特集　11
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New Forming Process of Thermoplastics Sheet by Using Strain Recovery

プラスチック薄板の熱誘起成形

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1. Introduction

It is wellknown that many thermoplastic resins, especially the cold worked ones tend to be changed in shape by the heat and the time in practice. The phenomena seem to be caused by the recovery of the residual strain. The similar but surprisingly greater deformation is recently recognized by authors [1]. For example, the thin plate that was sliced off form the round screw-extruded bar can naturally yield or flow without the applied force to make the deep conical shell at the high temperature by its melting point. By using this thermal deformation, which is provisionally called "Recovery–Induced–Deformation" here, the excellent container can successfully be made on the simpler forming process.

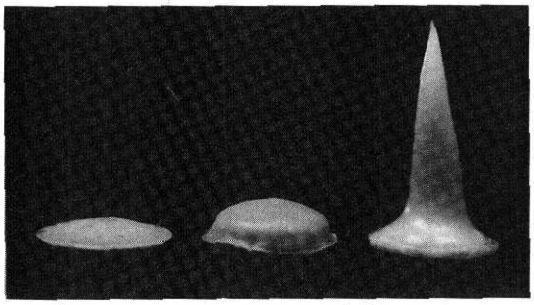
2. Behaviours of Recovery–Induced–Deformation

2.1 Experimental

Two kinds of the ordinary thermoplastics bar i.e. high density polyethylene (PE, ϕ 50& ϕ 100) and polyvinyl chloride (PVC, ϕ 50) are mainly used for testing of the thermal flow. The physical and mechanical properties of them are generally put in Table 1. To prepare the specimen (blank), both round bars were sliced into the circular sheets of about 2 mm thickness by the saw. And then the both surfaces of the blank were finished with the emery papers.

It was found that the blank was changed naturally from the flat sheet to the conical shell by the isothermal flow or deformation while it was kept in the warm oil bath or drying oven for a given time. The dimensional changes in the forming cone and the strain distribution of it are measured after air cooling.

2.2 Phenomena of Recovery–Induced–Deformation



(a) 120 ℃×10min　(b) 130 × 10　(c) 140 ×10
Fig. 1　Examples of isothermal deformation of polyethylene

Table. 1　Physical and mechanical properties of testing materials

resin	glass transition temperature Tg ℃	melting point Tm ℃	tensile strength kg / cm^2	elongation %	elastic modulus kg / cm^2	compressive strength kg / cm^2
PE (H. D.)	−85	135	218 387	15 100	4,218 10,550	225
PVC (hard)	82	180	352 632	20 40	24,610 42,180	562 914

The typical examples of the isothermal deformation on PE sheet (ϕ 50×t 2) are shown in Fig.1; the blank is remarkably yielding or flowing to be

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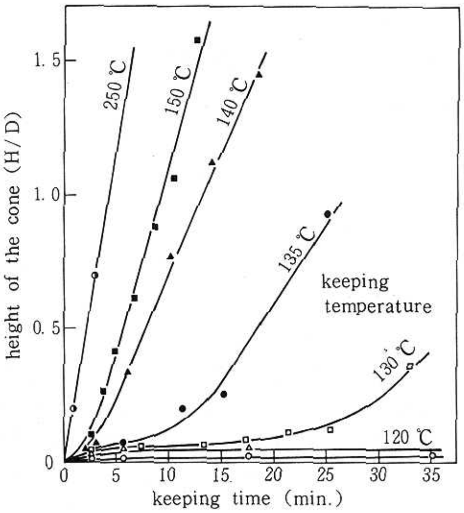


Fig. 2　Effects of keeping temperature and keeping time on the isothermal deformation of polyethylene

the bulged shape like the cone without any applied force at the high temperature by the melting point.

The height of the cone grows slowly as the keeping time increases until the parabolic curve becomes saturated at lower temperature, while at higher temperature, especially above 140 ℃ the rate of the deformation increases with increasing temperature as shown in Fig. 2. The form of the curve is almost linear at the higher temperature and by the melting point it is combined with these two types. The similar sorts of the flow are also clearly noticed in the case of the other thermoplastic material such as polypropylene (PP), polyacetal (POM), polyamide (Ny 6) and so on. Furthermore, it is experimentally confirmed that the start of the natural flow is retarded with increasing the initial thickness of the sheet but the rate is not considerably affected.

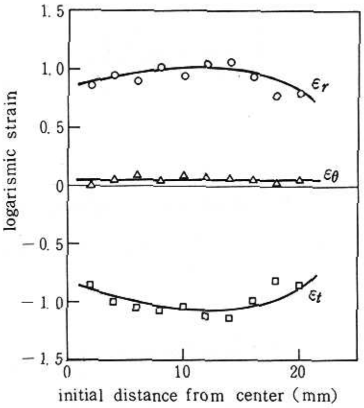


Fig. 3　Example of strain distributions in the cone after the isothermal deforming of polyethylene (keeping : 140℃×10min, *height : 61mm*)

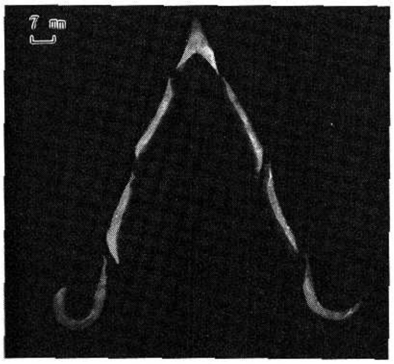
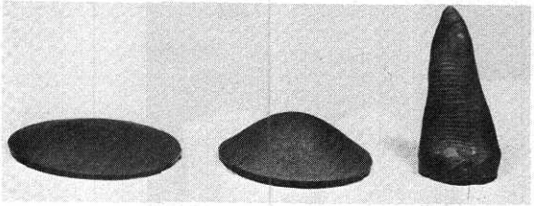


Fig. 4　*Independently isothermal deformations* of segments of polyethylene sheet after keeping at 140℃ for 10min.

The strain distributions of the naturally formed cone of PE ($\phi 50\times t2$) are very interested. The most noticeable feature is that the values of circumferential strains (ε_θ) are almost nil and the radial strain (ε_r) positive, and they distribute almost uniformly, differing from that in the usual sheet forming, as shown in Fig. 3. As a result, the smaller variations in the thickness of the cone is most desirable properties, for a example, for the preformed shape to be blowformed as mentioned later.

The essential meanings of the recovery induced-deformation are made more clear by an another experiment. In Fig. 4, each segments, which were cut off from the circular sheet specimen ($\phi 50\times t3$) of PE along the centre line to the shape of $\ell 7\times w5\times t3$ and then kept in the oil bath at 140 ℃ for 10 min., are considered to be able to deform or elongate independently each other as if the shearing force was applied to the longitudinal direction. Therefore, the strain distribution of the cone can necessarily be made uniform by the integration of these individual deformation as mentioned above.

In the case of polyvinyl chloride, the behaviour of the isothermal deformation induced by heating it, is apparently different from that in the case of polyethylene. In this mode the growth of the cone is characterized by increasing the height followed by the shrinkage of the outer (base) diameter, as shown in Fig. 5. And, therefore, the circumferential strain (ε_θ) is not only negative, but also, along with the other strains, varies considerably from the top to the base. The effects of the keeping time and the keeping temperature only on the height of the forming cone are illustrated in Fig. 6.



(a) 100 ℃×40 (b) 140 ×40 (c) 180 × 2

Fig. 5 Examples of isothermal deformation of polyvinyl chloride

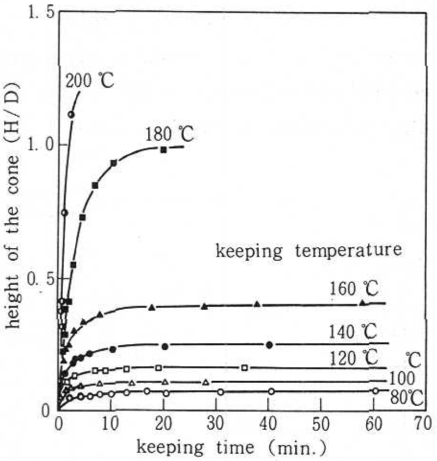


Fig. 6 Effects of keeping temperature and keeping time on isothermal deformation of polyvinyl chloride

3. New forming process by using the Recovery – Induced – Deformation

3.1 Apparatus and procedure

It is generally difficult to make a deep container having the uniform thickness distribution on the usual simple processes such as blow forming, vacuum forming and so on. However, this problem may be able to be solved by using the new forming process put forward here. To make the thin wall container of more uniform thickness and greater depth, the recovery - induced - deformation mentioned above is successfully used for the preforming. In this proecss, the blank which was sliced into the thickness of 3 mm from the round extruded bar (ϕ100) of PE is formed into various sorts of shape by a blow of the low compressed air after the free preforming by the recovery - induced - deformation.

Fig.7 shows schematically the trial apparatus of this method, that is the recovery - induced - forming. The blank on the lower chamber which is selectively able to include the various sorts of axissymmetrical dies, is naturally changed or preformed into the conical shell by the recovery-induced -deformation until the top of the cone reaches to the die face under a given condition of temperature and time, and then formed or stretched out by a blow of the low compressed air (room temperature, about 1 kg/㎠). The atomosphere in the chambers can be warmed by the resistance heater contacted on the outside of the cylinders, and the temperature can also be detected and accurately controlled by the thermometer and the bimetal.

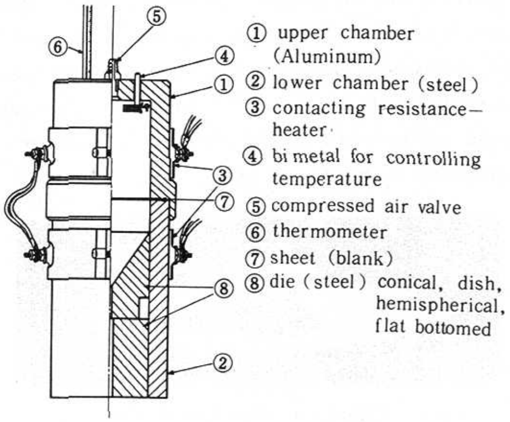


Fig. 7 Testing apparatus for the recovery -induced-forming

3.2 Recovery – induced – forming

The recovery–induced–forming procedure and some products are photographically shown in Fig.8; (a) blank (ϕ100×t 2), (b) free preformed, and (c) – (f) some examples of formed parts with various bottoms. The qualities of these cups are much higher than that of the usual process on many points such as being deep, having the thin wall, uniformity of thickness, having sharp contour and so on. This process is not so difficult but the suitable choice of the forming conditions, for examples, keeping temperature, keeping time, blowing pressure, thickness of blank, shape of die etc. is most important, because the insufficient preforming and higher pressure cause the cup to be locally thinner but the excessive preforming tends to make the buckled parts.

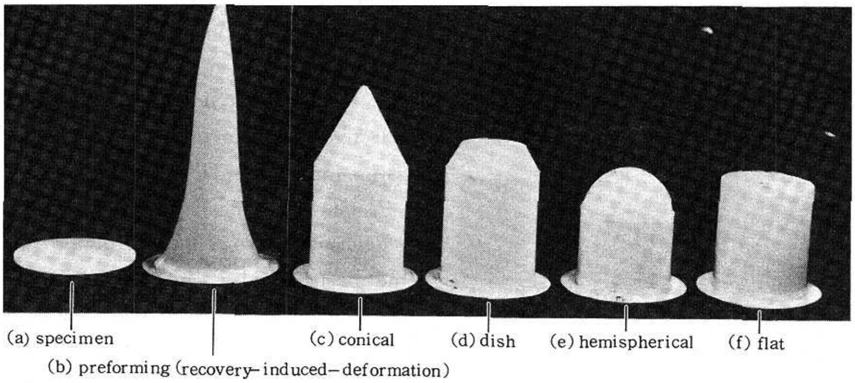


Fig. 8 Procedure and examples of products of heating induced forming (ϕ100×t3,polyethylene)

On the other hand it was experimentally confirmed that an usually commercial sheet, that was not sliced from the round extruded bar, could not successfully be formed by the same treating owing to the failure as shown in Fig. 9, because it did not have the similar recovery-induced-deformability as mentioned above.

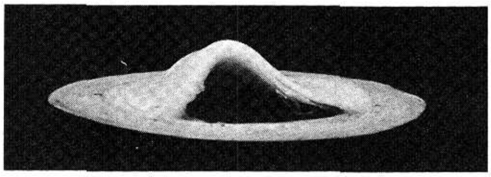


Fig. 9 Breakage in forming of usually commercial sheet of polyethylene after keeping at 180℃ for 30min.

In the recovery-induced-forming, the thickness distribution of the conical preform is made more uniform than that by the other method. Therefore, the final products of various shapes are also naturally able to have less variation of thickness. An example of the measured result is shown in Fig. 10 on the conically bottomed cylindrical cup, whose shape is similar to the preform. Apparently the distribution of thickness is considarably uniform there.

Furthermore, the shrinkage of parts after forming (blowing) is almost negligible, and hence the dimensional accuracy of the part to the die is most excellent. In addition, the thermal stability of the cup in using at room is also essentially more reliable than that by the other methods, because the recovery-induced-forming process is performed in hot stage and mainly based on the release or the unpinning mechanism of the own residual deforming ability of the blank. For examples, the dimensional changes of the cylindrical vessels, which were made from the sheets of 3 and 7mm thickness to the outer diameter of 80mm and the depth of 95 mm, was almost not measured under the conditions of the empty and the filling with water 100 ℃ for 30 minutes. As results, it is

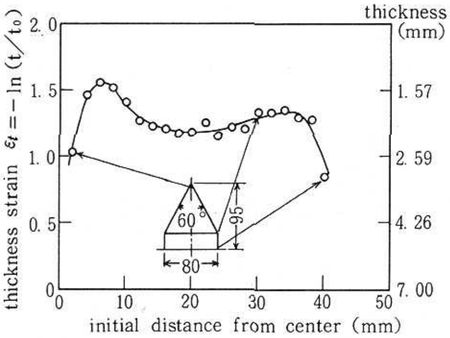


Fig.10 Thickness variations of the cone-bottomed cup of polyethylene (initial thick.: 7mm, keeping: 180℃×35min, blowing pressure: 1kg/cm²)

seemed that the internal energy becomes more stable while recovery–induced–forming and hence the dimensional changes do not appear differing from the ordinary hot working process.

On the view point of the forming speed, the rate of the preforming tried above is comparatively slow but can considerably be fastened by using the much higher temperature than the melting point, for example, about 400℃. And also it is, in practice, unnecessary to slice with the saw and finish by polishing as in the present work. Because the usual cutting methods with the knife or the other tools are enough to deform the blank without any troubles, the processing speed can more be raised.

4. Conclusions

It was found that some thermoplastics sheets sliced off from the round extruded bar get the great growth into the conical shell by the melting point without any applied force, while the usual sheet have no change. This thermal deformation i. e. recovery –induced –deformation seems to be caused from the recovery of the strain–memory when extruding, and is characterized by the uniform growth. A new forming process which is essentially based on the recovery –induced –deformation is put forward. In this process, the vessels of higher quality can successfully be manufactured by more simple procedure. Furthermore, the relation of the extruding condition to the behaviour of the recovery –induced –deformation and the application of the local heating to the control of the deforming are being investigated from all approaches.

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Reference

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次号予告（3月号）

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