特輯 한국정밀공학회지 제9권 제2호 1992. 6
Journal of the Korean Society of precision Engineering Vol. 9. No. 2 Jun. 1992.

Counter-Pressure Deep Drawing and its Application in the Forming of Automobile Parts

Hiroyuki Amino, Kazuhiko Nakamura, Takeo Naragawa

Industrial Summary

Sheet metal forming with hydraulic counter-pressure has several advantages compared with conventional drawing, such as higher forming limits, higher accuracy of formed parts and the achievement of complicated formed shapes. About 50 special press machines have already been used in Japan for manufacturing lighting reflectors, aircraft parts and automobile parts, This report descirbes the techniques and the equipment used in the application of process.

1. Introduction of the process of counter-pressure deep drawing

In this report, the present situation of the counter-pressure deep drawing process is introduced and typical formed parts used in Japan are shown. Further, several new technical achievements concerned with the process that have been developed the authors will be explained briefly [1]. However the main subject of this report is the application of hydraulic counter-pressure deep drawing in the forming of automobile panels. The process is illustrated in Fig. 1 : its main advantages are that the forming limit is increased, complicated shapes can be formed by a single operation, better shape and surface quality of formed parts can be obtained and, also, there is no need of a female die.

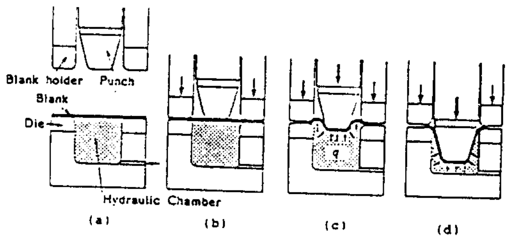


Fig. 1 The hydraulic counter-pressure fluid-forming process.

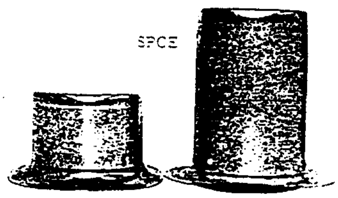


Fig. 2 Comparison of formable heights between : on left, conventional deep drawing, where $D_o/dp = 2.26$; on right, counter-pressure drawing, where $D_o/dp = 2.90$.

In the deep-drawn examples shown in Fig. 2, the left-hand side cup has been drawn in the conventional way and the right-hand side cup by the hydraulic counter-pressure method. A higher forming limit is achieved by the three effects shown in Fig. 3 [2, 3]. The first effect is the strong holding of the sheet by the hydraulic pressure to prevent fracture at the bottom of punch. The second effect is the perfect lubrication between the blank holder and the sheet metal which reduces the deep-drawing force. The third effect is pre-bulging, which gives uniform elongation of the material and makes it easy for the sheet, of greater surface area, to make contact with the punch head at an early stage of drawing.

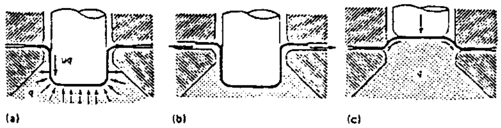


Fig. 3 Fracture-suppressions effects in the counter-pressure forming process : (a) friction-holding effect; (B) friction-reducing effect; (c) initial expansion effect.

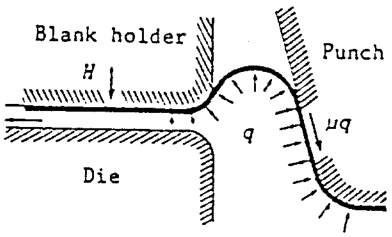


Fig. 4 State of the part-drawn sheet in the counter-pressure deep drawing of a truncated conical shell.

Table 1 Main featrues of hydraulic counter-pressure deep drawing

(1)	Increase of limiting drawing ratio
(2)	Single-stroke deep drawing of shells of complicated shape
(3)	Improvement of shape and surface accuracy and uniformity of thickness
(4)	Die-less drawing

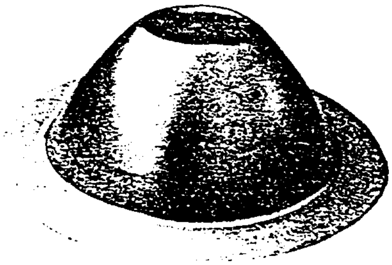


Fig. 5 A truncated conical shell obtained by counter-pressure deep drawing.

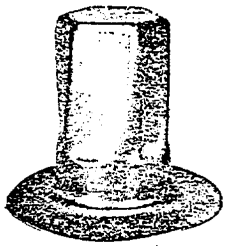


Fig. 6 A helically-twisted cup obtained by counter pressure deep drawing.

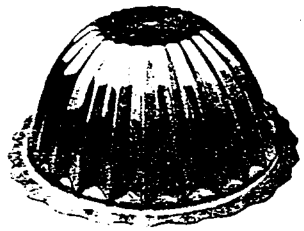


Fig. 7 A radially-grooved cup obtained by counter-pressure deep drawing.

The next advantage is the prevention of body wrinkling [4]. In conicalshape forming, wrinkling is likely to appear on the wall of the cup in conventional deep drawing. Such body wrinkling is prevented in this process by the strong radial stretching induced by upward bulging, as shown in Fig. 4.

By utilizing the last advantage of Table 1, i. e., the elimination of the female die, a cup with a helical twist (Fig. 6) and one with radial grooves (Fig. 7) can be formed easily using only a punch.

2. Examples of forming by counter-pressure deep drawing

Several photographs of parts formed by this process are shown in the following.

Figure 8 shows a 270 tonf fluid-forming machine constructed by Amino Corporation. A reflector panel in sheet aluminuum formed by this machine is shown in Fig. 9. If the parts are small, the forming cycle is 7-8 pieces per minute. The leakage of water or oil is avoided by the use of a cover plate and the liquid is recycled in this machine.

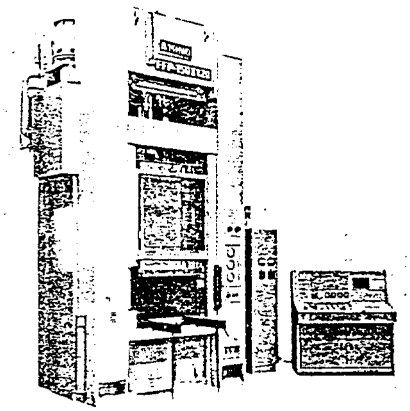


Fig. 8 A hydraulic counter-pressure forming press. Inner capacity : 150 tonf; outer capacity : 120 tonf; table area : 1000×1000mm; inner stroke : 650mm.

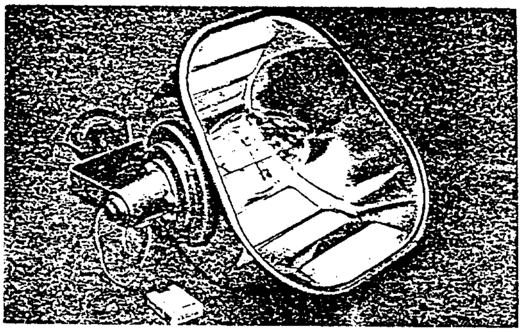


Fig. 9 A lighting reflector.

Lamp reflectors of much more complicated shape are manufactured also by this process (Fig. 10), in materials such as pure aluminium, that are not so easy to form. These sophisticated reflector shapes are now designed

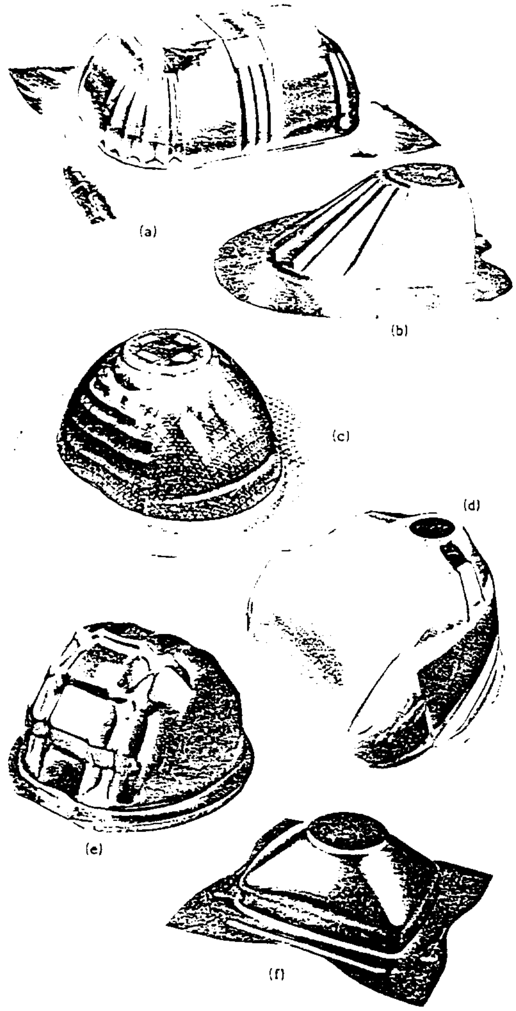


Fig. 10 A range of lighting reflectors obtained by counter-pressure deep drawing.

by a CAD system : If this process had not existed, such newly designed reflectors could not appear on the market.

Figure 11 shows examples of aircraft parts. All the materials are aluminium alloys, which have, in general, poor formability.

The samples shown in Fig. 12 are some what special parts. In the case of the product in Fig. 12(a), the Teflon-coated steel sheet can be drawn without damaging the surface coating. The product in Fig. 12(b) is a car part where the die face is not flat.

Figure 13 also shows a rather special

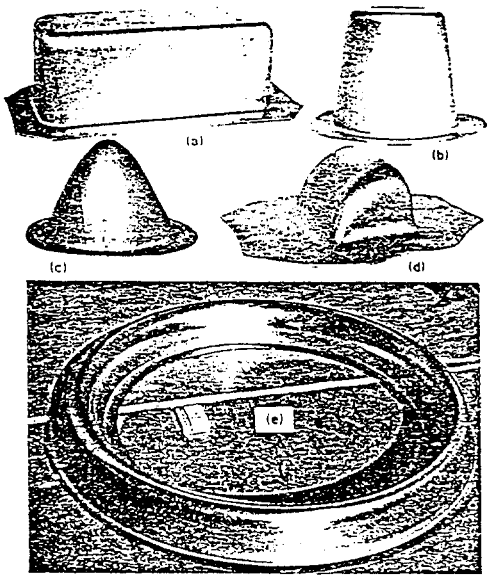


Fig. 11 Aircraft parts obtained by hydraulic counter-pressure forming.

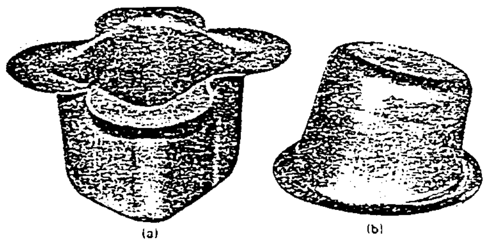


Fig. 12 Formed products : (a) using a Teflon-coated steel sheet; (b) a car part where the die face is not flat.

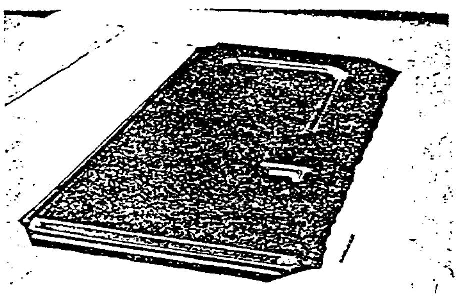


Fig. 13 A door panel obtained by hydraulic counter-pressure forming.

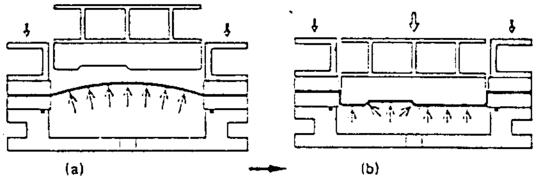


Fig. 14 Fabrication of a door by hydraulic counter-pressure forming : (a) pre-bulging; (b) drawing.

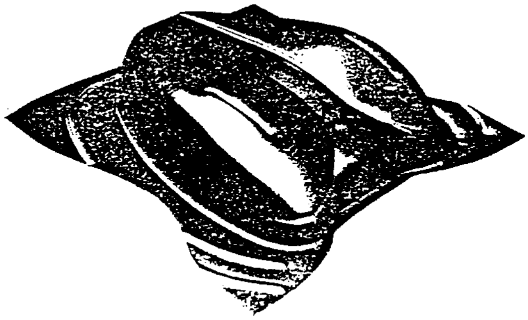


Fig. 15 A motorcycle part obtained by counter-pressure deep drawing.

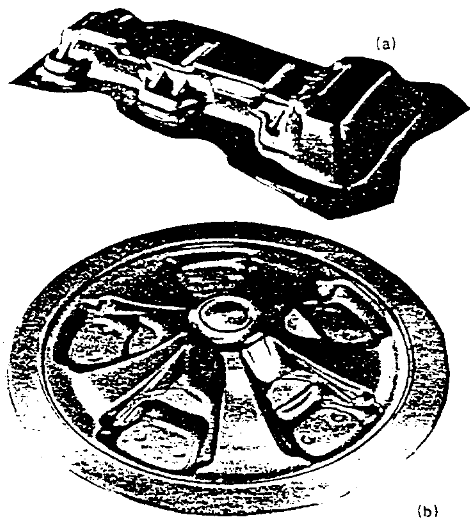


Fig. 16 Automobile parts obtained by counter-pressure forming : (a) an engine cover; (b) a wheel cover.

example, in which a door is formed by this process. Before drawing, some a, mount of pre-bulging is effected to obtain better shaping in the embossing zone (Fig. 14).

The panel shown in Fig. 15 is the oil-tank cover of a motor cycle whilst the samples shown in Fig. 16 are both automobile parts : an engine cover and a wheel cover.

3. New technologies in counter-pressure deep drawing

In the next step, four types of new technologies related to counter-pressure deep drawing will be explained : these are usage of a single-action press [5]; punch stretching [6]; stretch flanging [7]; and the radial-pressure method [8, 9].

As will be appreciated, it is necessary to use a specially designed double-action hydraulic press for the counter-pressure deep drawing process, the fluid chamber should be set into the upper ram. The authors have designed a special upper fluid chamber sealed with a movable plug incorporating a stop valve, which can allow the release of fluid, when it is necessary. Figures 17 and 18 show the the comparison of the forming sequence for two different locations of the fluid chamber. Figure 19 shows the upper fluid chamber and the forming tool. Several parts formed by this tool-set shown in Fig. 20. The formablility is equal to that of normal counter-pressure deep drawing and it has been demonstrated that this tool is able to be

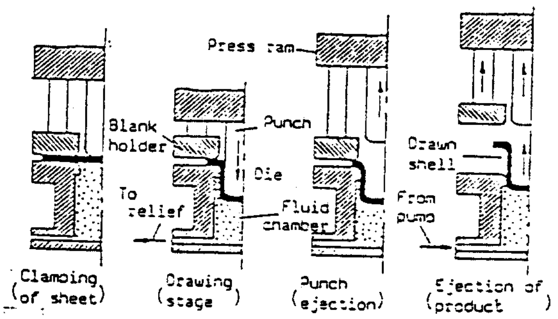


Fig. 17 Schematic procedure for counter-pressure deep drawing using a specially designed machine.

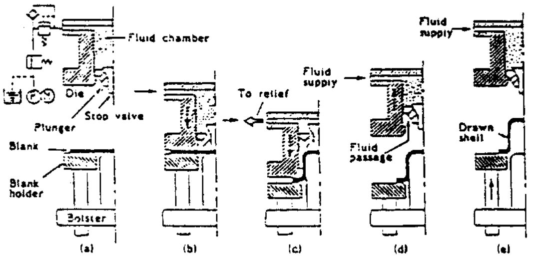


Fig. 18 Schematic drawing procedure with the simplified counter-pressure drawing method using an inverted chamber : (a) ready to move down (chamber filled with liquid) ; (b) clamping of the blank and opening of the valve; (c) drawn stage (with the passage open) ; (d) ram retracted and valve closed; (e) ejection of the shell.

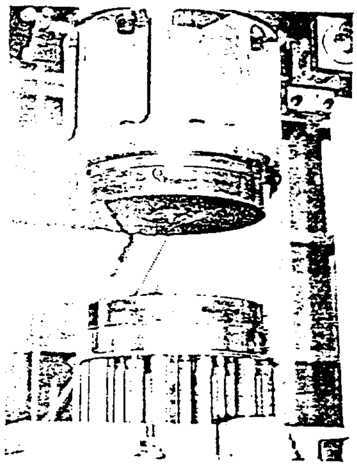


Fig. 19 Upper fluid chamber and forming tool for inverted-type counter-pressure drawing.

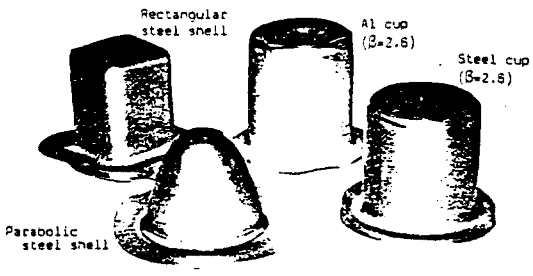


Fig. 20 Samples produced by inverted-type counter-pressure drawing.

attached to a conventional mechanical drawing press.

The next new technology is the combination of deep drawing and stretch flanging (Fig. 21). A sheet metal blank with a hole is drawn to some extent by counter-pressure deep drawing, after which the counter-pressure is reduced to zero and stretch flanging or hole fanging effected. By achieving these two processes during a single action of the punch, it is possible to obtain quite long tubes with a small flange, directly from sheet metal (Fig. 22).

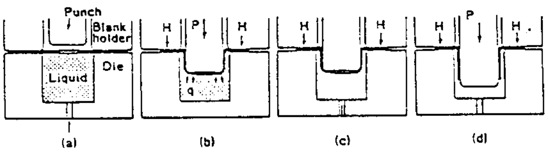


Fig. 21 Sequence of operations for the hydraulic counter-pressure forming of a tube with a flange from a blank with a hole : (a), (b) hydraulic counter-pressure deep drawing; (c), (d) drifting.

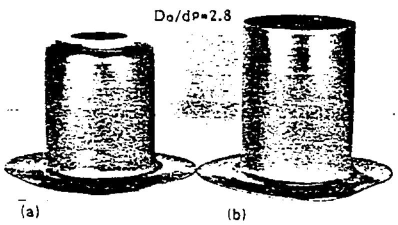


Fig. 22 Tubes with a flange obtained by counter-pressure forming : (a) before drifting; (b) after drifting.

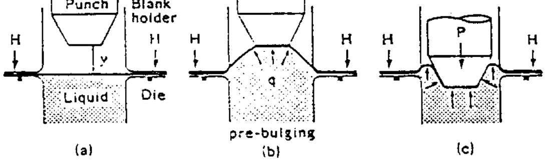


Fig. 23 Counter-pressure punch stretching with pre-bulging.

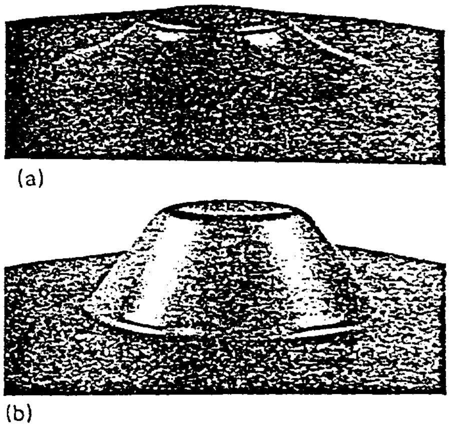


Fig. 24 Appearance of shells at the forming limit : (a) conventional punch stretching; (b) counter-pressure punch stretching.

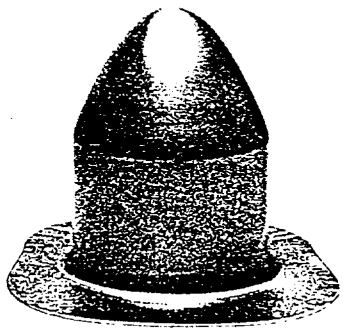


Fig. 25 A shell with a steep nose obtained by stretch-and-draw forming.

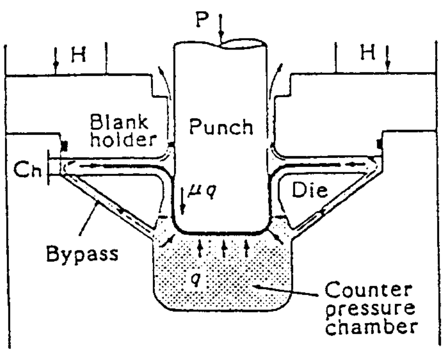


Fig. 26 Principle of the new method of counter-pressure deep drawing assisted by radial fluid pressure.

The next new technology is the application of hydraulic counter-pressure deep drawing in punch stretching (Figs. 23 and 24). Before punch penetration, the sheet metal is subjected to hydraulic bulging. After uniform elongation of the sheet and the enlargement of the sheet surface; the final shaping is done by the punch and hydraulic pressure. This resembles very closely the vacuum forming of a polymer sheet. After this procedure, counter-pressure deep drawing can be carried out : in this case, a deep cup with a sharp or steep nose can be drawn quite successfully (Fig. 25).

The greatest drawing limit can be obtained by applying radial fluid pressure to the blank periphery (Fig. 26). The fluid pressure is supplied form the same bottom chamber and in this case fluid lubrication between the blank holder and the sheet is achieved, in addition to lubrication between the die and the sheet.

Figure 27 shows aluminium cups drawn by three different methods an enables an appreciation of how effective the radial-pressure method is in securing a greater drawing limit.

The redial-pressure method can be applied to reverse re-drawing, as shown in Fig. 28. The first drawing is a conventional drawing but in the second reverse re-drawing stage both counter-pressure and radial-pressure are applied at the same time. As shown in Fig. 29, a remarkably deep cup with a total drawing ratio of 4. 9 was obtained in the condition of a re-drawing ratio of 2. 3 by this reverse re-drawing method.

4. Forming of an automobile panel by counter-pressure deep drawing

The next topic is the application of this process to the fabrication of automobile body panels.

The capability of die-less forming, i. e.,

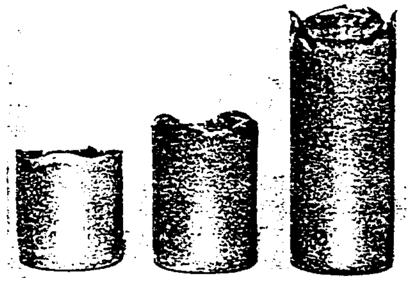


Fig. 27 Comparison of the drawn heights obtained by different drawing methods : (a) conventional drawing, where $D_o/dp = 2.33$; (b) counter-pressure drawing, where $D_o/dp = 2.61$; (c) radial-pressure drawing, where $D_o/dp = 3.31$. (Material : JIS, A1100-0, $tD_o = 0.8$mm.)

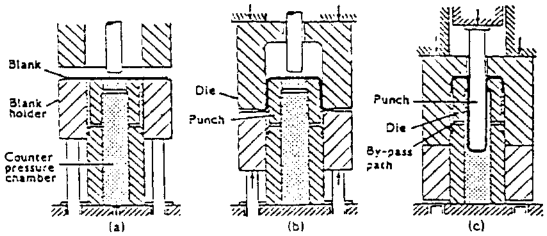


Fig. 28 Operational sequence for hydraulic counter-pressure reverse re-drawing assisted by hydraulic force on the edge of the drawn shell : (a), (b) frist drawing (conventional drawing) : (c) re-drawing (hydraulic counter-pressure drawing with radial pushing).

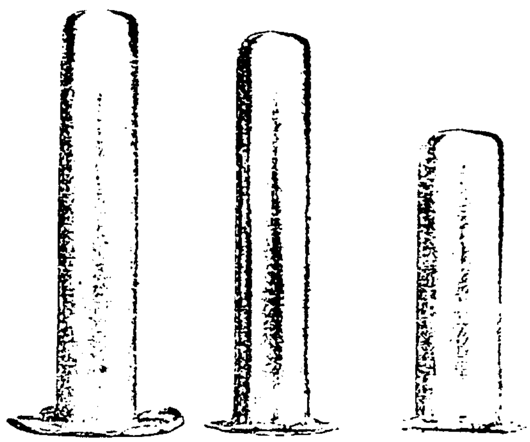


Fig. 29 Comparison of drawn heights obtained by various methods of counter-pressure reverse re-drawing : (a), (b) with hydraulic pushing force; (c) without pushing force.

forming without usting a female die, is another important advantage of this process, to which a great deal of attention has been paid.

The number of different models of automobile and the frequency of model changes have been increasing continuously. In the case of the development of new types of automobile, the reduction in time for the fabircation of a trial model, the cost reduction of the new trial die, and then the elimination of a female die in the trial model, become very advantageous. Recently in Japan, many types of automobile have been produced in relatively small lots and this tendency will become more and more prominent in future. The ratio of the tooling cost to the total manufacturing cost is now increasing, therefore, and the effect resulting from the elimination of the female die becomes significantly large.

In the cases of both a trial model and small-lot production, however, it is essential to establish that the products formed by counter-pressure deep drawing can attain a sufficient quality-similar to that obtained by conventional forming-especially in the case of an automobile skin panel. In the present experimental studies, the authors have investigated the following four points which need to be satisfied in the actual application : (i) capability of the formed products to have a sufficiently satisfactory degree of quality without the use of a female die; (ii) a relatively short time for changing the dies and for forming; (iii) reduction of cost and time for the manufacturing of the tool; (iv) durability of the tool for a small amount of production.

In the experiments, several kinds of automobile parts, including an outerskin panel-like fender, were formed by counter-pressure deep drawing to check the feasibility of the process.

In order to investigate the possibility, the 1500 tonf hydraulic pressure shown in Fkig. 30 was constructed for the experimental programme. In this machine, the blank-holder cylinder is built into the main supper ram and water mixed with an anti-corrosion element is used for the fluid in the counter-pressure chamber.

After the experimental forming tests of several automobile parts, the formed parts were divided into four categories based on the difference in forming conditions.

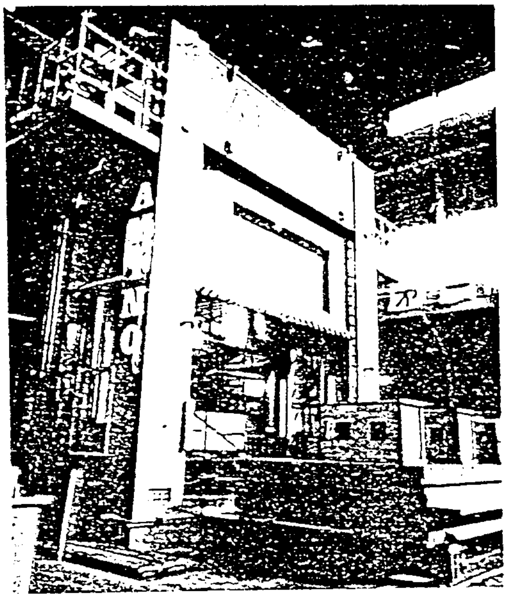


Fig. 30 A hydraulic press with a built-in blank-holder cylinder.

For parts with flat-bottomed surfaces, there is no need of any special control of the blank holding force and the fluid pressure (Fig. 31) : however, in the case of the forming of automobile parts, it is very rare that the bottom surface of the part is flat as in this case.

In most cases, the bottoms of the panels have a curved surface, an inclined surface or a stepped surface. In the door outer-and inner-panels shwon in Fig. 32, the cross-setional configuration is relatively symmetrical, the depth of panel is shallow, but the bottom has an embossed surface. In this case the shaping of the bottom is achieved mainly by stretching deformation, so that the blank holding force can be kept almost constant, but the counter-pressure should be increased very greatly at the last stage of forming, to define the bottom shape.

From the above experimental forming tests, it has been found that in some cases sharp corner shapes can not be defined distinctly because of an insufficient level of hydraulic counter-pressure. In such cases a urethane polymer cushion or a bottom-striking partially solid die, located at the bottom of the pressure chamber, must be used.

The panels shown in Fig. 33 have stepped portions at the bottom of the panel. In this case, when the counter-pressure is too high during the initial stage of the forming process, the blank is elongated or bulged in the opposite direction, such that body wrinkles often appear due to excessive elongation of the sheet metal in the early statge of forming. Then, in this case, it is necessary to control the counter-

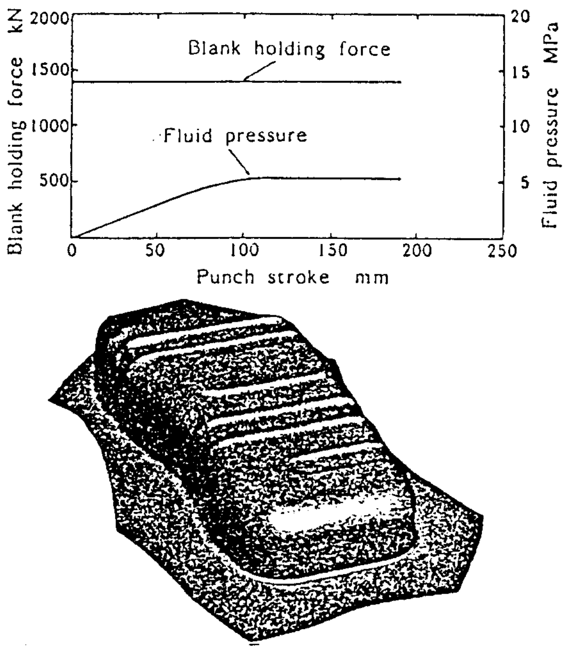


Fig. 31 The lower part of a fuel tank obtained by hydraulic counter-pressure forming.

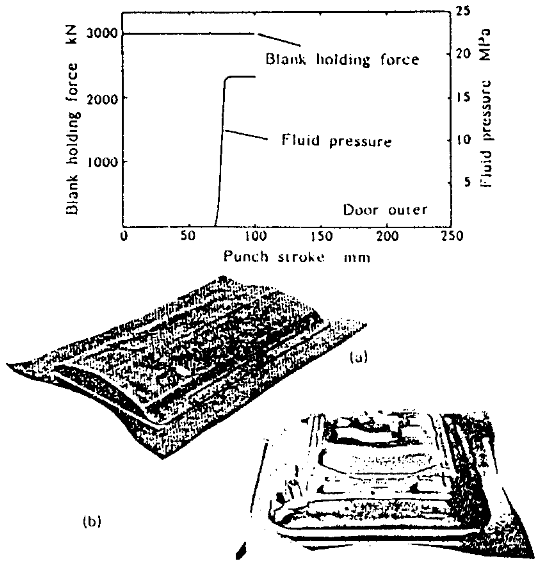


Fig. 32 Door panel parts obtained by hydraulic counter-pressure forming : (a) a door outer part; (b) a door inner part.

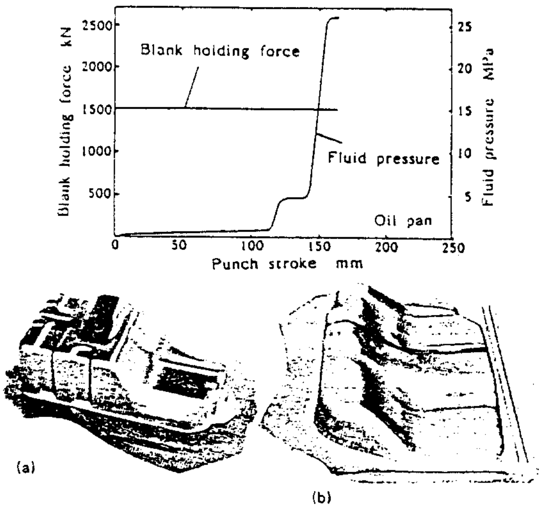


Fig. 33 Parts obtained by hydraulic counter-pressure forming : (a) an oil pan; (b) the upper part of a fuel tank.

pressure at a lower level in the initial and the middle stages of forming in order to minimize the expansion or bulging of the sheet. However in the last stage, the counter-pressure must be increased progressively to prevent body wrinkling.

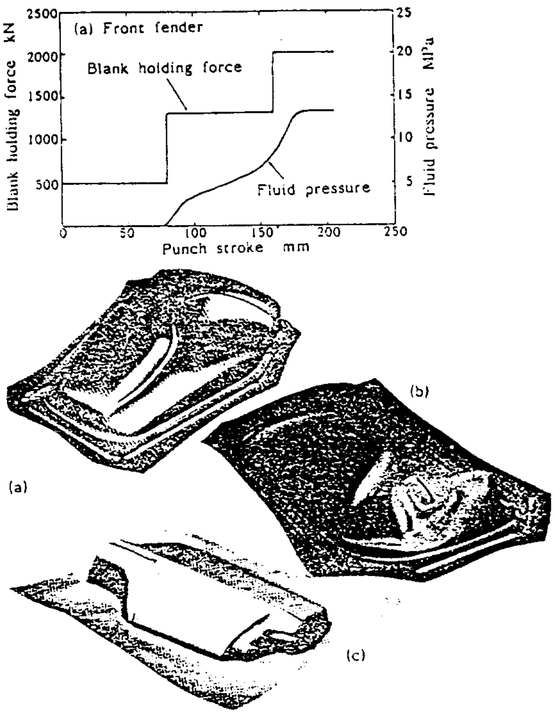


Fig. 34 Parts obtained by hydraulic counter-pressure forming : (a), (b) a front fender; (c) a rear fender.

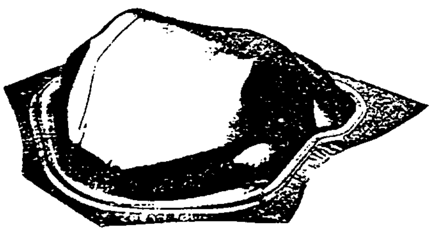


Fig. 35 A wheel house inner panel obtained by hydraulic ounter-pressure forming.

In the last example, the depth of the formed panel is very great and its shape has a complicated longitudial-section configuration (Fig. 34). Both fracture and body wrinkles are likely to occur very often. During the forming stroke, not only the counter-pressure but also the blank holding force should be controlled properly and precisely to obtain defect-free panels : this control is effected by micro-computer in the Amino press.

The wheel house inner panel in Fig. 35 is formed by the similar control of the blank-holding force and the counter-pressure.

In addition to the advantage of not requiring a female die, a more econmical punch made of non-metallic material can be used in counter-pressure forming. During the forming operation, a static hydraulic pressure is applied on the punch surface in the normal direction through the sheet metal, and due to the high friction induced between the punch and the blan, the displacement of the blank with respect to the surface for the punch is much less, as compared with the conventional drawing process. Damage to the punch can be kept to a minimum therefore, and it becomes feasible to use a moulded punch made from plastics or concrete.

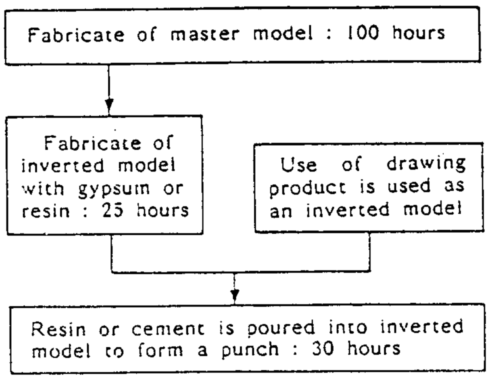


Fig. 36 The procedure for manufacturing a punch.

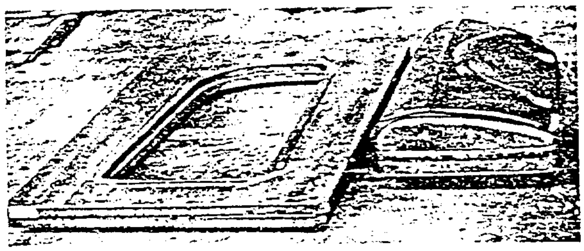


Fig. 37 The punch and die used in forming a front fender (Punch : resin type).

The manufacturing procedure for the punch is presented in Fig. 36. From the master model, an inverted model of gypsum or resin is produced and resin or cement material is then cast into the inverted model. The total manufacturing time is 55 hours, excluding the 100 hours manufacturing time of the master model.

The front-fender punch shown is Fig. 37 is a resin punch but the drawing die is of course made of thick steel plate. The total manufacturing time of the punch and the die is about 200 hours including that for the model, compared with the 800 hours that are necessary for the conventional process.

For the manufacture of the cement punch, a high-density polymer cement is prepared into which 3 vol. % Short-length steel fibres are premixed for reinforcement. From the wooden model, in this case, just an inverse plaster model is produced by the casting process. By using this plaster model as a casting tool, a cement punch is produced (Fig. 38). The rear-fender punch shown in Fig. 39 is a cement punch. In the present experiments a rear fender, a fuel-tank upper, and a fuel-tank lower part have been formed using this type of cement punch. All other panels have been formed by resin punches in these forming tests.

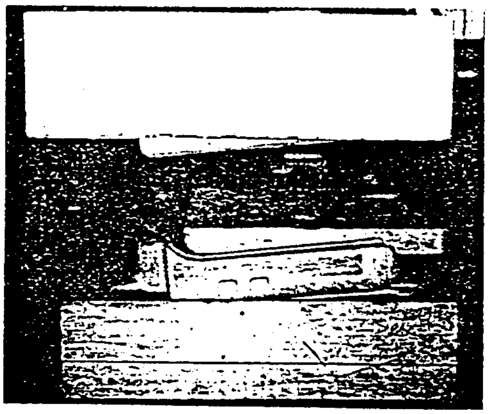


Fig. 38 A master model and an inverse plaster model.

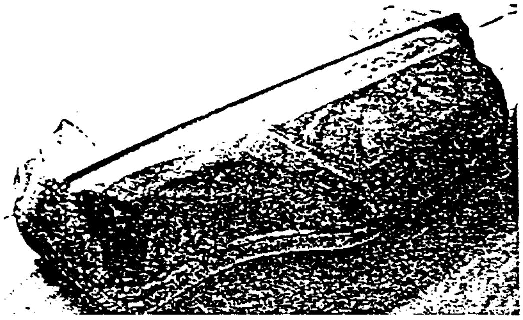
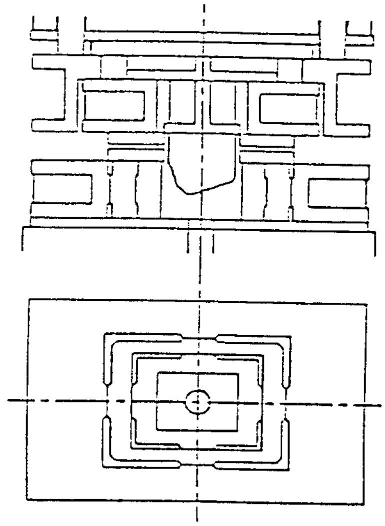


Fig. 39 The cement punch used in forming a rear fender.



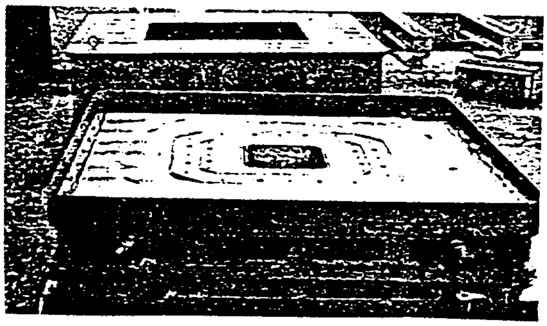


Fig. 40 A built-in type hydraulic chamber.

In order to reduce the cost of manufacturing the hydraulic chamber the authors have developed the built-in type of chamber shown in Fig. 40. By using this chamber, different sizes of parts can be formed with a single common chamber, by changing the steel die-plate for each different part.

The present hydraulic counter-pressure deep drawing operation can be applied only to the first drawing in the series of operations involved in producing the panel. Subsequent trimming and piercing operations can be carried out by laser-beam cutting, as shown in Fig. 41, or by the plasma-cutting process, with the help of a robot. However, especially in case of subsequent edge bending, no suitable means of forming are available at present. The authors need to develop flexible new techniques to complete the manufacturing system.

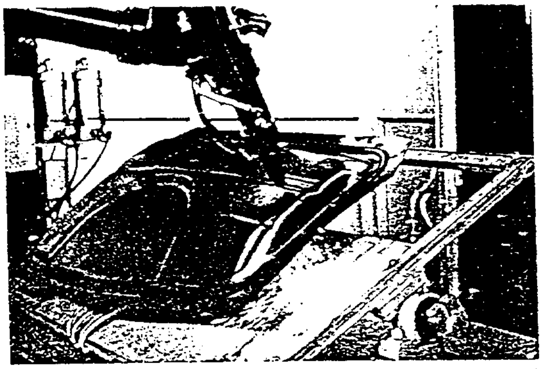


Fig. 41 Laser trimming.

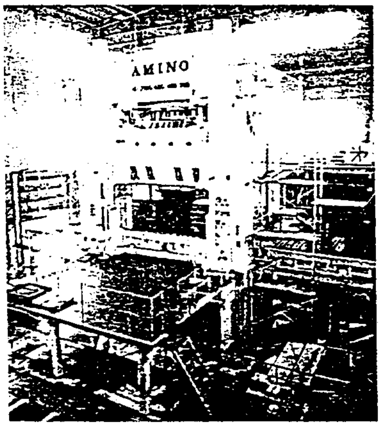


Fig. 42 A double-action fluid-forming press of 2600 tonf capacity.

Amino Iron Works has already developed a specially designed counter-pressure deep drawing machine for automobile panels. The capacity of this double-action press, shown in Fig. 42, is 2600 tonf in total (Inner : 2000 tonf, Outer : 600 tonf), and it can make 2 to 3 automobile panels per minute.

5. Conclusions

In concluding this report, the results may be summarized as follows :

(1) A specially designed hydraulic press has been developed for the counter-pressure deep drawing of automobile panels.

(2) An automobile panel can be formed successfully by the hydraulic counter-pressure deep drawing process, without using a female die.

(3) A non-metallic, economical and rapidly manufactured punch, moulded directed from a model or from a drawn panel, can be used for this forming process.

(4) Trimming and piercing operations on the panel after the main drawing or forming operation, can be achieved by flexible robot cutting, using a laser beam.

(5) A suitable simplified edge-bending process for the drawn panels should be developed for the subsequent hemming and flanging processes. Finally the authors would like to point out that this process has just started to be applied to the forming of automobile panels. With the help of automobile panel stampers, Amino will continue their efforts to continuously improve forming technology and to make this forming system available to their customers.

References

1. K. Nakamura, Sheet metal forming with hydraulic counter-pressure in Japan, Ann. CIRP, 36(1) (1987) 191.
2. K. Nakamura, T. Nakagawa, Fracture mechanism and fracture control in deep drawing with hydraulic counter-pressure, J. JSTP, 25 (284) (1984) 831.
3. K. Nakamura, T. Nakagawa, Fracture mechanism and fracture control in deep drawing of square shells with hydraulic counter-pressure, J. JSTP, 26(298) (1985) 1110.
4. K. Nakamura, T. Nakagawa and K. Suzuki, Hydraulic counter-pressure deep drawing of truncated conical shells, J. JSTP, 26(299) (1985) 1189.
5. K. Suzuki, T. Nakagawa, Counter-pressure drawing by using single action press, Proc. 1st ICTP, 1984, pp. 769-774.
6. T. Nakagawa, K. Suzuki, C. S. Sharma, H. Kawase, Punch stretching of thin metal sheet by using hydraulic counter-pressure, Proc. ICPE, 2VIII, 1977, pp. 127-136.
7. T. Nakamura, T. Nakagawa, Hydraulic counter-pressure forming of tube with flange, J. JSTP, 27(310) (1986) 1298.
8. K. Nakamura, T. Nakagawa, Hydraulic counter-pressure deep drawing assisted by radial pressure, Proc. 1st ICTP, 1984, pp. 77-780.
9. K. Nakamura, T. Nakagawa, Reverse deep drawing with hydraulic counter-pressure using the peripheral pushing effect, Ann. CIRP, 35(1) (1986) 173.