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Centrifugal Powder Forming of Thermoplastics
粉末プラスチックの遠心成形

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1. Introduction

Cylindrical parts of thermoplastics are mostly made either by extrusion or by injection moulding from liquid state. These processes, however, are not so simple because they involve longer time, more heating for pelletizing and melting of the powder, application of pressure, highly complex dies, and production of waste materials. To avoid the wastes and make the process more simple, the solution may be either cold forging of powder (powder metallurgy)[1] or sintering of the powder in a hot rotary die[2], but some problems are still to be solved. Thus a new powder forming process[3] has been developed that involves centrifugal force and simultaneous heating for powder forming in which instantaneous melting of the powder takes place and simultaneously the molten plastic is cast into shapes under the action of a higher centrifugal force by using a fairly heated forming die rotating at high speed. In this paper the examination and the discussion are based upon such features as the reduction in the processing steps, the possibility of producing composites, and so on.

2. Centrifugal powder forming technique

The technique involved in this forming method is almost similar to that of centrifugal casting of molten metal for making large diameter pipes, using a rotary cylindrical die. The main difference exists in the state of raw material being fed. In centrifugal casting the raw material is fed in molten state while in the present forming method of plastics, green powder of the plastics is fed initially. In addition to this other differences are that only the required amount of powder is fed and the pressing of the powder is affected by the centrifugal force developed due to large number of revolutions of the die itself. The powder fed is instantaneously pressed to the inner wall of the hot rotary die by centrifugal force and at the same time it melts resulting in casting or forming into a required shape. The products made by this method can constitute more than one kind of polymer for example, a mixture of two or three kinds of materials or it can be reinforced with glass fiber, thus making a composite. The experimental apparatus used in the process is illustrated schematically in Fig. 1 where two versions of this method are shown. In Fig. 1(a) the axis of rotation of the rotary die is vertical whereas it is horizontal in Fig. 1(b). The rotary dies in both the cases are heated to a predetermined forming temperature by electric resistance heating system with an output of 2.4kw. An extra heating element is also often used inside the rotary die along its axis as shown in Fig. 1(b) to enhance the rate of heating and its uniformity. The current and voltage in the heating system are precisely controlled by means of slidax to maintain uniform required temperature of the inner wall of the die.

3. Experimental

3. 1 Specifications of powder and glassfiber

Polyethylene powder (Hizex 2100; mesh size: 90~200; apparent density: 0.95; melting point: 137°C) was used for the forming experiment in general. In case of the experiment

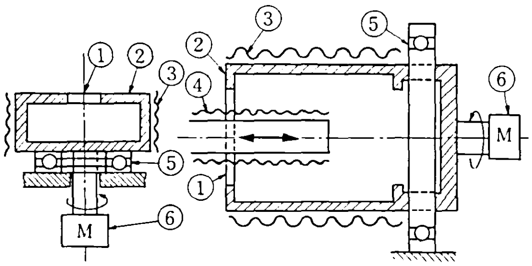

Fig. 1 Two versions of the experimental apparatus used in centrifugal powder forming of thermoplastics
1. die opening 2. die 3. electric resistance heater 4. inside heater 5. bearings 6. motor [(a) 600–3000, (b) 60–500rpm]

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on reinforcement with fiber, glassfibers (diameter of monofiber: 10.9μ, gathering: 5~10, density: 2.55 and tensile strength: 220 kg/mm^2) were used.

3.2 Die

The vertical rotary die has an inner diameter of 80mm and a height of 30mm while the inner diameter and length of the horizontal rotary die were 96mm and 120mm respectively. Two kinds of grooved dies were also used. One of them was for making an external spur gear with outside diameter – 62.5mm; number of teeth – 60; tooth width – 10mm and module – 1.1. The other one was a cylinder with screw thread on its outer diameter having an outside diameter – 101.5mm; thread height –3.175mm; thread peak radius – 1.515mm; number of threads per inch – 4 and pitch – 6.350mm. All dies and stoppers were made of mild steel.

3.3 Selection of forming condition

An experimental cycle of the centrifugal powder forming is illustrated in Fig. 2 which indicates the temperature at which the powder must be fed to the die and the time duration. Thus, the required amount of powder should be fed to the rotating die which is being heated rapidly to the forming temperature that should be higher than the melting point of the polyethylene. Any variation in the forming temperature causes a bad effect on the process itself; for example, too low forming temperature or a short forming time results in the presence of some unmelted powder particles on the inner surface of the product. On the other hand, if the temperature is too high, some of the polyethylene would burn away from the surface of the product due to overheating. In the present experimental trial it was found that the best result would be obtained by keeping the forming temperature in the range of 150~200°C for a time duration of 20~30 seconds, and hence the same was recommended in the final experimental work of this paper. The die was cooled by means of air or water flow after completion of forming to a temperature of 50~70°C at which the product could be taken out of the die.

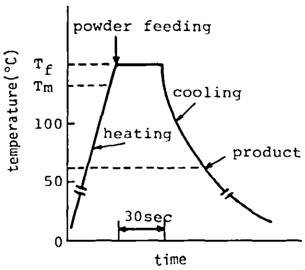


Fig. 2　Experimental cycle used in the centrifugal powder forming

As no excess feeding of the powder may be expected in this method, the amount of the powder fed can be closely related to the wall thickness of the cylinder as shown in Fig. 3. The specific weight of the powder fed can be expressed as

$$w = \frac{\gamma (D-s)\, s}{D},$$

where w is the specific weight of the powder fed (g/cm^2), s – the wall thickness, D – outside diameter and γ – density of the polyethylene (plastics formed).

The number of die revolutions is also very important factor in maintaining an uniform thickness of the product in the axial direction. It becomes more prominent particularly in case of vertical type where the thickness tends to change uniformly from top to bottom due to the effect of gravity which causes the molten polyethylene to concentrate at the bottom during forming. In an experimental trial, it was found that this variation could be kept below 7% at a rotating speed of 2000rpm. Thus, the requirement was that the variation must be kept to a minimum possible value, and therefore the height to outer diameter ratio of the cylindrical product made by vertical type die was kept very low. But in case of horizontal type die, a moderate speed of 200~300 rpm was found adequate to assure a quality product. As a result in the actual experiment a rotating speed of 3000 rpm was selected for the vertical type and 300 rpm for the horizontal type.

3.4 Fiber reinforcement

The glass fibers to be used for reinforcement in the plastic parts were cut into lengths from 2~200 mm and were added in volume fractions from 5~25%. The shorter fibers

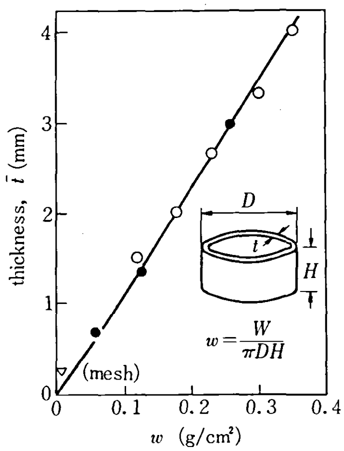


Fig. 3　Relationship between the amount of powder fed and the wall thickness of cylindrical product

of 5~10 mm lengths could easily be mixed with the polyethylene powder before forming but the longer fibers could only be added after feeding the powder during forming due to the difficulty in mixing with the powder.

3. 5 Properties of the product

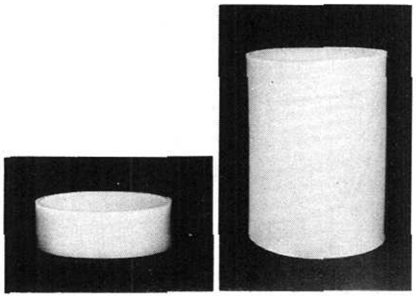
The cylindrical parts as they appear after forming are shown in Fig. 4 by separate photographs. The product shown in Fig. 4(a) was made by using the vertical type die and that shown in Fig. 4(b) by using the horizontal type die of the centrifugal forming apparatus. The outer and inner surfaces of the cylinder thus produced were remarkably smooth. However, if the amount of powder required to be fed is less than sufficient a hemitransparent product, which is ordinarily produced, can become porous or like a mesh as shown in Fig. 5.

The important features of products made by this method are clearly shown in Fig. 6. Fig. 6(a) shows the photograph of a cylinder with screw thread on the outer surface that might have been a very difficult task in conventional process. On the other hand a very thin gear shown in Fig. 6(b) can also be made successfully using a vertical type die. In both the cases the polyethylene powder particles at the top portion of either the thread or gear tooth were compacted with high pressure due to larger centrifugal force action, thus resulting in precise shape and higher strength of the top portion.

Fig. 7 shows the products of composite material (plastics surface being covered with stone powder) made by this process. As a large difference exists between the densities of polyethylene and stone powder, the stone powder being heavier is thrown on the inner surface of die while the polyethylene powder being light remains above it. This results in the concentration of stone powder on the outer surface of the product as if it were plated or painted on the surface. It was, however, not found in case of mixture of two materials having the same density as each other.

The shrinkage in outer diameter, after completion of the forming and taking out the product from the already cooled die, is almost of same order as found in injection moulding. This shrinkage, however, can be reduced uniformly from about 3% of die size by increasing both the fiber content and fiber length as it is apparent from the result shown in Fig. 8.

The effect of fiber reinforcement was examined by lateral compression test of a cylindrical specimen (diameter – 96mm; height – 60mm and thickness – 2.2mm) obtained



(a) vertical (b) horizontal

Fig. 4 Examples of cylindrical products obtained in centrifugal powder forming

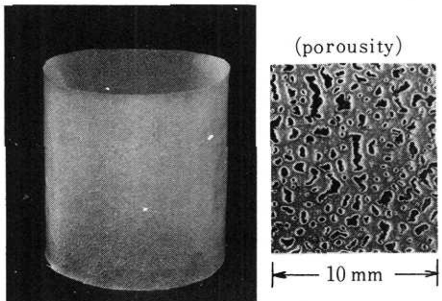
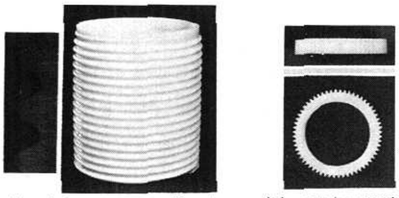


Fig. 5 Meshes obtained in a cylindrical products in case of smaller amount of powder fed



(a) screw thread form on outer diameter by horizontal type (b) gear by vertical type

Fig. 6 Photographs of cylindrical products with screw thread on the outer diameter and gear tooth

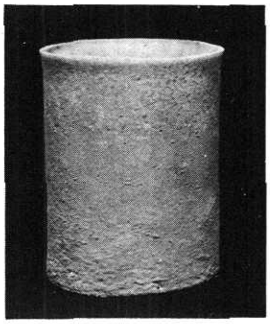


Fig. 7 Composite parts having stone powder on the polyethylene base

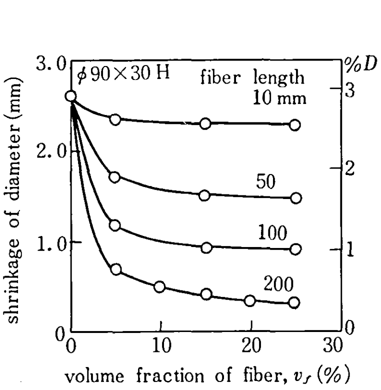
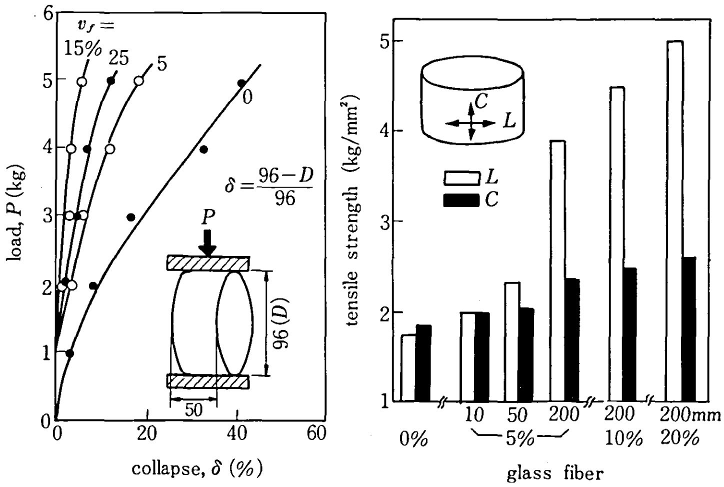


Fig. 8 Effect of the increasing amount of fiber content on the shrinkage of the products



(a) lateral compression (b) circumferential and axial tension

Fig. 9 Results showing the improvement in strength by glass fiber reinforcement

in horizontal rotary die, and by circumferential and axial tension test of a cylindrical specimen (diameter – 90mm; height –30mm and thickness –3mm). The results are plotted in Fig. 9 along with the illustration of the test. In Fig. 9(a), the curve representing the relationship between the lateral load and the deflection or collapse tends to shift towards the higher load with increasing fiber content (fiber length = 10mm) until it is 25% at which the curve suddenly falls down to a lower load side corresponding to a large deflection or collapse. This is supposed to be due to the lack of binding between fibers and matrix because of higher fiber content.

The circumferential tensile strength of the reinforced composite cylinder shown in Fig. 9(b) is found to be imporving with the increasing fiber content and such an increase in strength goes upto three times of the polyethylene product without any reinforcement. The axial tensile strength, that is parallel to the axis of revolution, is imporved only slightly; this may be most probably because of the orientation of the fiber lengths in the circumferential direction caused by its rearrangement during forming as a result of the tangential force induced by rotation of the die. In fact, it is desirable to have higher strength in the circumferential direction in practice, for pipes with high internal pressure. In addition to this it is also apparent that for a lower fiber content such as 5%, the efficiency of reinforcement is greater for longer fiber than that of shorter one.

4. Conclusions

The centrifugal forming of plastics powder discussed in this paper has many merits such as simplicity of the process, simple die, shorter cycle, absence of scrap and the treatments followed by the possibility of producing complex outer surfaces such as thead and gear tooth. In addition, the formed part by this method is almost free from residual strain or shape change caused by the working time and heat as different from the products by cold forming. The product is more ductile as compared to the product by usual sintering methods because it is essentially produced in molten state. Though some problems such as in heating, compositation, handling etc. are still to be solved for improving the quality, the process may be applied to produce a number of complex parts.

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