Evaluation of the Formability of Plastic/Zn22Al/Plastic Sandwiched Structures by Gas Blowing

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For the manufacturing of electromagnetic interference (EMI) shielding enclosures for portable 3C (computer, communication, and consumer electronics) products, a superplastic Zn22Al thin sheet is inserted in between plastic plates and formed by in-mold blowing with gas pressure. In order to evaluate the formability of a plastic/Zn22Al/plastic sandwiched structure, free bulging tests are conducted in the temperature range between 135°C and 200°C in an infrared furnace. The results show that the ABS/Zn22Al/ABS sandwiched structure can be free bulged at 150°C with 0.21 MPa of gas pressure at a forming rate similar to that of the monolithic Zn22Al sheet. The PC/Zn22Al/PC sandwiched structure cannot be effectively bulged until the forming temperature is raised to 185°C. The optimized forming condition for PC/Zn22Al/ABS is either at 150°C with a gas pressure of 0.35 MPa or at 165°C and a gas pressure setting of 0.21 MPa. Also, the thickness distributions for Zn22Al and a variety of plastic/Zn22Al/plastic specimens after free bulging at various temperatures with various gas pressures are placed in comparison in this study.

INTRODUCTION

Although superplastic forming (SPF) technology has been in existence for many decades, most of its applications are reportedly involved with the aerospace industry. For 3C (computer, communication and consumer electronics) products, their manufacturing processes are usually designed with a strict concern for low cost and high production rate. Such requirements have hindered SPF technology from exerting its full capacity over the 3C markets. Among a number of superplastic alloys, Zn22Al stands out for its low material cost, low SPF temperature, a higher SPF rate and good mechanical properties. Consequently, it has been considered for superplastically forming the enclosures of portable 3C products such as notebook PCs, mobile phones and cameras—as a solution to the electromagnetic interference (EMI) problem prevalent in those fields. However, the relatively high specific weight of the Zn22Al alloy constitutes a disadvantage when competing with other metallic materials such as magnesium or even aluminum alloys in the manufacturing of portable equipment enclosures. This disadvantage can be circumvented by employing an innovative manufacturing method (*Fig. 1*) developed by one of the authors (1): inserting a superplastic thin metal sheet between two plastic plates and blowing this plastic/metal/plastic sandwiched structure in a heating mold to form a workpiece. For this purpose, the superplastic temperature of the metal sheet must be compatible with the softening temperature of the plastic plates.

Owing to their amorphous structures, ABS and PC plastics display the merit of size stability. As a result, they have been widely employed as enclosure materials for 3C products. The softening temperature for ABS and PC plastics as adopted in this study are 90°C and 156°C, respectively. A promising candidate for the superplastic metal sheet is the Zn22Al alloy, which displays superplasticity in an optimized temperature range between 200°C and 250°C as reported by many (2–7). Recently, through a modified thermomechanical treatment, the authors have developed a new Zn22Al thin sheet material that exhibits an ultrahigh superplastic forming rate in a low temperature range of 120°C to 200°C (8, 9). By clamping the Zn22Al thin sheet in an injection mold and then injecting the molten plastic into the mold cavity, a metal-cladded workpiece can be produced (10). The high temperature of the injected plastic (about 150° to 250°C) causes the Zn22Al thin sheet to become superplastic instantly and prevents it from breaking under the high forming pressure in the injection mold.

High tensile and impact strengths are also required to effectuate satisfactory plastic enclosures for portable wares. For this purpose, PC and ABS+PC

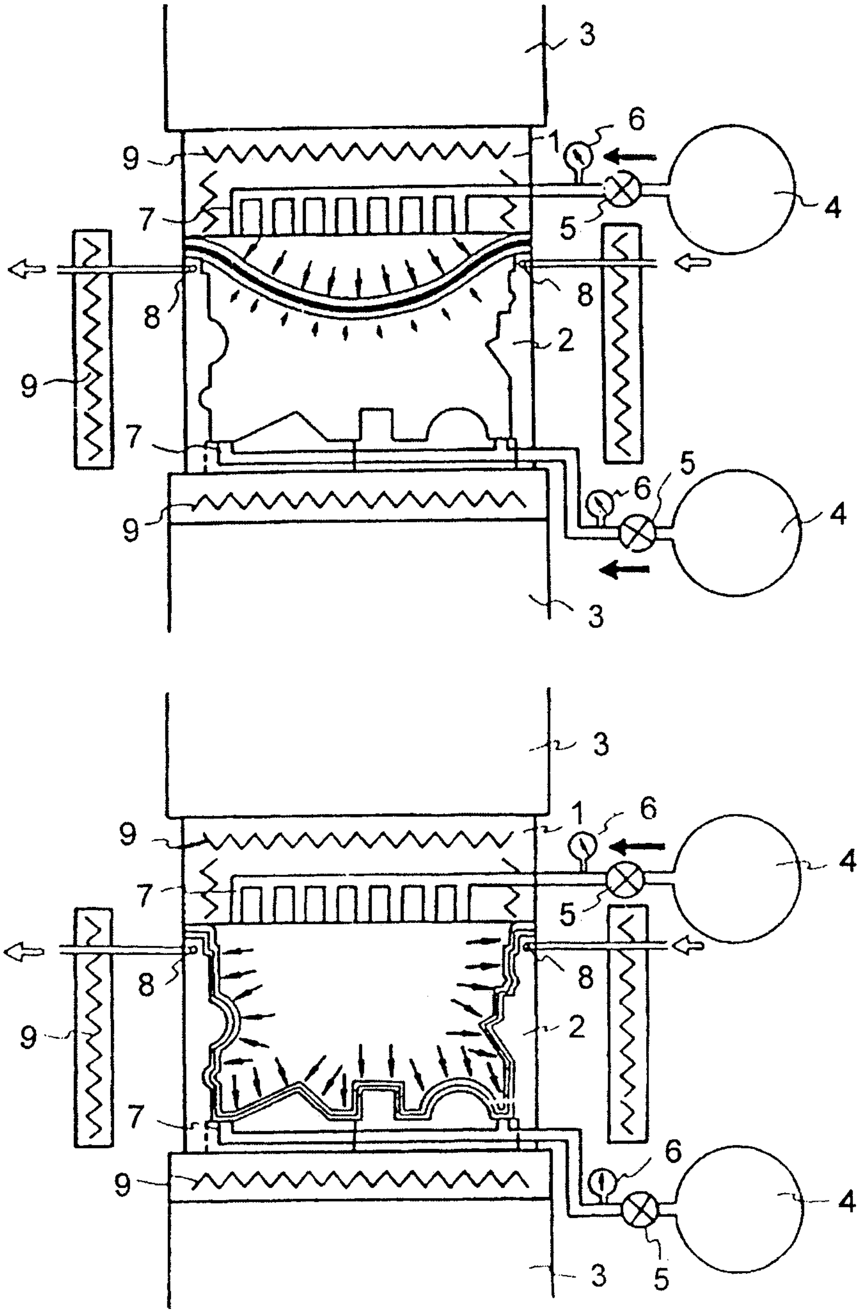


Fig. 1. An innovative process (1) for manufacturing a plastic/Zn22Al/plastic sandwiched structure as an EMI enclosure (1. upper mold , 2. lower mold , 3. oil pressure rod, 4. pressure system, 5. pressure valve, 6. pressure gauge, 7. runner, 8. thermocouple, 9. electric heater).

plastics are superior to the ABS plastic in spite of their higher costs. However, the use of the less expensive ABS plastic is made possible by a reinforcing Zn22Al thin sheet, as improvements can be made to the plastic structure of the composite workpieces produced via the proposed innovative methods (1, 10). Since the material cost of the superplastic Zn22Al sheet is somewhere close to that of ABS plastic, its innovative composite structure can also provide a cost-effective solution when competing with monolithic PC or ABS+PC plastic enclosures. For the manufacturing of an EMI enclosure by the gas blowing method exemplified in *Fig. 1*, the formability of such a plastic/Zn22Al/plastic sandwiched structure has to be evaluated. The influence of the cladded plastic plates on the superplastic flow of the Zn22Al thin sheet and the thickness distribution of the sandwiched structure are ascertained.

EXPERIMENTAL

The manufacturing process of the newly developed superplastic Zn22Al thin sheet material adopted in this study and the principle for attaining its ultra-high formability rate have been described in previous works (8, 9). The Zn22Al sheet was 0.2 mm thick. The engineering plastic plates with a thickness of 0.5 mm used in this study were acrylonitrile-butadiene-styrene (ABS) and polycarbonate (PC), which have softening temperatures of 90°C and 156°C, respectively. Three types of sandwiched structures were tested: ABS/Zn22Al/ABS, PC/Zn22Al/PC and PC/Zn22Al/ABS. The equipment for evaluating the formability of the sandwiched structures by gas blowing is shown in *Fig. 2*. The furnace was infra-red heated and the forming height of the workpiece was recorded by a PC-camera. Prior to testing, the Zn22Al thin sheet was inserted in between two plastic plates and cladded together by a hot-molten adhesive. The sandwiched structure was cut into disk-shaped specimens with a diameter of 150 mm, clamped in the formability-test equipment as shown in *Fig. 2*, and blown with air compressed pressure into bulging dome-shaped workpieces with a diameter of 95 mm. After the forming test, the workpieces were cut along the centerline. The cross section of the sandwiched structure was observed and its thickness distribution measured.

RESULTS AND DISCUSSION

Figure 3 shows the typical dome-shaped workpieces of the Zn22Al thin sheet alloy and the plastic/Zn22Al/plastic sandwiched structure after free-bulging. The cross section of such a plastic/Zn22Al/plastic sandwiched structure is shown in *Fig. 4*. It can be seen that a sound joint of the plastic plates and the Zn22Al alloy is achieved through adequate employment of the hot-molten adhesive. The adhesive strength as measured is about 14.7 MPa. The microstructure of the as-received Zn22Al thin sheet material is shown in *Fig. 5a*, which contains a mixture of equiaxed zinc-rich (dark areas) and aluminum-rich phases. The grain size is about 0.5 μm. It can also be seen that the zinc-rich phase emerges as a layer structure dispersed along the rolling direction. After superplastic forming, the zinc-rich phase transforms into a uniform structure accompanied with a slight grain growth (*Fig. 5b*). When the Zn22Al alloy is inserted between two ABS plates and free bulged, it also shows a uniform distribution of the zinc-rich phase (*Fig. 5c*). However, the grain size in *Fig. 5c* is much larger than that in *Fig. 5b*. The higher grain growth in *Fig. 5c* should be attributed to the slower cooling rate of the Zn22Al sheet sealed between two slowly cooling ABS plates.

The specific dome heights (dome height / workpiece diameter, i.e., H/D) of the ABS/Zn22Al/ABS specimens after free-bulging at various temperatures under various pressures are shown in *Fig. 6* as a function of blowing time. For comparison, a like result of the monolithic Zn22Al specimen is also given in *Fig. 6*. When placed at 150°C under 0.35 MPa, the ABS/Zn22Al/ABS sandwiched specimen can be deformed to a dome height of 50 mm (H/D = 0.56) in as short a time as 10 sec. Even at quite a low temperature of 135°C and a lower pressure setting of 0.21 MPa, it can still be deformed in 50 sec to the same dome height. *Figure 6* also shows that under the same forming conditions (i.e., temperatures and pressures), the forming rate of the ABS/Zn22Al/ABS specimen is much higher than that of the monolithic Zn22Al specimen. Only after a longer stretch of time, the monolithic Zn22Al specimen can be free bulged faster than the ABS/Zn22Al/ABS specimen. The higher forming rate of ABS/Zn22Al/ABS is attributed to the high flowing capability of the ABS plastic at temperatures above 135°C, which causes the Zn22Al sheet to deform more easily. At the final stage, the ABS plates

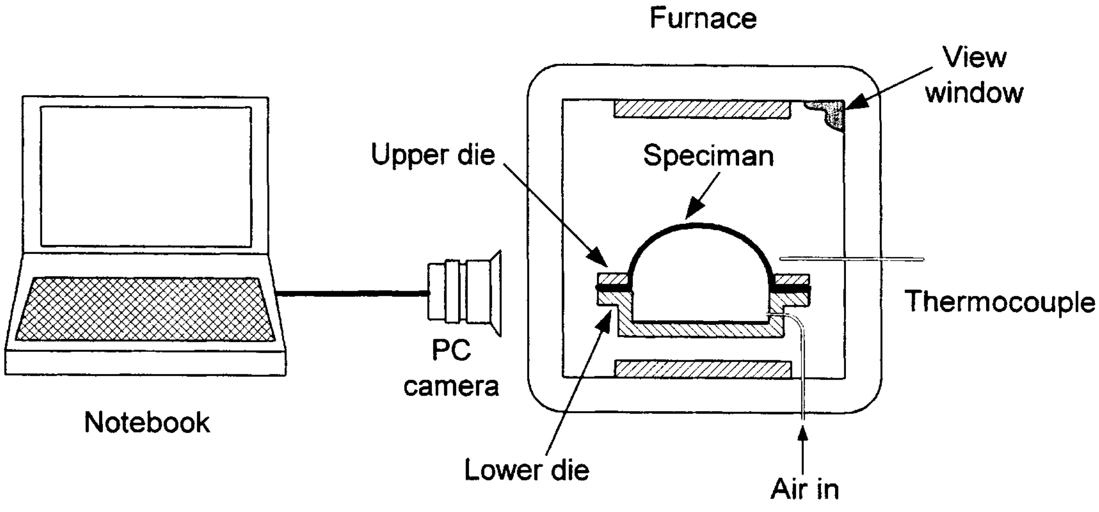


Fig. 2. Equipment for evaluating the formability of the plastic/Zn22Al/plastic sandwiched structure in this study.

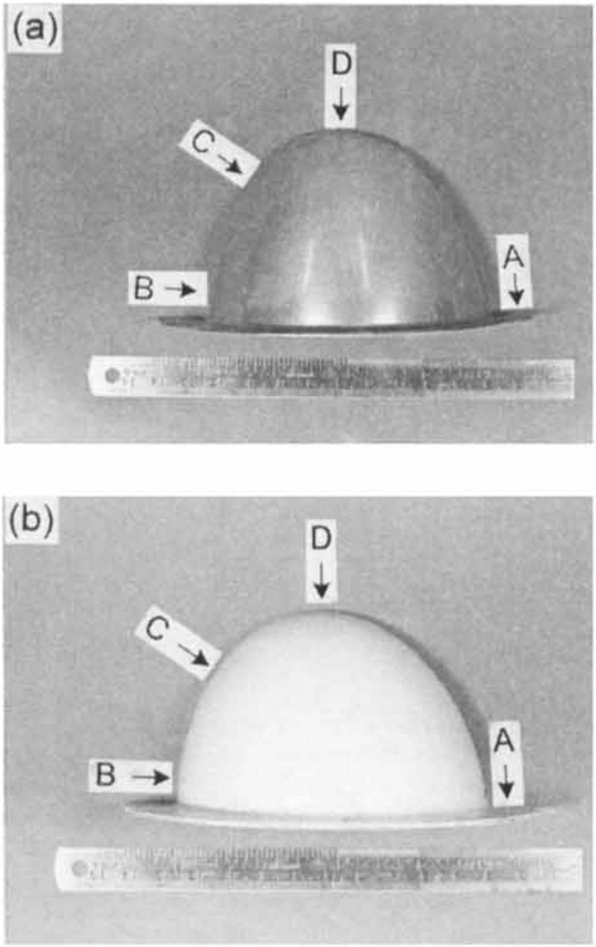


Fig. 3. Typical dome shapes of the different specimens : (a) monolithic Zn22Al thin sheet, (b) ABS/Zn22Al/ABS sandwiched structure.

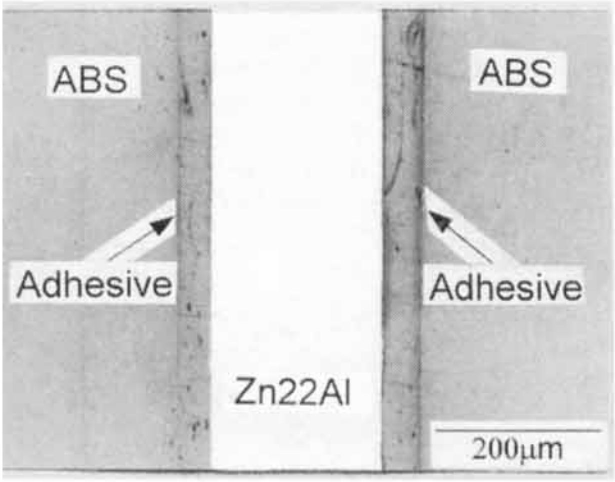


Fig. 4. Cross section of the plastic/Zn22Al/plastic sandwiched structure in this study.

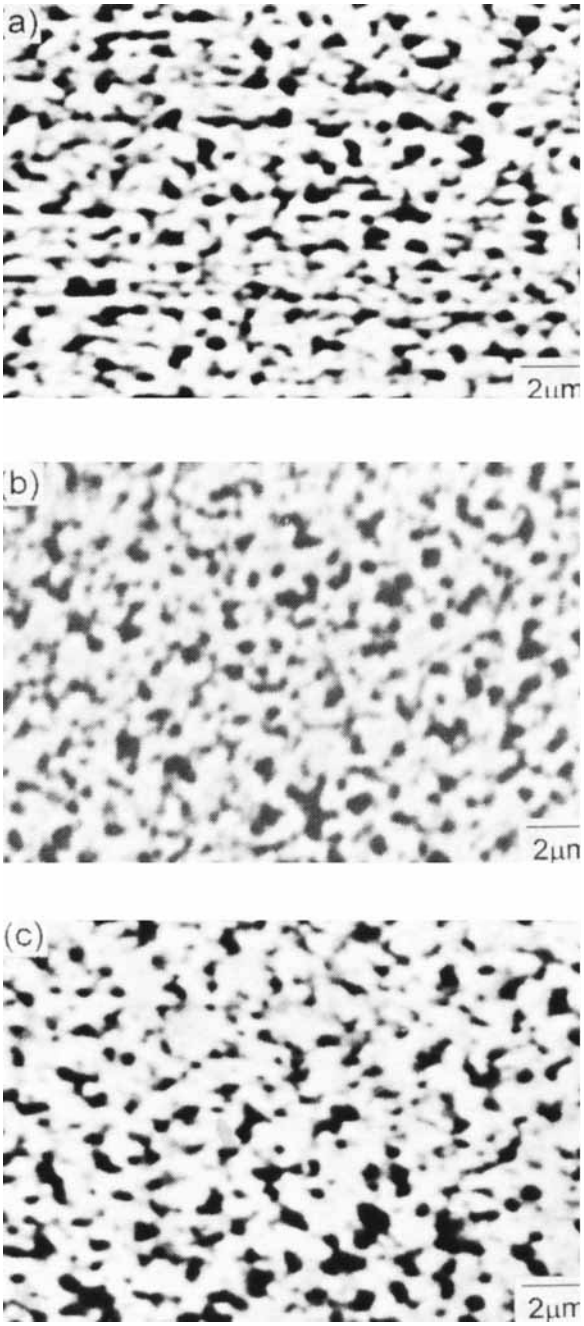


Fig. 5. Typical microstructures of the Zn 22Al thin sheet materials, (a) as-received Zn22Al, (b) superplastically formed monolithic Zn22Al, (c) Zn22Al in free-bulged ABS/Zn22Al/ ABS.

become too thin to maintain the same accelerating effect on the superplastic forming of the Zn22Al sheet. The specific thicknesses (*i.e.*, thicknesses of the ABS/Zn22Al/ABS and monolithic Zn22Al specimens after free-bulging/thicknesses of the original sheet materials; S/S_0) taken from various parts of the specimens are plotted in *Fig. 7*. The thickness distribution of specimens after free-bulging has been analyzed by Ragab (11): $\frac{S}{S_0} = \left[\frac{1 + \sigma H}{D^2}\right]^{-2}$ where σ is the height of

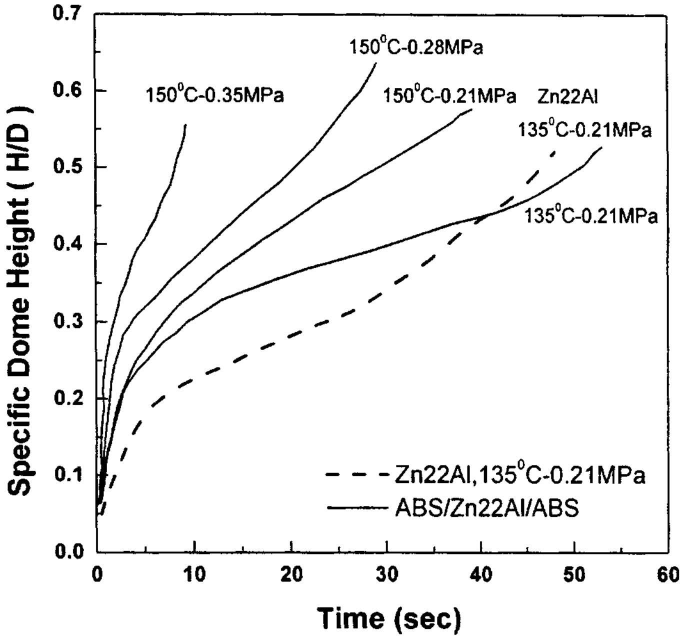


Fig. 6. The specific dome heights (dome height/workpiece diameter, H/D) of the three-ply ABS/Zn22Al/ABS specimens after free-bulging at various temperatures under various pressures.

the bulge annulus of the section during free bulging, and H is the height of the bulge during free bulging (*Fig. 8*). The theoretical values calculated from his model (11) are also shown in *Fig. 7*. The results indicate that the experimental results are quite consistent with the theoretical values. From *Fig. 7*, it can also be seen that the central region of Zn22Al in the free bulged ABS/Zn22Al/ABS is thinner than that of the monolithic Zn22Al sheet. In other words, the thickness distribution of Zn22Al in ABS/Zn22Al/ABS after free-bulging becomes more uneven than that of the superplastically formed Zn22Al sheet.

To evaluate the effect of different plastics on the formability of such a plastic/Zn22Al/plastic sandwiched structure, the PC/Zn22Al/PC and PC/Zn22Al/ABS specimens are also formed by free-bulging. When *Fig. 9* and *Fig. 6* are placed in comparison, it can be found that at temperatures below 165°C the forming rate of PC/Zn22Al/PC is much lower than that of ABS/Zn22Al/ABS. *Figure 9* also shows that at such lower temperatures the PC/Zn22Al/PC specimens are deformed at a slower rate than the monolithic Zn22Al specimens, which stands in sharp contrast to the case of ABS/Zn22Al/ABS in *Fig. 6*. However, at

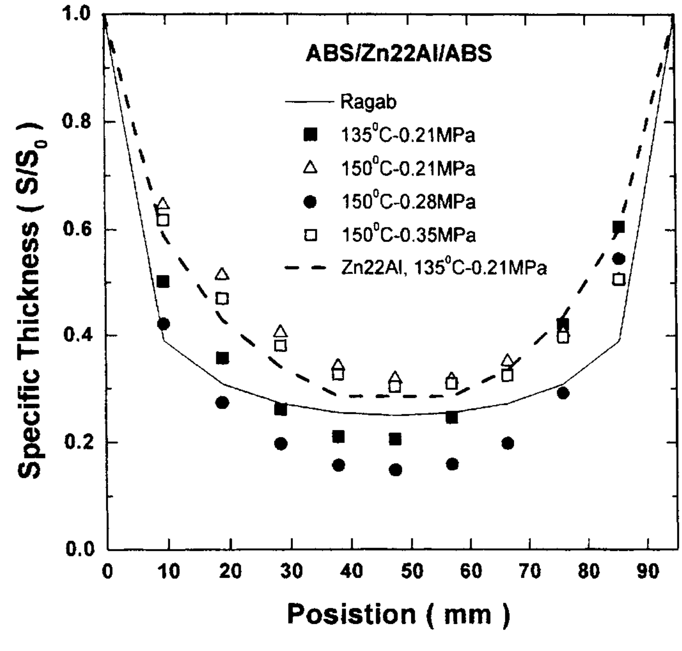


Fig. 7. The specific thickness (thickness of specimen after free-bulging/thickness of original sheet material, S/S_0) at various sections of the three-ply ABS/Zn22Al/ABS and monolithic Zn22Al specimens formed under different conditions in comparison with the theoretical values calculated from Ragab's model (11).

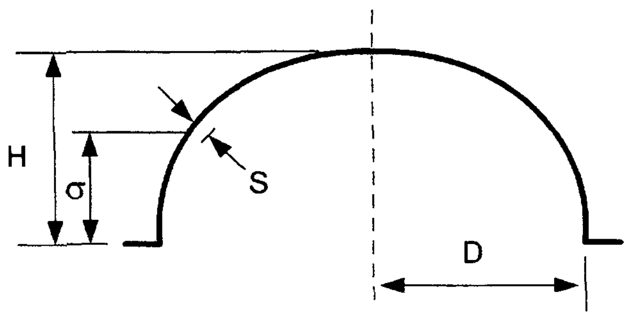


Fig. 8. Geometry of deformation during free bulging of the circular sheet.

temperatures above 185°C, the forming rate of the PC/Zn22Al/PC specimens increases drastically. Also, the forming rate of PC/Zn22Al/PC is higher than those of the monolithic Zn22Al specimens, which is similar to the case of ABS/Zn22Al/ABS in *Fig. 6*. The results can be attributed to the higher softening temperature of the PC plastic. Although the Zn22Al alloy at a temperature of 165°C or 150°C possesses good superplasticity, the poor flowing capability of the PC plastic obstructs the forming of such a PC/Zn22Al/PC sandwiched structure. *Figure 10* shows that at 165°C and 185°C, the thickness distributions of the monolithic Zn22Al sheets after free bulging are similar. However, the Zn22Al sheets in the PC/Zn22Al/PC specimens after free bulging at various temperatures show a quite different type of thickness distribution. The effect of gas pressure on the thickness distributions of the Zn22Al sheets in the PC/Zn22Al/PC specimens is not as significant as the effect of the forming temperature upon free bulging at 165°C and 185°C. Thus, the thickness distributions of the Zn22Al sheets in the PC/Zn22Al/PC specimens are more uniform than those of the monolithic Zn22Al sheets.

The specific dome heights of the PC/Zn22Al/ABS sandwiched structure after free bulging at 150°C with various gas pressures are shown in *Fig. 11* as a function of blowing time. For comparison, the results of the monolithic Zn22Al sheet superplastically formed at 150°C with 0.21 MPa of gas pressure and PC/Zn22Al/ABS free bulged at 165°C with 0.21 MPa of gas pressure are also given in *Fig. 11*. It can be seen that the forming rate of PC/Zn22Al/ABS free bulged at 150°C has increased significantly at the increase of the blowing pressure. In the case of PC/ Zn22Al/PC as shown in *Fig. 9*, the forming rate at 150°C fails to improve through boosting the gas pressure. In addition, *Fig. 11* shows that at the same pressure setting (0.21 MPa), raising the blowing temperature from 150°C to 165°C can also improve the forming rate of PC/Zn22Al/ABS dramatically. Compared with the superplastic forming of the monolithic Zn22Al sheet at 150°C with gas pressure of 0.21 MPa, the PC/Zn22Al/ABS possesses a much lower forming rate, which is caused by the poor flowing capability of the PC plastic at this temperature, much the same as the case of PC/Zn22Al/PC in *Fig. 9*. Although the change of blowing pressure exerts a significant effect on the forming rate of the PC/Zn22Al/ABS specimens, *Fig. 12* shows that their thickness distributions are similar. The specific dome heights, as a function of blowing time at 150°C with 0.21 MPa of gas pressure for monolithic Zn22Al and various plastic/Zn22Al/plastic specimens, are compared in *Fig. 13*. It can be seen that the forming rate of the ABS/Zn22Al/ABS sandwiched structure is similar to that of the monolithicZn22Al

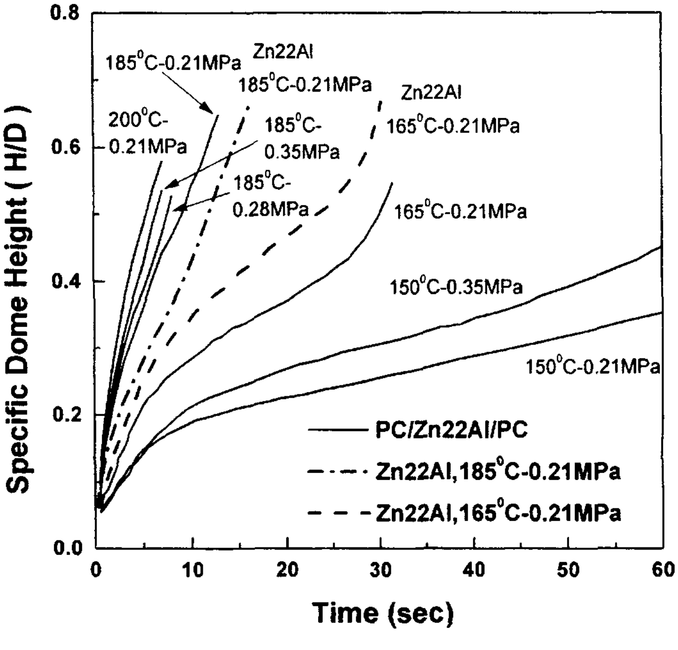


Fig. 9. The specific dome heights (dome height/workpiece diameter, H/D) of the PC/Zn22Al/PC and monolithic Zn22Al specimens after free-bulging at various temperatures under various pressures.

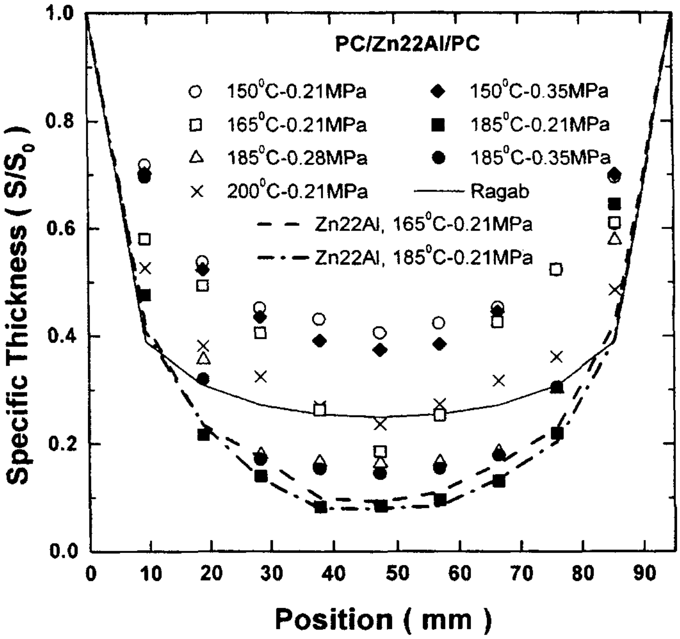


Fig. 10. The specific thickness (thickness of specimen after free-bulging/thickness of original sheet material, S/S_0) at various sections of the PC/Zn 22Al/PC and monolithic Zn22Al specimens formed under different conditions in comparison with the theoretical values calculated from Ragab's model (11).

sheet. However, the forming rates of PC/Zn22Al/PC and PC/Zn22Al/ABS are much lower than those of ABS/Zn22Al/ABS and Zn22Al.

CONCLUSIONS

The superplastic Zn22Al alloy can be combined with ABS or PC plastics and simultaneously formed by gas blowing. For the free bulging at 150°C with 0.21 MPa of gas pressure, the forming rate of the ABS/Zn22Al/ABS sandwiched structure is similar to that of the monolithicZn22Al sheet. For the PC/Zn22Al/PC specimens, the optimized forming temperature is 185°C. At this temperature, the gas pressure between 0.21 MPa and 0.35 MPa makes little difference on the forming rate and the thickness distribution of PC/Zn22Al/PC. Also, under such an optimized forming condition, both the forming rate and the thickness distribution of PC/Zn22Al/PC are similar to those of the monolithic Zn22Al sheet. The forming rate of PC/Zn22Al/ABS free bulged at 150°C increased significantly with the increase of blowing pressure. Its optimized forming condition is thus specified either at 150°C with 0.35 MPa of gas pressure or at 165°C with 0.21 MPa of gas pressure. Under such optimized

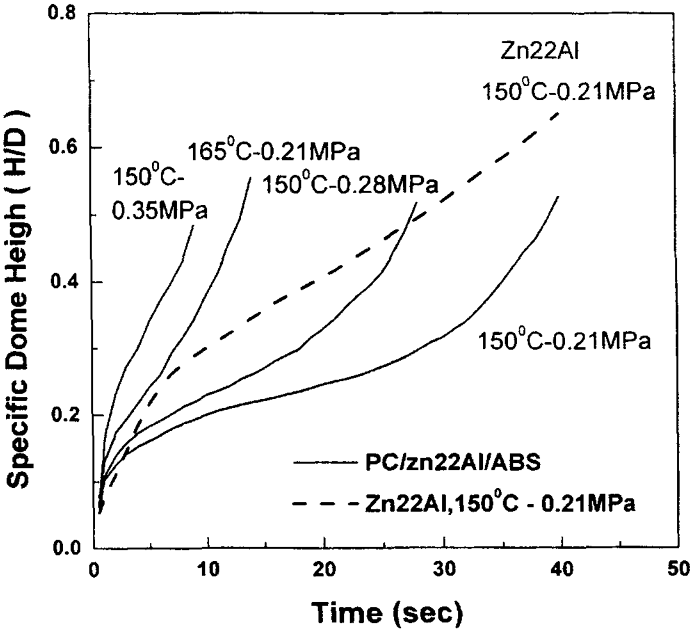


Fig. 11. The specific dome heights (dome height/workpiece diameter, H/D) of the PC/Zn22Al/ABS and monolithic Zn22Al specimens after free-bulging at various temperatures under various pressures.

Fig. 12. The specific thickness (thickness of specimen after free-bulging/thickness of original sheet material, S/S_0) at various sections of the PC/Zn22Al/ABS specimens formed under different conditions in comparison with the theoretical values calculated from Ragab's model (11).

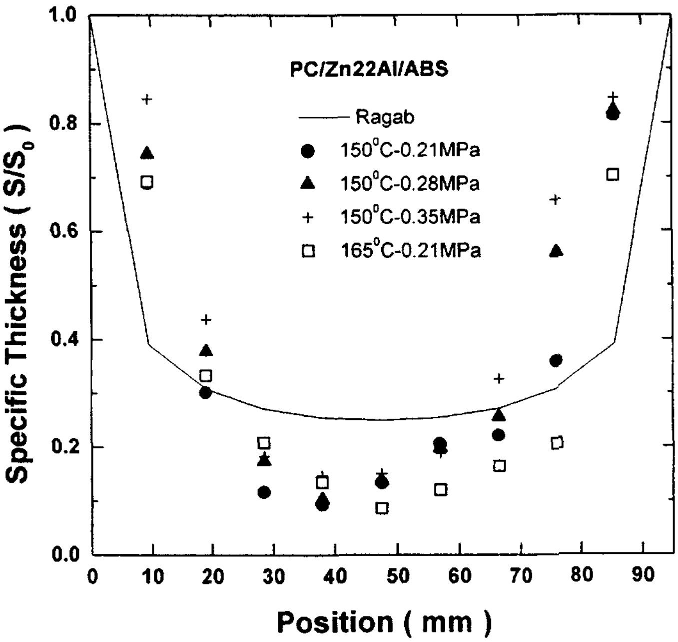
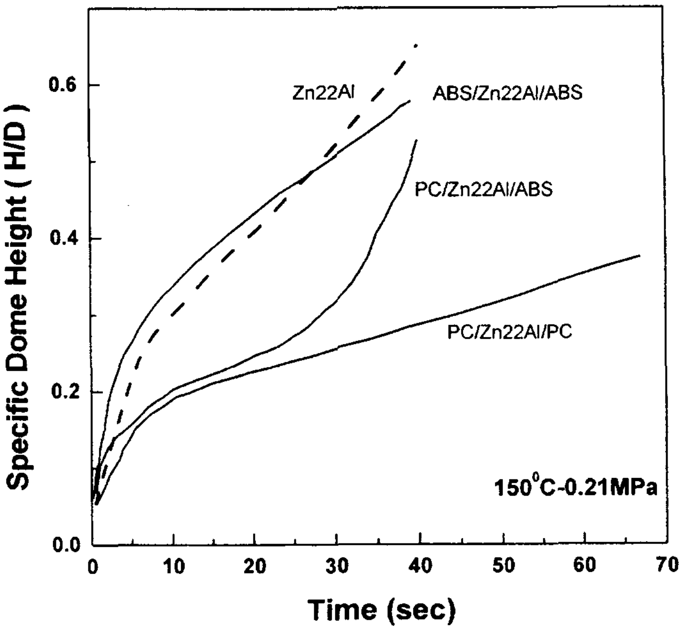


Fig. 13. The specific dome heights (dome height/workpiece diameter, H/D) of the monolithic Zn22Al and plastic/Zn22Al/plastic specimens after free-bulging at 150°C with 0.21 MPa of gas pressure.



forming conditions, the PC/Zn22Al/ABS specimens exhibit thickness distributions similar to those of the PC/Zn22Al/PC specimens.

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