Developing a progressive draw with ironing tool for manufacturing a solenoid casing

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Abstract. The present paper focuses on developing a progressive draw with ironing process for production of solenoid casings with the main aim of reducing the number of presses required to form the component thereby reducing the cost of the component and enhancing the productivity rate. The material used for the present study is extra deep drawing (EDD) steel. In progressive draw with ironing tool, the first draw operation takes place followed by the ironing operation in a single tool. The progressive draw with ironing tool consists of three different die inserts planned one below the other in single station. The solenoid casing is manufactured by using this progressive draw with ironing tool and the thickness is measured at the dome and wall regions using an ultrasonic thinning measuring device. Tensile tests were performed for EDD steel according to ASTM standards and mechanical properties were evaluated. Finite element method (FEM) simulations were performed using the mechanical properties evaluated from tensile tests to predict the thickness at the dome and wall regions by using the progressive draw with ironing tool. It is found that the simulated thickness is close to experimental results. It is also found that the surface finish on the component has improved and die life has increased due to use of internal lubrication with coolant supplied.

1. Introduction
The main aim in forming technology today is to manufacture more precise products [1-3]. The main reason for having products that are more precise is for technical, economical and human needs [1]. One such product that requires more accuracy is the solenoid casing. The major process that is used in manufacturing solenoid casings is ironing, together with drawing. In the ironing process, a metal sheet is progressively deformed by successive passes of a punch in order to reduce the thickness to a desired depth of the component. The manufacture of a solenoid casing is a multistage process and involves three stages. The disadvantage of a multistage process is the cost increase as the number of stages increases. In order to reduce the cost of a product these stages must be carried out in one tool. A proper process design tool should be carefully designed and arranged to make the desired part with the minimum possible number of stages without causing failure. Generally, design of such process usually requires a lot of trial and error, using experimental or analytical approaches [4-7]. Schunemann et al. [8] studied the prediction of process conditions in drawing and ironing of cans. Sacks and Lubahn [9] investigated the influence of the spacing between two ironing dies. Baillet et al. [10] studied the experimental and numerical dynamic modelling of ironing process for aluminium beverage cans.
Danckert [11] determined the residual stress distribution in the wall of a deep drawn and ironed cup experimentally and by FEM. Kim and Hong [12] studied FEM based optimum design of multistage deep drawing process. Literature has been published on multistage deep drawing, but limited literature has been published on progressive draw with ironing tools. In the current paper the focus was towards developing a progressive draw with ironing tool for manufacturing the solenoid casing. The present practice of manufacturing a solenoid casing is by using a tandem line. In a tandem line, multiple presses are used for draw and ironing operation to achieve the final component. This process takes more time and cost, so in order to reduce the cost and time, a progressive tool is developed. By using the developed progressive draw with ironing tool, the solenoid casing is manufactured and the thickness is measured at different regions of the solenoid casing and FEM simulations were performed for the same component and are compared with the experimental results.

2. Experimental procedure

The material that is used for the present study is EDD steel. To find the mechanical and anisotropy behaviour of EDD steel tensile and plastic strain ratio r-value tests were performed in rolling directions 0°, 45°, 90° on an Instron 5182 universal tensile testing machine according to ASTM E8 and ASTM E547 standards, respectively. For manufacturing a solenoid casing a blank thickness of 5 mm and diameter of 97 mm was used for the present study. In a transfer die the tools that are required are stage wise punches and dies with a complete press tool die set assembly. In the first stage, the blank is placed on the die which is fixed at the bottom half of tooling and punch which is attached with the top half tooling and travels down with the blank to produce the cup shape. Here the die is designed in such a way that the draw operation and ironing operation takes place in single die. Once the first stage is completed, the blank is transferred to second die and next to further stages for a complete solenoid casing. Here the punch geometry is the same and die geometry is different for both the cases. This is a time consuming process, so in order to save time and enhance the productivity rate a progressive draw with ironing tool is developed for manufacturing a solenoid casing. The progressive tool performs multiple operations in a single die in which close geometrical tolerances can be achieved. The progressive tool is shown in Figure 1.

![Figure 1. Schematic diagram of progressive deep draw tool for manufacturing a solenoid casing.](image-url)
The present practice of manufacturing a solenoid casing by using a tandem press involves mainly three stages. In the first stage a blank diameter of 97 mm and thickness of 5 mm is drawn to a height of 56 mm and wall thickness changes from 5 mm to 3.5 mm. This stage involves drawing and ironing operations simultaneously. In the second stage the same drawn cup is transferred to another press for further ironing to a depth of 75 mm and wall thickness changes to 2.6 mm from 3.5 mm. In the third stage sizing of the component takes place and depth of the component changes to 65 mm and wall thickness changes to 2.75 mm. In this stage bottom of the cup becomes flat. The next stage in the process is center hole piercing and bottom facing. Finally in the finishing stage machining is done. This is a time consuming process so in order to save the time and enhance the productivity rate progressive draw with ironing tool is developed. In this tool, all the operations like drawing and ironing, ironing 1 and ironing 2 are done in same tool. In tandem presses, the blank for drawing the component to 75 mm depth needs two stations but in progressive draw with ironing tool this process is done in one station. Figure 1 shows the schematic diagram of progressive deep drawn tool. In progressive draw with ironing tool the blank with diameter of 97 mm with thickness of 5 mm is placed on the die. There is a separate lubrication system attached at the bottom of the tool to reduce the friction. This lubrication system is attached to pneumatic cylinder. The pneumatic cylinder is synchronised with press stroke opening and closing condition. When the blank is placed on the die the spray nozzle moves forward which is attached to pneumatic cylinder and the lubricant is ejected on the blank by spray nozzle and once the lubricant is applied on the blank the spray nozzle pushes back to its original position. The punch comes in contact with the blank and the blank achieves to a depth of 34 mm in first die. In this stage only draw operation is involved so the thickness remains almost constant and in second die the component further achieves a depth of 56 mm where ironing takes place simultaneously and in this stage the thickness is reduced to 3.5 mm from 5 mm. In third die the component further achieves a depth of 75 mm with uniform wall thickness of 2.6 mm. The difference between tandem press and progressive draw with ironing tool is in transfer press to achieve a depth of 75 mm two presses are needed where as in progressive draw with ironing tool only one press is required and the transfer time for the component can also be reduced. Hence the productivity rate increases. The remaining process like piercing, bottom facing and finishing is same as in case of tandem press. The solenoid casing is manufactured by using the developed progressive draw with ironing tool. The final component thickness is measured at different regions like dome and wall regions of the solenoid casing using an ultrasonic thickness measurement system.

3. Simulation procedure
The mechanical properties that are evaluated from tensile tests are used in the FEM simulations. FEM simulations were performed to predict the thickness variation of a solenoid casing at different regions in the component. The commercial available software Hyperform is used for the simulations. The mechanical properties like yield strength, ultimate tensile strength, Youngs modulus, anisotropy ‘r’ values were incorporated in FE simulations and the material model used is Hill MMC (Modified Mohr fracture criteria). A progressive tool set up is done in CAD package software Solidworks and FEM simulations were performed in Hyperform to predict the thickness. The tools that are required like punch and die were modelled in Solid works and exported to Hyperform. Meshing was done in Hypermesh software and the mesh size of 2 mm was used. The explicit formulation was used in the FEM simulations. The tools that are required, such as the punch, die, blank were modelled in CAD package software Solidworks and exported to Hyperform. All the tools that were used in the simulations were assumed to be rigid bodies. Coulomb's friction law of 0.1 was used between the tools and blank sheet for all the simulations. The sheet blanks were discretized using solid element. The die was kept fixed and punch was given a downward motion in z direction. The contact interfaces were modelled using contact type 7. To represent the yield law Hill 72 and the constants like F, G, H, L, M, N were determined experimentally. The constants F, G, H, N were determined by using anisotropy ‘r’ values in different rolling directions. To mimic the results the same procedure that was done in
experimental was repeated in simulations to compare the thickness variations at different regions. The clearance was same in both experiments and simulations. The simulated results were compared with experimental results.

4. Results and discussion

Tensile tests were performed for EDD steel at different rolling directions 0°, 45°, 90° to find the mechanical properties of EDD steel. Figure 2 (a) and (b) shows engineering stress vs engineering strain and true stress vs true strain for EDD steel. The mechanical properties like Youngs modulus, yield strength, ultimate tensile strength were found from this plot. It is observed that the yield strength and ultimate tensile strength varies slightly in different rolling directions. The variation is around 5-10 MPa in different rolling directions in all the mechanical properties. The yield strength is around 288-312 MPa and ultimate tensile strength is 351-385 MPa. The ductility of the material is 25-31% in different rolling directions. It is found that uniform elongation is 13.3-15.8% in different rolling directions. There is a slight variation in uniform elongation in different rolling directions. To calculate the work hardening exponent ‘n’ and strength coefficient ‘K’ log (true stress) vs log (true strain) is plotted and shown in Figure 3. It is found that n value is 0.09-0.10 and K is 545-572. The n value is not varying much in different rolling directions but strength coefficient is slightly varying.

![Figure 2](image1)

**Figure 2 (a).** Engineering stress vs Engineering strain for EDD steel at different rolling directions. (b) True stress vs True strain for EDD steel at different rolling directions.

![Figure 3](image2)

**Figure 3.** log (true stress) vs log (true strain) for EDD steel at different rolling directions.

FE simulations were performed for the solenoid casing as explained in the simulation procedure to predict the thickness at different regions. Figure 4 shows the predicted thickness of a solenoid casing.
at different regions in three progressive dies during drawing and two ironing stages. It was found that the predicted thickness is close to thickness obtained from progressive deep draw ironing tool. The thickness obtained in intermediate stages is within the specification limits. Figure 5 (a) and (b) shows the experimental thickness and predicted thickness at different regions in a solenoid casing by using developed progressive draw with ironing tool. It is found that in the experiment, the thickness in wall regions is 2.6 to 2.64 mm and the predicted thickness is 2.44 to 2.60 mm. The difference in simulated and experimental thickness in wall regions is found to be 40-160 µm. There is not much difference observed between simulated and experimental thickness. At the bottom of the casing, the experimental thickness is 4.81 mm and predicted thickness is 4.86 mm which is very close to experimental thickness. It is also found that by using developed progressive draw with ironing tool the surface finish on the component has improved by macroscopic when compared with tandem press and die life has increased due to internal lubrication with coolant supplied.

![Figure 4](image-url)  

**Figure 4.** Predicted thickness of a solenoid casing at different regions in three progressive dies (a) during drawing (b) during ironing-1 (c) during ironing-2 in a single station.
5. Conclusion
The major conclusions that is derived from the present study are
1. A progressive draw with ironing tool is developed for manufacture a solenoid casing.
2. The predicted thickness measured at different regions in solenoid casing is close to experimental results.
3. The surface finish on the component produced by using developed progressive deep draw ironing tool is improved as compared to tandem press.

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