INVESTIGATIONS ON PEEN FORMING (2ND REPORT; ON THE FORMING MECHANISM)

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ABSTRACT

Mechanisms of bulging or sinking deformation of sheet metals in peen forming are basically investigated by using a two dimensional model of a roller tool depression against a rectangular plate specimen and the change of the forming mode is explained from the change of the planar strain distribution to the thickness direction. Detail experiments reveal that there are four types of the deformation process according to working conditions in bulging of a disc, that is, a monotonous bulging, a monotonous sinking, a bulging accompanying temporary sinking and a sinking accompanying temporary bulging. The reason for these differences of the deformation type are clarified from the effect of the bending moment by the restriction of the flange portion material. Effects of the shot size in the range from 0.4 mm to 8 mm in diameter on the forming efficiency and the surface quality of the products are investigated and the optimum working conditions are clarified.

KEYWORDS

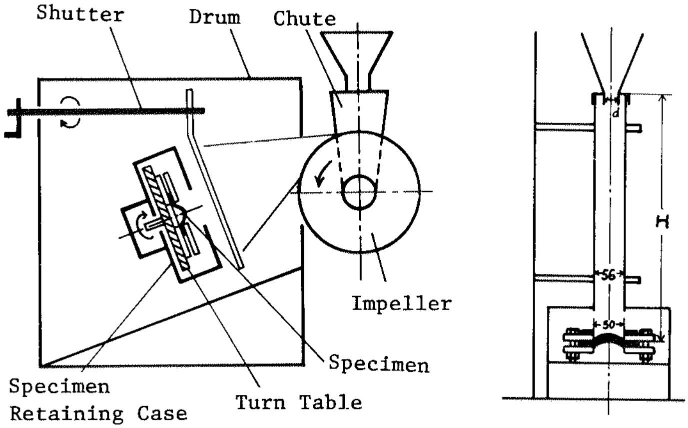
Bulging mechanism; roller indentation model; deformation type; flange restriction; optimum working conditions; forming efficiency; surface quality.

INTRODUCTION

In the first report, basic features of this process were investigated and successful conditions, quality of the products and applicability to low formability materials were clarified (Kondo, 1979). In this report, mechanisms of bulging or sinking deformation of sheet metals in peen forming are basically investigated by utilizing a roller indentation model and the reason for the occurrence of different types of deformation process are clarified. In addition, effects of the shot size in the wide range from 0.4 mm to 8 mm in diameter on the forming efficiency and the surface quality of the products are investigated and the data for the selection of the optimum working conditions are sought.

EXPERIMENTAL APPARATUS AND CONDITIONS

In the experiments, two types of apparatus shown in Fig. 1 are used. In centrifugal



(a) Centrifugal throwing type (b) Gravity-fall type

Fig. 1 Experimental apparatus

type apparatus, shots smaller than 4 mm in diameter are used and shot speed is regulated by the change of the revolution number of impeller. Gravity-fall type apparatus is suitable for large shot diameter and shot speed is regulated by the change of guide height H. Specimens are clamped on the holder shown in Fig. 2 and set in retaining case. Approximate uniformity of the shot distribution at this position is confirmed. Start and finish of peening operation are controlled by the shutter and a total amount of peened shot is regulated as exactly as possible. A funnel is installed at the top of the chute and shots are supplied from it in a uniform flow. The amount of bulging is represented by the height at the centre of the specimen shown in Fig. 2 as bulge height.

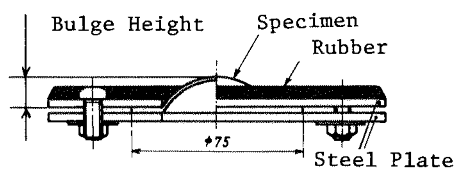


Fig. 2 Holder of specimen

Test specimens are half hard or annealed commercially pure aluminium disc blanks of 75 mm in diameter and their mechanical properties are shown in Table 1. Test shots are 5 kinds of shots for blasting and 8 kinds of steel balls for bearing which are summarized in Table 2.

TABLE 1 Mechanical Properties of Specimens

Material	A1050-H24		A1050-O*
Thickness (mm)	1.5	0.8	1.5
Tensile strength (Kg/mm^2)	13.0	13.7	8.0
Work-hardening index n	0.03	0.03	0.28
Vicker's Hardness Hv(50g)	42	44	23

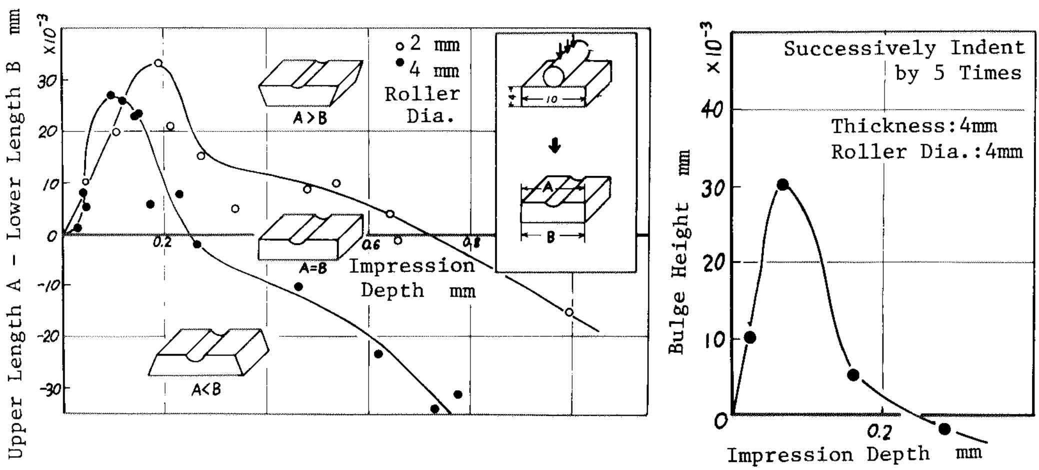
* A1050-H24 is annealed at 400°C for 1 hour

TABLE 2 Test Shots

Shot diameter ds (mm)	Remarks
0.4, 0.8, 1.0, 1.3, 2.3	Shots for blasting Centrifugal type
3.2, 3.5, 4.0, 4.8, 5.5 6.3, 7.1, 7.9	Steel balls for bearing Gravity-fall type

BASIC INVESTIGATION ON FORMING MECHANISM

It is difficult to understand forming mechanism directly from the actual operation because in peen forming a large number of incremental deformation by each shot are cumulated to large deformation. So, a roller tool indentation test is carried out as a simplified two dimensional model test. Needle roller of 2 or 4 mm in diameter is depressed against a rectangular half hard aluminium plate of 4 mm in thickness and 10 mm in width. Change of the shape in vertical section according to the increase of the impression depth is summarized in Fig. 3(a). When the amount of indentation is small, the section becomes a trapezium which has a longer upper side. While, when its amount becomes large, the section deforms to a trapezium which has contrary a longer lower side and on the middle of thes change a transition point exists. The impression depth at this transition point becomes larger as the roller diameter becomes smaller. It may possible to understand that this edge shape can indicate directly the distribution of lateral material flow in thickness direction. If these roller impressions are cumulated, for instance, by five times, bulging or sinking deformation appears as is shown in Fig. 3(b) and its transition point coincides to the point in Fig. 3(a). Therefore, it can be concluded that when the upper material flow is larger than lower flow, its cumulation results bulging and when the lower material flow is larger, its cumulation results sinking as is shown in Fig. 4. These mechanisms must be understood as basic forming mechanisms in this process.



(a) Indentation of roller

(b) Bulge by cumulation of roller indentation

Fig. 3 Roller tool indentation test results

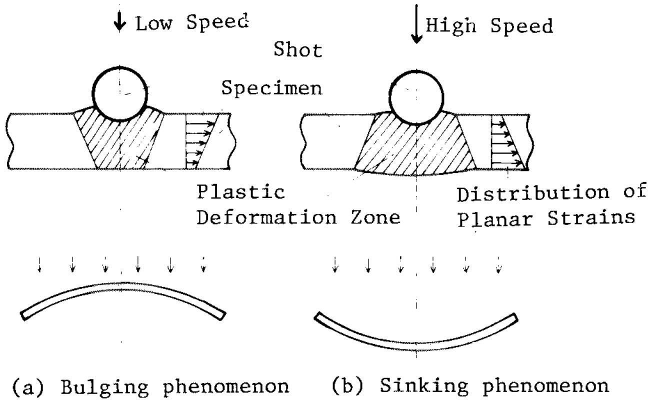


Fig. 4 Principle of peen forming

INVESTIGATION ON FOUR TYPES OF DEFORMATION PROCESS

Detail experiments extending to wider peening conditions reveal that there are four types of deformation process in bulging of a disc, that is, a monotonous bulging, a monotonous sinking, a bulging accompanying temporary sinking and a sinking accompanying temporary bulging. In this paper, these are denoted by deformation type A to D, respectively. The reason for these differences of deformation type is considered consistenly from the effect of the bending moment by the restriction of the flange portion material. In order to understand the effect of the restriction of flange portion in deformation type A and B, forming behaviour in peen forming accompanying restriction of flange portion of material by clamping specimen on the holder is compared with that accompanying mere masking of flange by rubber sheet. Test results are summarized in Fig. 5(a) and (b). In figures, h denotes bulge height by the former method and h_R the latter method. Change of the flange angle θ_F after removal of the flange restriction is also shown in Fig. 5.

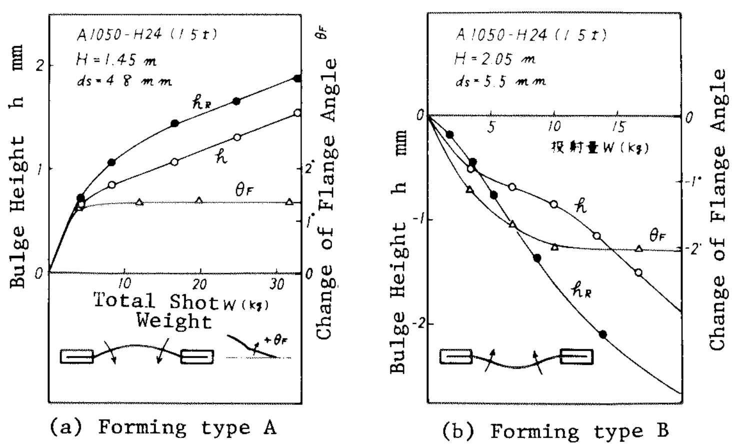


Fig. 5 Effect of flange restriction on deformation process

Forming mechanism of deformation type A corresponds to Fig. 4(a). However, it can be recognized from Fig. 5(a) that there exists a bending moment to downwards which prevents bulging of the specimen and the moment is large in earlier stage of peening and becomes almost constant afterwards. In the same way, the restriction of flange causes a bending moment which prevents sinking and promotes bulging in deformation type B shown in Fig. 5(b). Based on these results in deformation type A and B, deformation process in the cases of deformation type C and D are considered. h, h_R and θ_F curves in the case of deformation type C are shown in Fig. 6. When the flange portion is not restricted, bulge height curve corresponds to that of type B, so planar strain distribution in this peening condition can be represented by that in Fig. 4(b). However, deformation process gradually changes to bulging. This must be attributed to the effect of the restriction of flange. That is, in the earlier stage, specimen sinks and flange angle θ_F takes negative value, so the bending moment which promotes bulging exerts to the specimen and when its effect becomes dominant, forming direction can be reversed. Next, in the case of deformation type D in Fig. 7, the planar strain distribution in the thickness direction corresponds to

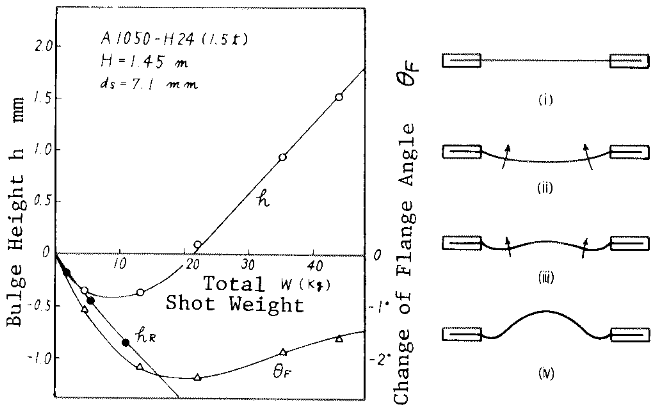


Fig. 6 Deformation type C

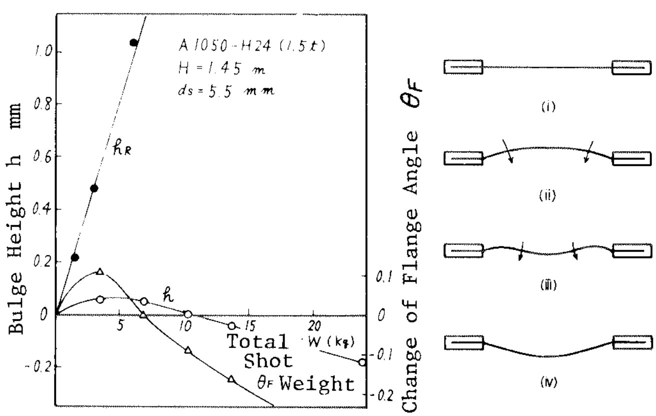


Fig. 7 Deformation type D

that in Fig. 4(a), hence temporary bulging occurs in the earlier stage. But, the bending moment which promotes sinking exerts to the specimen similarly to the case of deformation type A and if the effect of this bending moment were dominant in some working conditions, forming direction may be reversed. As a result, this forming method has four types of deformation process and the type is determined principally by the state of the planar strain distribution in the thickness direction, but depending on the peening conditions, it may affected by the restriction of the flange portion material.

INVESTIGATION ON THE OPTIMUM WORKING CONDITIONS

The optimum shot speeds for several shot diameters in the case of 1.5 mm thick specimens are summarized in Table 3. This speed means the maximum speed which takes the above deformation type A and corresponds to the most effective condition for a specified shot size. In the table, V_N means the peripheral speed of impeller and V_H in the cases of shots smaller than 4 mm in diameter means the calculated shot speed based on the equivalent fall height. That is, the diameter of a shot impression on the specimen is measured in centrifugal type test and the equivalent fall height H which makes the same diameter impression on the specimen is determined experimentally by using gravity-fall type test and used for the calcuration of V_H.

TABLE 3 Optimum Shot Speed

ds(mm)	N(rpm),H(m)	V_N (m/s)	V_H (m/s)	V_H/V_N
0.4	N=3900	57.2	61.0	1.07
1.0	3900	57.2	59.4	1.04
1.3	3000	44.0	53.3	1.21
2.3	1400	20.5	30.0	1.46
4.0	400	5.86	9.70	1.66
5.5	H=1.55	-	5.51	-
6.3	1.05	-	4.54	-
7.1	0.80	-	3.96	-

$V_N = \pi DN/60$ D:Outer Diameter of Impeller
$V_H = \sqrt{2gH}$ g:Gravity Acceleration

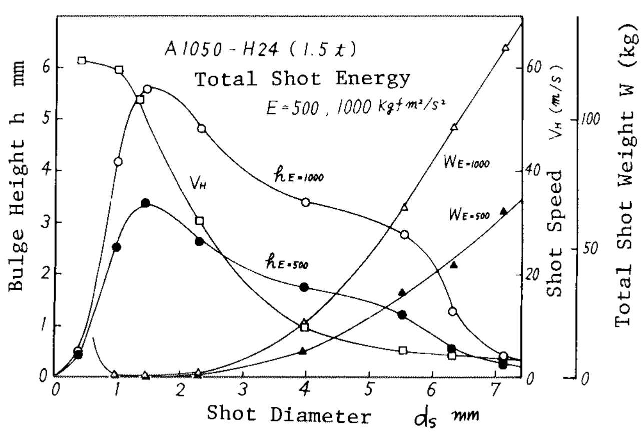


Fig. 8 The optimum working conditions (constant peening energy)

Figure 8 shows the relation between shot diameter and bulge height in the condition of constant peening energy $E = \frac{1}{2}WV_H^2$. The optimum shot speeds in Table 1 and necessary amount of shots are also plotted in the figure. Decrease of the optimum shot speed and increase of total shot weight with increase of shot diameter are both steep. From the view point of working energy, shot diameter of 1.3 mm is the optimum. Change of working energy, working time and surface roughness of the products according to the increase of shot diameter in the condition of constant bulge height (h = 2 mm) are shown in Fig. 9. Concerning to the working energy, shot diameter of 1.3 mm is the optimum similarly to Fig. 8. But surface roughness of the products becomes maximum in this condition. So, this working condition becomes unsuitable when the appearance of the products is thought much of. The surface roughness is improved contrary in the conditions of large shots or much smaller shots where working efficiency is low. As to working time, simple comparison is difficult because the weight of peened shot per unit time differs much between two types of apparatus. In Fig. 9, working time is distinguished by T in centrifugal type and T* in gravity fall type. Working time increases rapidly with the increase of shot diameter. As a result, the optimum working condition must be selected case by case according to the purpose of the work, for instance, high speed peening by d_s = 1~2 mm becomes the optimum when working efficiency is important and low speed peening by d_s = 4~5 mm or much higher speed peening by $d_s \ll 0.4$ mm is the optimum when the surface quality of the products is thought much of.

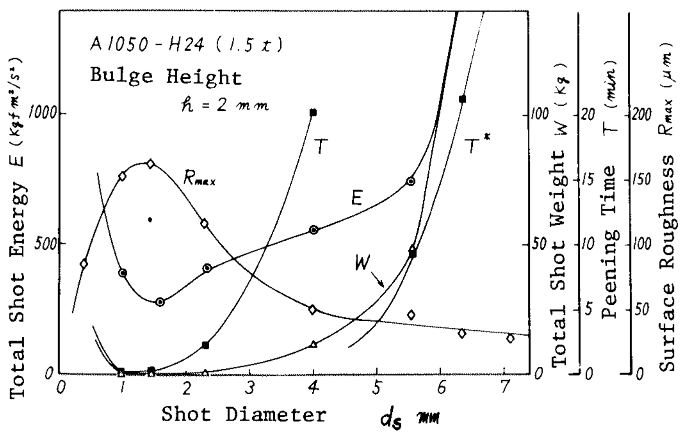


Fig. 9 The optimum working conditions (constant bulge height)

CONCLUSIONS

The difference of the forming mechnism between bulging and sinking was well explained by using a two dimensional model of a roller tool indentation test. The reason for the differences of four types of deformation process was consistently clarified from the effect of the bending moment by the restriction of the flange portion material. Data for the selection of the optimum working condition were obtained.

REFERENCES

Kondo, K. and others (1979). Bull. J.S.M.E., 22, 893-900.