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Rubber Pad Sheet Metal Forming of Round Metal Blanks into Multi Shape Axisymmetric Cups by FEA and Experimental Methods

Abstract- *Rubber-pad forming process of round sheet blanks into axisymmetric cups is studied by numerical and experimental approaches. In the experiments, round metal sheets are formed into the axisymmetric cups by pressing them between a rubber pad and a former block with desirable shape. To investigate influences of different parameters on the forming load, three former blocks with different shapes, blank material of low carbon steel (ST12) with thickness 0.5 mm ,three polyurethane rubber with different hardness (50,60 and 70) shore A and rubber pad having three different thickness (40,60 and 80) mm . ANSYS Workbench utilized to perform the numerical part of this research. The results showed that the produced cup height is significantly affected by rubber pad hardness.*

Keywords- *Rubber pad forming, sheet metal forming, rubber hardness, rubber thickness, cup height, numerical modeling, ANSYS Workbench.*

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1. Introduction

An effective process of decreasing the initial tooling costs and simplifying the forming process is to replace metallic tools with a Flexible-die forming (FDF) process. Such flexible tools supplement the traditionally matched rigid steel tooling [1]. FDF method utilizes a flexible pressure-carrying medium instead of metallic die or punch. The medium might be gas (expanding or pressured air), liquid (oil or water), or elastic body (a pad of rubber) [2]. However, sheet flexible-die forming methods have been broadly used in industries like aerospace and automotive factories. The concept of the rubber-pad forming can also be used for drawing, embossing, bending and punching sheet metals into a variety of shapes and contours [3]. These processes reduce the number of manufacturing stages, tool and production costs. Using a rubber tool offers the advantage of comparatively feasible and secure processing of the drawing operation. The punching procedure with a rubber tool is capable of producing components, which are impossible, or very difficult to produce using conventional tools [4].

Rubber pad sheet metal forming as a modern forming method has been extensively used in the drawing, flanging and blanking, bulging processes. Xiang et al. [5] studied forming features of two styles of deformation in detail with numerical modeling and experimental approaches. They evaluated the suitable range of process parameters for convex and concave deformation styles used to manufacture a particular metallic bipolar plate.

Wrinkling is a familiar defect in the forming of sheet blank resulting from the insufficient metal capability to shrinkage. Sun et al. [6] found that high forming velocity delays the beginning of wrinkling. The rubber hardness has a substantial influence on the wrinkles width and height. On the contrary spreading of wrinkles is less affected by rubber hardness.

Abbas et al. [7] have examined experimentally the rubber pad forming process of the metal sheet. Some process variables like the thickness of blank, type of material, rubber pad thickness and the geometry of the die are studied. The results are obvious that the forming load is inversely proportional to the sheet for the same forming travel. In addition, it was found that increasing the rubber pad thickness, improved the necessary forming energy.

Elyasi et al. [8] introduced the influences of convex and concave former and rubber features on the rubber pad sheet metal forming process. In their paper, the blank material was steel 316 having a thickness of 0.1 mm and a rubber pad with a hardness of 85 Shore A was employed to produced final products.

The results showed that, for a similar subjected forming load, the convex former presented less filling capacity than the concave former. Moreover, when an increasing forming load, no significant increase in filling capacity occurs with both formers but increasing the forming load leads to rupture in rubber pad.

Koubaa et al. [9] investigated the ability of rubber pad forming, by comparison, tube bulging using rubber and hydroforming bulging. In order to compare, a numerical simulation model was created for each forming process and discussed. A noteworthy result was that utilizing rubber as a pressure-carrying medium has recommended enhancing thickness distribution and improving formability.

This study focused on the effect of thickness and hardness of the rubber on cup height produced by rubber pad sheet metal (RPSMF) process. At first appropriate range, these parameters will be determined in ANSYS Workbench through the parametric model for each deformation styles where three former blocks have been adopted to study (flat, hemispherical and complex).

2. Numerical Modelling

One of the major requirements for computer simulations is to check proposed design validity and finding the range of process parameters. In order to reduce the processing time and to improve the precision of calculations which lead to the right design of tool dimensions as well as identifying the suitable range of rubber hardness, 2D axisymmetric parametric models were created for many RPSMF variable. Figure 1 illustrates the geometrical model created by ANSYS Design Modeler.

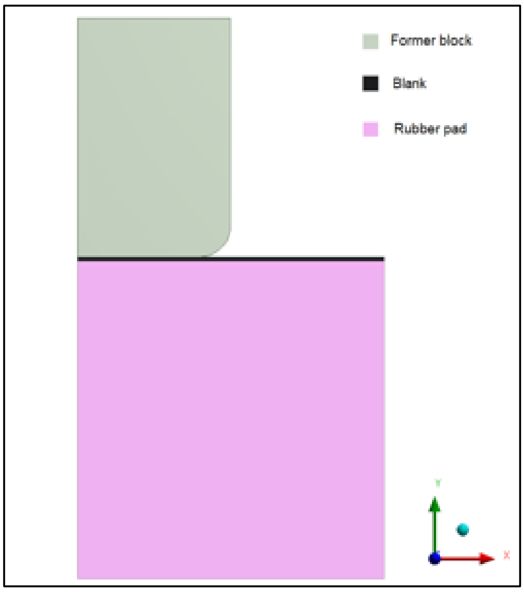

Figure 1: a Part arrangement in design modeler of ANSYS Workbench

The models in finite element analysis (FEA) included three parts: a former block, a sheet and a rubber pad. To simplify the model, the rubber container rubber pad was replaced with specific constraint applied on the rubber right edge.

Multilinear isotropic hardening assumption is used to define material properties of work piece (blank material). The elastic region is defined by elastic constants, as illustrates in Table 1. The plastic region is fitted with linear segment contact the plastic curve at slope called tangent modulus(TM), the values of these tangent moduli are determined as a sloping lines tangent to the plastic curve in a tensile stress-strain curve as shown in Figure 2 while their values listed in Table 2.

Table 1: Mechanical properties of blank material

Material property	Modulus of elasticity (E)	Poisson's ratio(ν)	Yield stress (σ_Y)
Magnitude	200 GPa	0.3	220 MPa

Table 2: Tangent modulus used to model plastic region

Tangent modulus	TM1	TM2	TM3	TM4	TM5	TM6
Magnitude(GPa)	3.33	1.2	1	0.6	0.4	0.18

All the models were meshed by using mesh control tools in the following procedure:

- Mesh the entire model with global mesh control.
- With local mesh, control refinement was applied on the surface of blanks whereas more elements are required.
- With local mesh control, the free mesh was subjected to certain edges of former blocks. Mesh of the hemispherical model is demonstrated in Figure 3.

The numerical modeling work in this research adopted 2D axisymmetric geometry accompanied by the use of appropriate constrained in order to represent the full physical model as described in the following:

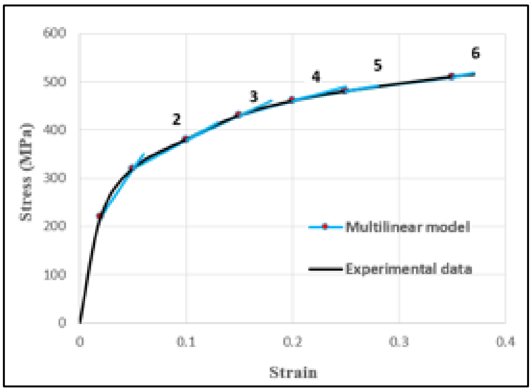

Figure 2: Experimental data fitted with multilinear plastic model

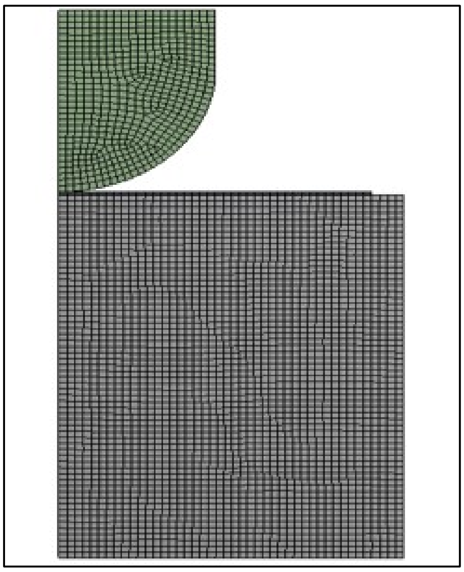

Figure 3: Hemispherical model mesh in ANSYS Workbench

Define axis of symmetry at the left edge of the former block, blank and rubber pad.

1. Fixed support at the lower edge of the rubber pad to present die lower plate.
2. Fixed support at the edge above to represent pressure plate that restrained the vertical movement of sheet and rubber at this region.
3. Frictionless support at rubber pad right edge to restrict rubber move in the horizontal direction while it free to move in a vertical direction.
4. Applying velocity at former block upper edge subrogates press head movement.

These boundary conditions and constraints presented in Figure 4 fora complex former as an example.

3. Experimental work

Allow carbon steel is chosen to be the material of work piece to be drawn in rubber pad sheet metal forming (RPSMF); this choice was because it possesses good draw ability. This material is taken as a sheet with the thickness (to= 0.5mm), the reason in choice this thickness due to the problems in the drawing of sheet arises with decreasing thickness gauge, subsequently by using RPSMF trying to eliminate this problem. Circular blanks of 80 mm diameter were cut out from the sheet. A chemical composition test was carried out by using a spectrometer device to check the manufacture certificate of material, as shown in Table 3. In order to determine the mechanical properties of sheet material, tensile test specimens were cut from the materials according to ASTM (E8M) standard. The tensile test was performed on a computerized universal testing machine (WDW-200E). The true stress-strain curve and the obtained mechanical properties were introduced figure in Tables 1 and 2, where these properties are used to define blank material in the numerical model.

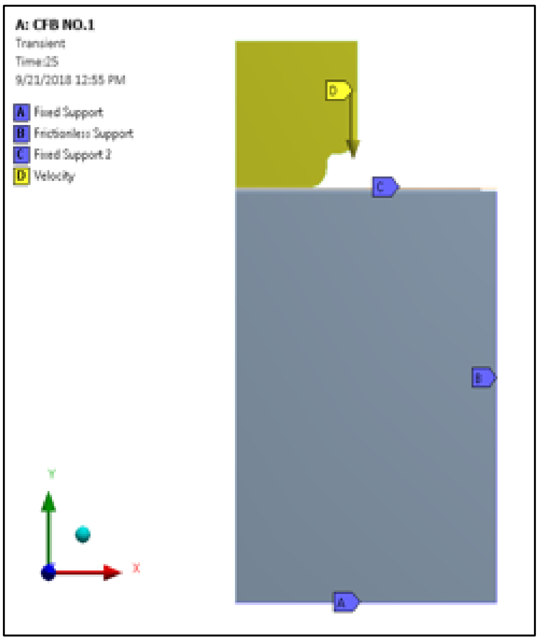

Figure 4: Constraints applied to the complex former model

Table 3: Chemical composition of low carbon steel

Component	C	Si	Mn	S	P	Cr	Ni	Fe
Percentage %	0.093	0.018	0.41	0.024	0.023	0.028	0.022	Rest

Sheet metal forming drawing die was designed and manufactured. To meet the requirement of planned experimental tests, certain parts of the die were interchangeable. The following tool has been prepared and manufactured:

1. Three former blocks with different shapes (Flat, Hemispherical and complex). As illustrated in Figure 5.
2. Rubber container. As illustrated in figure 6.
3. Drawing dies auxiliaries include (upper plate, lower plate, guides, spring and bolt).

Drawing experiments are carried out to obtain cylindrical cups by mounted RPSMF die on the testing machine, as shown in Figure 7. The testing machine type is (WDW-200E) has a capacity of (200KN) and stroke speed ranging from 0 to 500 mm/min. After placing sheet blank on the rubber pad upper surface, the former block will drop down towards the blank to enforced it inside the rubber ,while the rubber generates counter force thereby the blank to take the shape of former block gradually. The stroke speed is 100 mm/min is used in experiments.

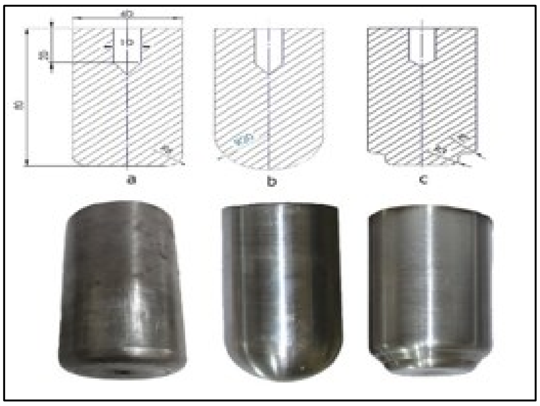

Figure 5: Cross-sectional view and manufactured former block (a. Flat, b. Hemispherical and c. Complex)

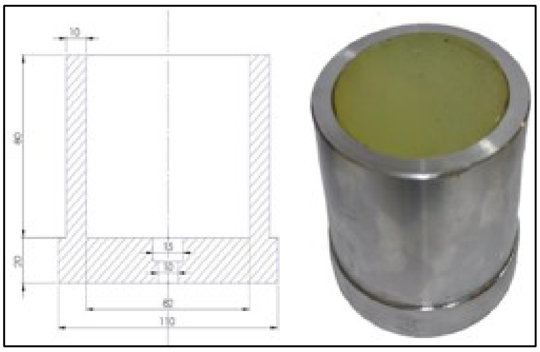

Figure 6: Cross-sectional view and manufactured rubber container

Figure 7: RPSMF die mounted to the computerized testing machine

4. Results and Discussions

The ability of sheet blank to form as possible as the highest cup does not only depend on formability of sheet material but also on geometrical and mechanical features of rubber pad used. The rubber dimensions and hardness significantly effect on forming travel, but the improvement in travel may not mean an increase in product height since the elastic deformation of rubber pad represents the former block travel, not all of this former progress may be reflected on the height of the product.

Consequently, to study the effect of various process parameters on cup height, these factors are divided into groups ,which will be discussed in the next sections.

I. Flat Former Block (FFB)

For flat former when the rubber pad of 40 mm thickness has been used there is significant increase in cup height with decrease in rubber hardness especially in the transition from 70A to 60 A. Where the heights were 11.2 mm ,13.4 mm and 14.1 mm when the rubber hardness are 70 , 60 and 50 shore A were used respectively as demonstrated in Figure 8. The reason is related to the elastic capability of rubber to support or enforce blank material to take the shape of the former block, as the capability will be greater at lower pad thickness since it gets support from the bottom of the container.

Utilizing rubber pad thickness (RPT) of 60 mm leads to increase in cup heights to 15.8 mm, 16 mm and 14.7 mm when the rubber hardness 70, 60 and 50 shores A were used respectively. However, no significant increase has been achieved with rubber pad hardness (RPH) of 50 shores, where it was just 0.6 mm. When RPT of 80 mm was used, there was no increase in cup height, on the contrary, there was a decrease in cup height to 14.8, 15.6 when the rubber hardness 70 and 60 shores A were used respectively. The only exception occurred in RPH of 50 shores A where a slight increase of 0.1 mm has performed.

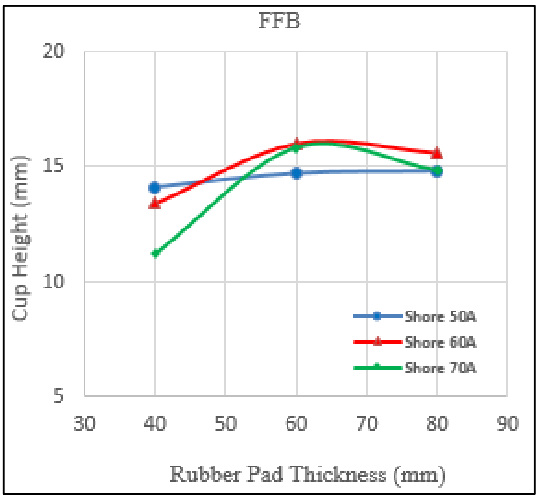

Figure 8: Effect of rubber hardness and thickness on cup height for the former flat block (Experimental

II. Hemispherical Former Block (HFB)

Now, the results for the hemispherical former are shown in Figure 9, almost have the same tendency of flat deformation style, increase in cup height with an increase of rubber thickness for RPH of 50 A and 70 A has been observed. Also, the maximum cup height was 18.3 mm appear in RPH = 50 A when RPT = 60 mm, the reason for this is due to rubber pad thickness which has adequate support from container bottom which consistent with the rubber pad state (thickness and hardness). On the other hand, the minimum cup height was 14 mm occurred in RPH = 70 A when RPT = 40 mm, that result from poor in flexibility of rubber at this hardness accompanied with little forming travel at this rubber thickness.

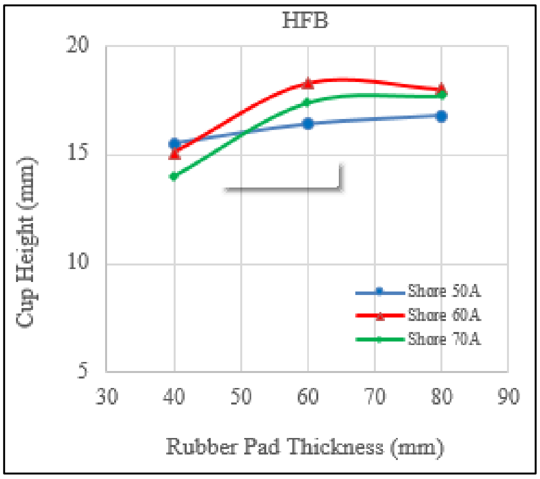

Figure 9: Effect of rubber hardness and thickness on cup height for the former hemispherical block (Experimental Results)

III. Complex Former Block (CFB)

The lowest values of cup height amongst all former blocks appear in CFB, which results from the complex geometry of the cup bottom as presented in Figure 10. The highest cup was 13.7 mm occurred in RPT of 80 mm and RPH of 50 A, while the shortest on was 9.5 occurred in RPT of 40 mm and RPH of 70 A. in contrary of flat and hemispherical deformation style, in CFB the cup height increases with increase rubber thickness for all rubber hardness without exceptions. Furthermore, the cup height is decreased with an increase in rubber hardness for all rubber thickness.

IV. Numerical Simulation Results

Apparently, the numerical simulation results shown in Figures 11, 12 and13 corroborates the findings of experimental tests in the main tendency. But that doesn't mean there is no variation between experimental and numerical simulation values, where this variation reaches up to 10%, 11.4% and 7.3% when FFB, HFB and CFB were used respectively. The only unanticipated result was the maximum cup height in HFB appeared in when rubber hardness is 60 A and rubber thickness is 80 mm. Figure 14 shows the numerical models for all former blocks, while Figure 15 shows the completely drawn cup for numerical and experimental work.

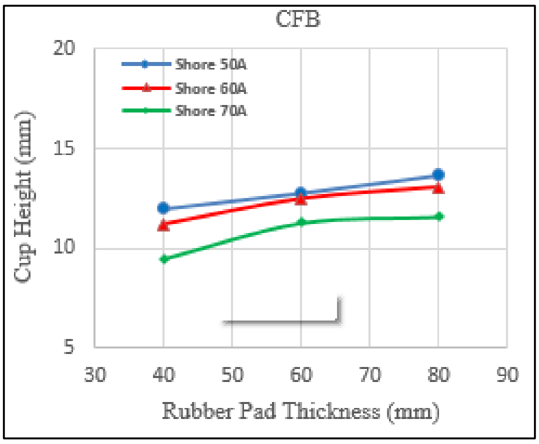

Figure 10: Effect of rubber hardness and thickness on cup height for the complex former block (Experimental Results)

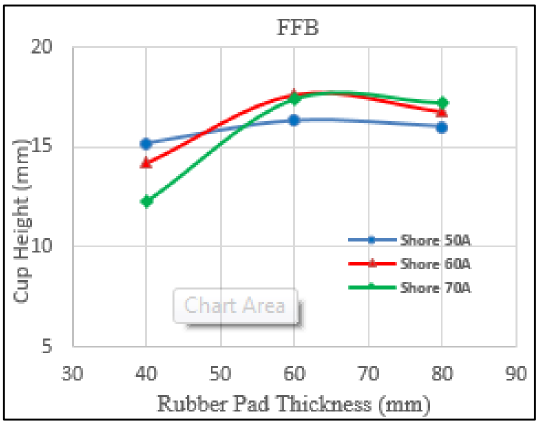

Figure 11: Effect of rubber hardness and thickness on cup height for the former flat block (Numerical Simulation Results)

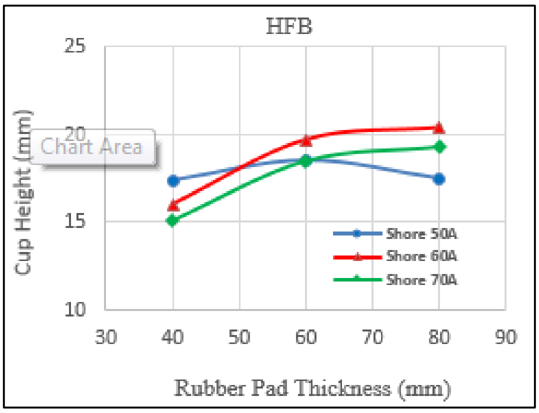

Figure 12: Effect of rubber hardness and thickness on cup height for the former hemispherical block (Numerical Simulation Results)

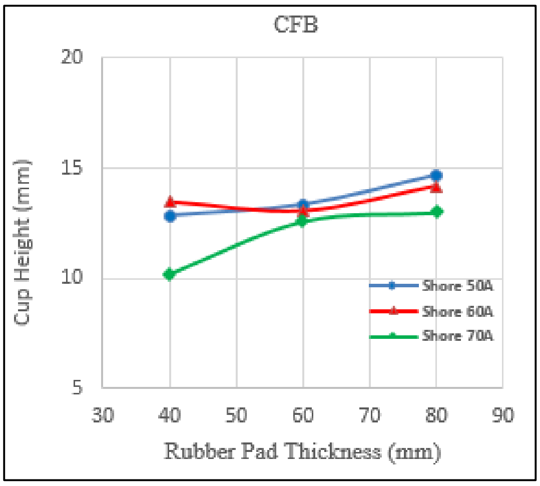

Figure 13: Effect of rubber hardness and thickness on cup height for the complex former block (NumericalSimulation Results)

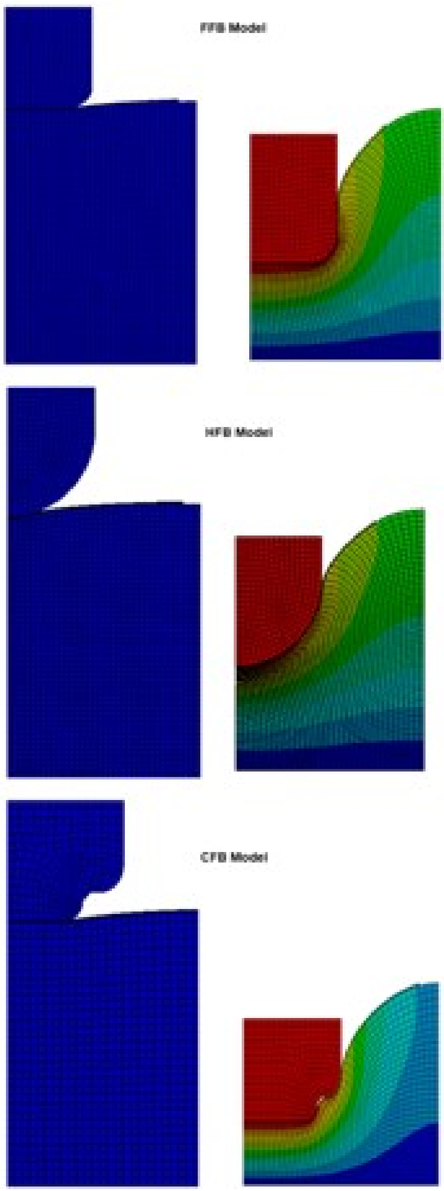

Figure14: Numerical simulations model for flat, hemispherical and complex former block

5. Conclusions

1. The results of this study indicate that for the rubber pad of 40 mm thickness, the cup heights are decreased with the increase of rubber hardness for all former blocks types.
2. For rubber pad thickness of 60 mm and 80 mm the cup heights are increased with increase in rubber hardness form 50 shore A to 60 shores A for FFB and HFB and decreased in with a further increase in rubber hardness.
3. The cup height for CFB is increased with increase rubber pad thickness and decreased with increase rubber pad hardness without exceptions.
4. The numerical simulation results shown in figure corroborates the findings of experimental tests in the main tendency, but there is a variation between experimental and numerical simulation values , reach up to 10%,11.4% and 7.3% when FFB ,HFB and CFB were used respectively.

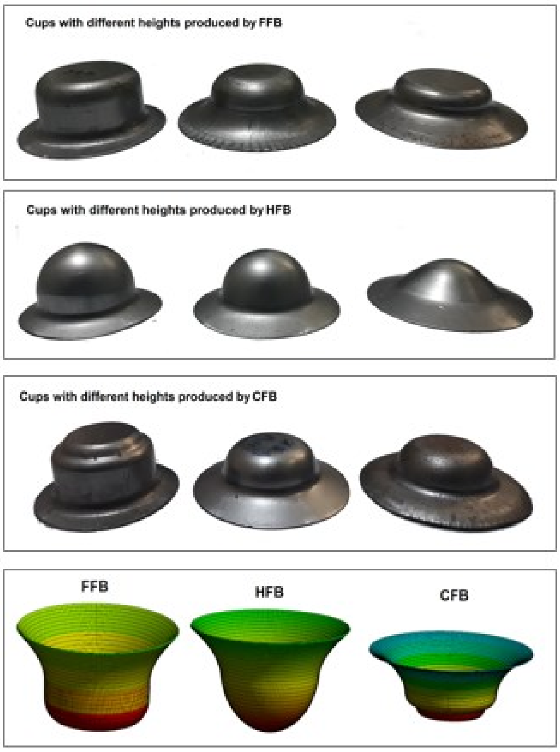

Figure15. Samples of completely drawn cup of experimental work and numerical simulations

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