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Hydroironing: A Novel Ironing Method with a Higher Thickness Reduction

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A new ironing method entitled hydroironing is proposed for producing cup shaped components especially those with lower formability to overcome the problem of low ironing limit ratio in the conventional ironing process. Lower ironing limit ratio in conventional ironing process increases the number of ironing stages and also manufacturing time and expenses. In this new method, unlike the conventional ironing process, forming punch is pushed to reduce the thickness from the inner surface of the cup starting from the cup edge while at the same time applying hydrostatic pressure onto the inner surface of the cup. The tools required for the proposed method were designed and manufactured and hydroironing tests were carried out. The results showed that a higher thickness reduction of about 70% was achieved only after a single hydroironing stage. The proposed hydroironing operation compared with the previous methods was observed to have three important advantages including higher thickness reduction, lower fluid pressure, and higher strength of ironed cup. This new process could be very promising for future industrial applications to reduce the product cost.

Keywords Experiment; Fluid; Forming; Ironing; Reduction.

INTRODUCTION

In the conventional ironing process, drawn cup is pulled by a punch through a die with a smaller inner diameter than the outer diameter of the cup, and the material is thinned and stretched. In practice, few strokes through dies of decreasing diameter are needed when the required thickness reduction is about 90%. The number of ironing stages would be equal to almost seven in conventional ironing process (30% reduction). In such a multistage ironing process, it is almost necessary to anneal the workpiece, between stages, to remove hardening and recover plasticity. Thus, other factors such as pollution and energy consumption are involved in addition to the increase of the number of stages of deformation, which calls for additional tooling and operators [1]. This drawback was recognized and suggestions to overcome this were presented in previous works. Some researchers tried to reach higher thickness reductions to decrease the number of ironing stages by improving workability of the material. The possibility of improving the workability of the material in the ironing process using ultrasonic vibration was studied [2]. Kampaš and Nardin [3] used an imposed axial force on the cup wall before the entrance to the forming zone to obtain a better material deformation. Derivation of governing equations for the limiting ironing ratio and the optimal die angle was presented by Chang [4]. Delarbre and Montmitonnet [5] determined the maximum reduction for the safe operation of the ironing process. Courbon [6] investigated the evolution of the damage with strain in wall ironing and obtained the optimal thickness reduction to damage.

The hydrostatic fluid pressure was extensively used in sheet metal forming processes during last few decades to increase the efficiency of these processes. One of the most famous methods was Hydro-mechanical deep drawing process originating from hydroforming technology [7]. In hydromechanical deep drawing, higher values for the limiting draw ratio are obtainable in comparison with the traditional deep-drawing process [8].

Applying the fluid pressure to the ironing process will make it possible to reach higher thickness reductions of the workpiece by pushing both the working material and the lubricant to the working zone. This Application is not studied widely in previous works. Only Tirosh et al. [9] developed a new fluid-pressure assisted ironing process which was named “Hydrostatic Ironing” and achieved a reduction amounting to 60% of the cup initial thickness using a semi-industrial hydrostatic ironing machine with fluid pressure drive of 600 MPa, which is a very high pressure for industrial applications. The main objective of the current study is to develop a new ironing process with a higher thickness reduction while using low fluid pressures by taking advantage of applying both the fluid pressure and the axial imposed force on the cup wall.

MATERIALS AND METHODS

Schematic illustrations of the conventional ironing process and the hydroironing process in the beginning and during the processes are shown in Fig. 1. In the
conventional ironing process, the material is deformed between the punch and die. At the beginning of the hydroironing process, deep drawn cup (drawn to a height in which some flange area was left to be held by the cup holder) is put into the die and the ironing punch comes down and establishes a pressing contact with the cup wall. The holder clamps the cup flange, and a "loader" imposes a force of about 63 KN to the cup bottom while a hydrostatic oil pressure of 15 MPa is applied to the inner surface of the cup. The interior fluid from the cup comes from the central hole of the punch. The ironing process starts from the cup edge, making it easier to apply the hydrostatic oil pressure to the workpiece material. The punch is pressed down to iron the cup wall and to reduce its thickness.

MATERIALS AND METHODS
A round blank sheet of 3 mm thickness and 130 mm in diameter made of aluminum alloy 1050 was used as raw material and annealed at 415°C for 3h to achieve an equiaxed re-crystallized microstructure [10]. The hydroironing die was set up in a 30 tons universal testing machine, and the hydroironing process was carried out with a punch speed of 50 mm/min. Standard tensile test along the axial direction, hardness, and thickness measurements were conducted on the raw material and ironed specimens. The ironing ratio was taken as IR = (t_f - t_i)/t_i where t_i and t_f represents the initial and final thicknesses, respectively. Hydroironing process parameters and their values are given in Table 1.

RESULTS AND DISCUSSION
Short height deep drawn and large height hydroironed cups are shown in Fig. 2(a). A significant decrease in thickness of the cup wall was achieved only after one stage of the hydroironing process. Comparative cross sections of deep drawn and ironed cups are shown in Fig. 2(b), where “a” is the starting point of the cup wall, “b and c” are the start and end of the vertical part of the cup wall (start and end of the deformed wall, respectively), “d” is the half way of bottom curvature, and “e” is the center of the cup bottom. As shown in this figure, uniform thickness distribution could be observed for the hydroironed cup. The thickness of the cup was decreased to about 1.02 mm from the initial mean value of 3.3 mm after one stage of the hydroironing process (~70% thickness reduction). Figure 2(c) shows the thickness distribution along the preformed and ironed cup walls in the axial direction. The initial wall thickness of 3.6 ± 0.05 mm at the upper part of the wall and 3.00 ± 0.05 at the lower part of the drawn cup were decreased to 1.02 ± 0.02 after hydroironing. As shown in this figure, the thickness of the ironed wall gradually increases as the distance from the base of the cup increases.

For the conventional ironing, the cup wall experiences the tensile stresses, but in the hydro-ironing process, the deformation takes place due to the loader force and the fluid pressure, which is almost compressive and a little tensile stress. In hydroironing process, the stress in the cup wall near its edge is compressive. It helps to reduce the possibility of fracture in the sidewall at the start of the process, and the cup holder force is used just for the purpose of stability [6].

The workability in the ironing process can be improved by increasing the percentage of compressive stresses in the forming zone, which could be achieved by applying an additional compressive axial force imposed on the cup wall before the forming zone [11]. Furthermore, it is seen that a high contact shear between the workpiece and die and low contact shear between the workpiece and the punch is very useful to increase the allowable thickness reduction. Prescribing a high hydrostatic fluid pressure helps to generate such a desirable phenomenon [9]. In other words, the oil pressure will press the cup material to the die and increases the total interfacial friction on cup-die interface. Moreover, the oil pressure will push the oil (as a lubricant) to the forming zone on the cup-punch interface. It will improve lubrication in this region which is desirable in the ironing process.

The success of the hydroironing process hinge mainly on applying both an imposed axial force on the cup wall (the resultant of loader force (63 KN) and the oil

| Table 1.—Process parameters and their values. |
|-----------------------------------------------|---------------------------------|
| Conditions | Descriptions |
| Raw material | AL1050-O |
| Cup outer diameter | 70 mm |
| Punch speed | 50 mm/min |
| Ironing ratio (% IR) | 69% |
| Loader force | 63 KN |
| Fluid pressure | 15 MPa |

FIGURE 1.—A schematic illustration of (a) conventional ironing and (b) hydroironing methods.
pressure force) and hydrostatic pressure to the interior of the cup, helping to better drive of the material into the deformation zone. The difference between loader force and the force resulted from internal pressure applies a compressive force of about $\sim 14\,\text{KN}$ on the cup material, which leads to better formability in the hydroironing process. The inner pressure also prevents the wall from collapsing which otherwise may have been caused by compressive forces.

Nominal stress–strain curves of annealed and ironed aluminum are shown in Fig. 3(a). The tensile strength increases two folds compared to the annealed condition, while the elongation is drastically decreased as expected. Hardness distribution along the cup wall in the bottom edge and through thickness directions are shown in Fig. 3(b) and (c), respectively. The mean hardness values are 21 and 40.1 HV for the drawn and ironed cups, respectively. As shown in Fig. 3(b), the hardness of the severely deformed area of the hydroironed specimen part is high (b–d), whereas the hardness values for the areas which have not been ironed (a-b and d-e) are the same as the counterpart area in the preformed specimen. Distribution of the hardness in the wall of annealed deep drawn cups is more uniform along the thickness than that of hydroironed cup. The hardness distribution seems to be uniform throughout the thickness of the product.

Figure 4 shows the ironing ratio after hydroironing process in comparison with other ironing techniques. When ironing with several dies is arranged one after the other, 12% more deformation can be allowed while the permissible reduction for one-pass ironing with a single die is 30% for aluminum and 36% for some types of steel [12]. Courbon [6] indicated that the maximum healing of voids is reached close to the intermediate reductions since damage is probable for the highest reduction close to 30%. This phenomenon is explained by shear stresses in the vicinity of the die that became dominant as the thickness reduced. The maximum increase of 15% in reduction rate was achieved by Kampus and Nardin [3] using a superimposed force on the cup wall before entering the forming zone. Also,
Tirosh et al. [9] reached 60% reduction using a fluid pressure drive of 600 MPa for 18 Ni 250 steel. Hence, an important advantage of the new process compared to conventional ironing is the capability of having higher thickness reductions leading to the reduced number of ironing stages. For example, hydro-ironing may reduce the number of ironing stages of an aluminum production to only single stage, whereas it needs three stages in the conventional process. Though, this conclusion needs some experimental evidence. This may lead to reduce the production cost and time. Also, the process may be used for ironing of hard to deform materials because of the compressive nature of the process.

**CONCLUSIONS**

In this study, a new ironing process with the capability of higher thickness reduction through only a single stage, based on hydroironing, was developed. The new hydroironing process was described, and the tooling, materials, and conditions used in experiments were presented. Hydroironing technique showed three important advantages including achieving higher thickness reduction, requiring lower pressure fluid, and higher strength of ironed cup compared to the previous methods. The mechanical properties were also enhanced after
the process. Tensile strength and hardness increased by about two folds compared to the original annealed condition. Through this new method, a significant reduction ratio (~70%) was achieved in only one stage of ironing. Based on the compressive nature of this process, low ductility metals also could be ironed with higher reductions compared to other methods.

REFERENCES