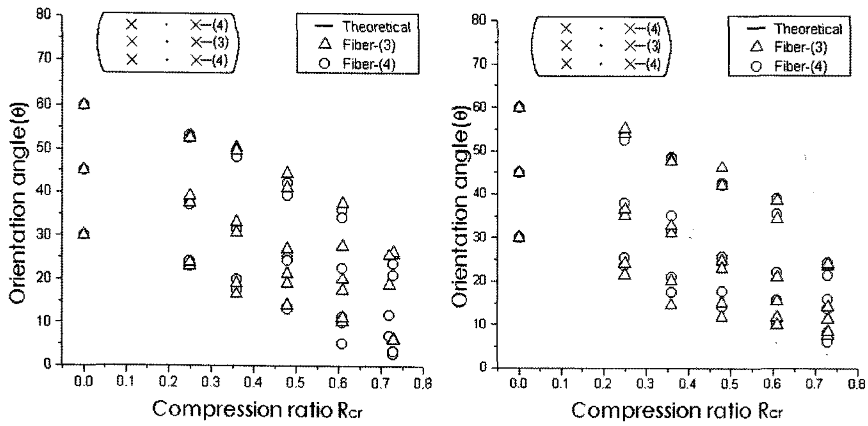
4. Results and Discussion

Fig. 4 shows the results of experiment of fiber orientation angle generated by the difference of displacement after high temperature compression press molding by changing closure speed and compression ratio R_{cr} of press by orienting intersection angle θ° of fiber as Fig. 3. Diagram of Fig. 4 calculated with separation coefficient K_{sp} = 0 as presuming that it is not separated using the Eq. (15). In the Fig. 4 (a), orientation angle θ of fiber (1) located in the central part of molding product conformed to theoretical angle. In addition, orientation angle θ of fiber (2) placed in the vicinity of wall surfaces of mold and theoretical angle also conformed. However, it was noticed that measured orientation angle of fiber became larger than theoretical angle as it is more affected by friction influences of wall surfaces of mold than the influences of compression speed as the speed of flow becomes slower by the friction influences of wall surfaces according to the increase of compression ratio.

In case of fiber (3) in the Fig. 4(b), as it is positioning relatively in the center compared to fiber (4), it is less affected by friction influences of wall surface of mold and angle of fiber rotation turn in the direction of +θ by



(a) A-part



(b) B-part

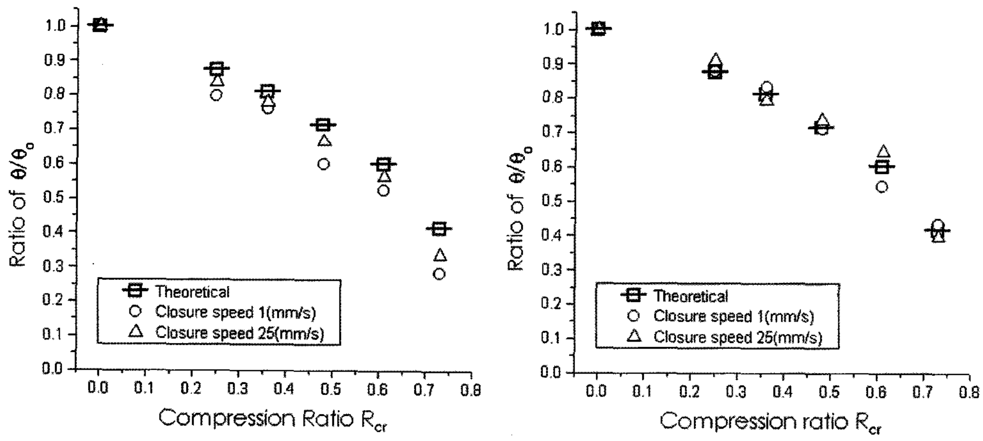
Fig. 4. Relationship between compression ratio and orientation angle.

velocity incline of the direction of x axis and rotates in the direction of $-\theta$ by velocity incline of the direction of y axis. In fiber (4), flow fiber flows toward the direction of walls of mold as material flows toward walls of mold from the center at vertical hemline and rotation by velocity incline of the direction of x axis is not carried out, it rotates in the direction of $-\theta$ than velocity incline of the direction of x axis. Moreover, it also rotates in the direction of $-\theta$ by velocity incline of the direction of y axis. As the result, angle of fiber rotation becomes larger than theoretical angle because fiber orientation is not done well.

Also, as the more the compression ratio is bigger, the more velocity of material becomes faster and as material flows fast toward walls of mold from the center at flow, velocity incline of the direction of y axis becomes larger. Therefore, as angle of rotation by velocity incline of the direction of y axis becomes larger, the difference with theoretical angle becomes larger.

Fig. 5 shows the orientation angle ratio of fiber according to the changes of compression ratio by laminating with matrix and chopped strand of intersection angle of 60° in case compression velocity was changed at the time of press molding. As the case of fiber of A part is positioning at the central part than fiber of B part, it is only affected by velocity incline of x axis and less affected by velocity incline of y axis appearing at flow, the measured angle becomes a little smaller than theoretical angle. In case of fiber of B part, angle of fiber orientation at the central part was similar to theoretical angle but fiber orientation in the vicinity of walls of mold showed a little difference with theoretical angle than the central part due to the influence of friction of wall surface and velocity incline of the direction of y axis.

Fiber orientation generated during compression molding is formed by both of velocity incline of the direction of x axis and velocity incline of the direction of y axis and it was noticed that the more closure speed is faster and the more compression ratio is bigger, the more the flow of material becomes longer and measured angle of fiber orientation



(a) A-part　　(b) B-part

Fig. 5. Relationship between ratio of θ/θ_0 and compression ratio R_{cr}.

becomes larger than theoretical angle. In addition, influence of velocity incline of the direction of x axis becomes larger at the central part of molding product and velocity incline of the direction of y axis is generated due to friction influence in the vicinity of wall surfaces of mold and it affects fiber orientation. And as angle of fiber orientation at vertical hem of flow is oriented to the direction of y axis, it is noticed that the measured angle becomes larger than theoretical angle.

5. Conclusions

(1) The Basic formula of short fiber orientation was induced and in the central part of molding product, there was almost no influences of velocity incline of the direction of y axis and as it was oriented by velocity incline of the direction of x axis, theoretical angle of fiber orientation and measured angle of fiber orientation conformed each other.

(2) For QTi3.5-3.5In the vicinity of wall surfaces of mold, because of friction influences, velocity incline of the direction of y axis was generated and affected on fiber orientation and angle of fiber orientation at vertical hem of flow was oriented into the direction of y axis and therefore, it was noticed that the angle becomes larger than theoretical angle.

(3) Influences of fiber orientation by compression velocity and compression ratio during high temperature compression press molding was noticed that as the more compression velocity becomes faster and also the more compression ratio becomes bigger, the more flow of material becomes longer, measured angle of fiber orientation becomes larger than theoretical angle.

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