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Numerical and experimental investigation of parameters affect the forming load during rubber pad sheet metal forming

Karem M. Younis[1], Adnan I. Aljarjary[1], Jalil J. Shukur[1]
[1]Department of Production Engineering and Metallurgy, University of Technology, Baghdad, Iraq
E-mail: Jaliluot@gmail.com (Jalil J. Shukur)

Abstract. The flexible die forming of sheet metal with the aid of rubber pad as a pressure-carrying medium is one of the advanced forming technologies for sheet metal forming components. In this research, rubber pad forming process was used to produce cups with different shapes. The sheet made from low carbon steel with a thickness of 0.5 mm. The rubber pad has made from polyurethane with different values of hardness and thickness which are (50, 60 and 70) shore A, and (40 and 80 mm), respectively. This pad is used to apply counter pressure to form the sheets. The former block is with three different shapes, which are flat, hemispherical, and complex. A numerical study has conducted to look into the deformation style of this process by 2D-FE simulation under the ANSYS Workbench platform. Numerical and experimental results illustrate that the forming load increases with increase rubber hardness while it decreases with increase the rubber pad thickness.

Keywords: rubber pad forming, numerical simulation, rubber hardness

1. Introduction

Rubber pad sheet metal forming (RPSMF) utilizes a former block on the ram of the press and rubber pad a in the metallic container. The former block is commonly instead of punch in a traditional stamping tool [1]. The rubber performs comparatively as hydraulic fluid in applying almost uniform force on all blank faces to enforce it to take the shape of former. The major advantages of forming operations with rubber pad as a medium to apply forming load, several conventional dies can replaced by one rubber piece, retrieving its initial dimension after unloading, tools have fewer components, and are made of easier to machine materials, than traditional tools[2]. The radius of forming diminishes gradually over the forming travel, In contrast to fixed radius of traditional forming die and thinning of the produced parts, (like that appears in traditional stamping process) is almost eliminated using rubber pad forming . Figure 1 demonstrated schematic comparison between traditional drawing and drawing using rubber pad.

In recent years, rubber pad sheet metal forming (RPSMF) process has gained increasingly important, particularly in the field of automobiles and aeroplanes manufacturing. Because of the rising demands of manufacturers of sheet metal products to interesting environmental influences, it is nowadays extensively known that efforts toward reduce product weight as much as possible .Until now, many researches on this process have carried out a numerical simulation and experimental work. The efficient parameters in sheet forming using rubber pad, were introduced by Vafaeesefat and

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Mahshidifar [3] have investigated the effective factors in the rubber pad forming method on workpiece containing curvature radius, thickness of rubber pad, lubrication condition and spring back phenomena have been analyzed. The research results proved that the quality and formability of the formed parts have increased by finding an appropriate friction condition between the rubber-sheet, and sheet-form block interfaces.

Wrinkling is a familiar defect in the forming of sheet blank resulting from the comparatively insufficient metal capability to shrinkage. Sun *et al* [4] studied effect of rubber hardness on the formation of wrinkling of convex flange using the rubber pad forming. The findings showed 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 are less affected by rubber hardness.

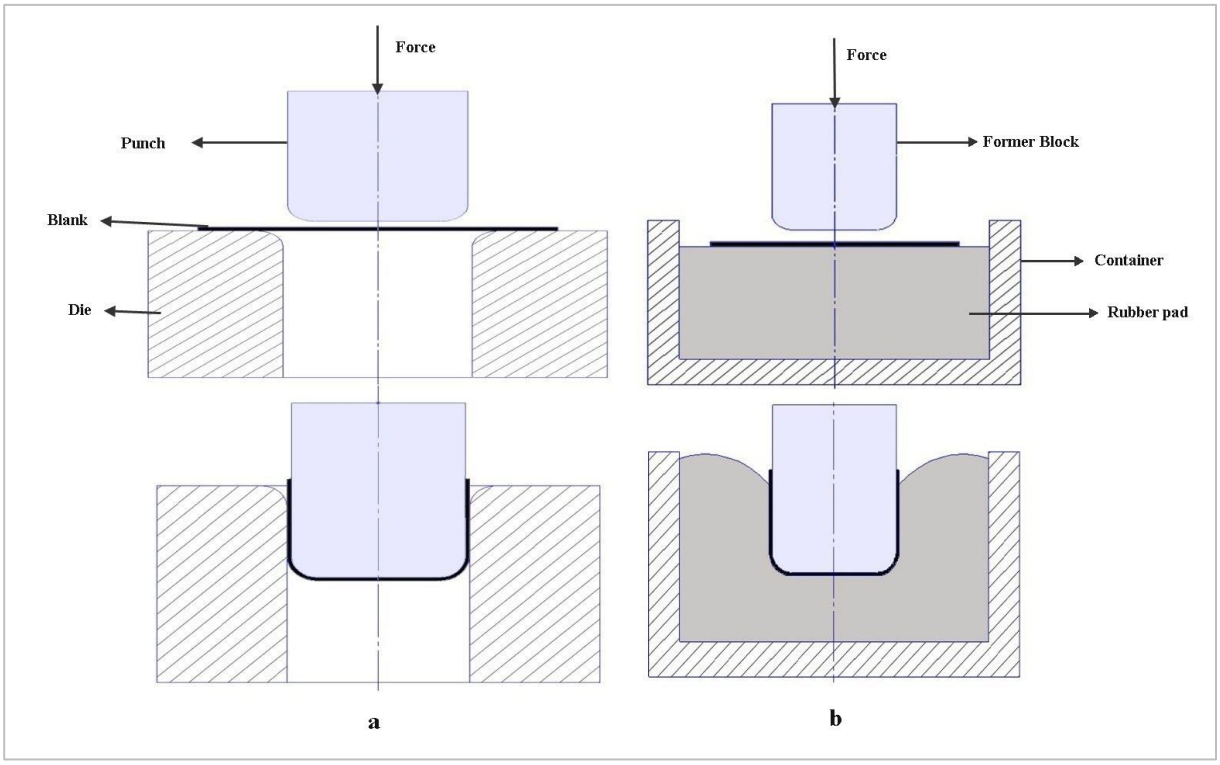


Figure 1. (a), conventional deep drawing, and (b), rubber pad deep drawing

The Influence of material thickness and type on the rubber pad sheet metal forming process studied in In the paper of Niknejd and Karami [5] their findings presented that the radius of bending for the formed parts increase when width cavity of former block enhanced, therefore the forming load reduces. The results also obvious that the forming load increases with increases sheet initial thickness.

Several studies had been utilized finite element analysis (FEA) to check the rubber pad forming validity and predict the forming force, thickness distribution of produced shell as well as the induced stress in rubber pad and product. Subbaramaiah et al [6] introduced a comparative investigation between experiment and FEA of rubber pad forming. The results concluded that numerical methods can accurately predict the intricate rubber pad forming process with high accuracy. Minimal thinning of less than 6% has observed in this process with no wrinkles. The forming force and tool travel estimated by numerical analysis a good agreement with the experimental results.

Belhassen et al. [7] discussed the influence of rubber pad forming factors such as rubber hardness and rubber type on the thickness distribution, the spring back and tearing of aluminum workpiece. The research findings showed that increase the original sheet thickness leads to increase the spring back amount, this result applies to all rubber factors (types and hardness). The results also verified that

using harder rubber increase markedly the final product thinning, thereby tearing probability rises and formability diminishes.

Koubaa et al [8] 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 to enhancing thickness distribution and improving formability.

The filling capacity of rubber pad is predominated factor when drawing sheet metal through narrow cavity Elyasi et al [9] introduced the influences of convex and concave former and rubber features on rubber pad sheet metal forming process. In their paper, the blank material was steel 316 having 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 increasing forming load, no significant increase in filling capacity occurs with both formers, but increasing the forming load leads to rupture in rubber pad.

2. Numerical simulation

In recent decades, finite element analysis (FEA) has been adopted by many obtainable commercial software. Amongst a wide range of the available numerical simulation solutions offered by computer aided engineering (CAE) corporations, ANSYS Workbench distinguishes by its modern graphical user interface intended to easily integrate and appropriate of advanced numerical simulation techniques. The objectives of FEA in this research is to achieve the following points:

1. Predict the appropriate range of rubber pad dimensions (thickness and diameter).
2. Predict the adequate range of rubber hardness.
3. Check the validity of the process.
4. Analyzing stresses that induced in the rubber pad and workpiece.

FEA works of this research encounter high nonlinear behaviour since three types of nonlinearity have included in this FE model. Firstly the blank material is to be modelled with high deflection (plastic deformation) and the stress strain relationship for this region is nonlinear as well as the material of rubber pad introduce nonlinear elastic behavior throughout the forming process. On another hand, the numerical models exposed to change in contact status during the progress of modelling that leads to modifying the initial contact condition based on that the models contain the contact nonlinearity. Finally the large plastic deformation occurs in blank material accompanied with larger elastic deformation of rubber pad material which leads to geometrical nonlinearity arising in numerical models.

The FEA work in this research was adopted A transient structural analysis, where it can be either linear or nonlinear. All categories of nonlinearities have allowed, plasticity, contact, hyperelasticity, large deformations.

2.1. Define engineering data

The numerical simulation work of this research deals with two different materials, first is the blank sheet material where plastic deformation occurs as a result of former block movement which counter pressure induced by the second material. The rubber pad enclosed in rigid container. So two material models was used to define in numerical simulation:

1- Multilinear isotropic hardening assumption has used to define the material properties of the blank material. Figure 2 presents the true stress strain curve, the elastic region is defined by an elastic constant, as illustrated in table 1.While the plastic region which divided with linear segment contact the plastic curve at a slope called tangent modulus(TM),the value of these tangent moduli present in table 2.

2- Mooney–Rivlin model is used to defining the properties of rubber pad material based on the rubber hardness as shown in table 3.

2.2. Define geometry and meshing

To minimize the solution time and to enhance the accuracy of computations which lead to the accurate tool design and manufacture as well as identifying the suitable range of rubber hardness, two dimensional axisymmetric parametric numerical simulation models were generated for many RPSMF variables . The models in numerical simulation consist of three parts only: a former block, a sheet and a rubber pad (elastic punch). For the purpose of simplifying the model, the rubber container not included in numerical model and appropriate constrains were subjected on the rubber pad vertical edge as a substitutional to the container.

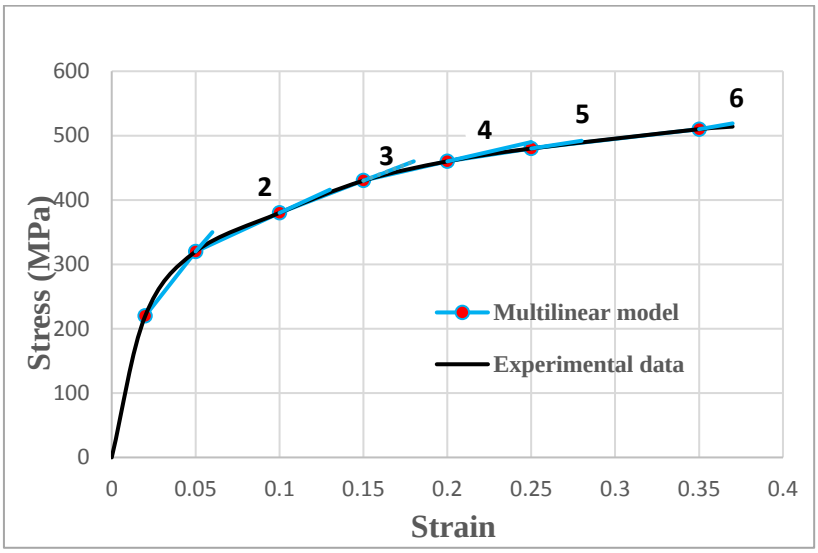


Figure 2. Experimental data fitted with multilinear plastic model.

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

Table 3. Mooney-Rivlin constant based on shore hardness.

		All values in MPa		
Shore A	G	E	C10	C01
50	0.755	2.397	0.302	0.076
60	1.185	4.268	0.474	0.118
70	1.839	7.289	0.736	0.184

The entire model has meshed with global mesh control. Then local mesh control refinement has applied on the surface of the blanks, whereas more elements are required. Moreover, with local mesh

control free mesh has subjected on certain edges of former blocks. Figure 3 illustrated the hemispherical former block (HFB) model after meshing.

2.3. Contact and boundary conditions

The contact as a physical sense is that touch occurs between two separated parts, thereby tangent region (surface or edge) will be generate on each part called contact side, two contact pairs have accomplished in each model, one contact pair between the former block and upper edge of blank, while the other contact pair between rubber pad upper edge and the edge of the blank. Coulomb friction model is used to define friction in contact interface.

The numerical modelling work in this research adopted 2D axisymmetric as shown in figure 4 geometry accompanied by the use of appropriate constraint in order to represent a full physical model as described in the following:

1. Define axis of symmetry at the left edge of the former block, blank and rubber pad.
2. Fixed support at the lower edge of rubber pad to present die lower plate.
3. Frictionless support at the right edge of the rubber pad to restrict rubber movement in a horizontal direction while it free to move in a vertical direction.
4. Applying velocity at former block upper edge subrogate press head movement.

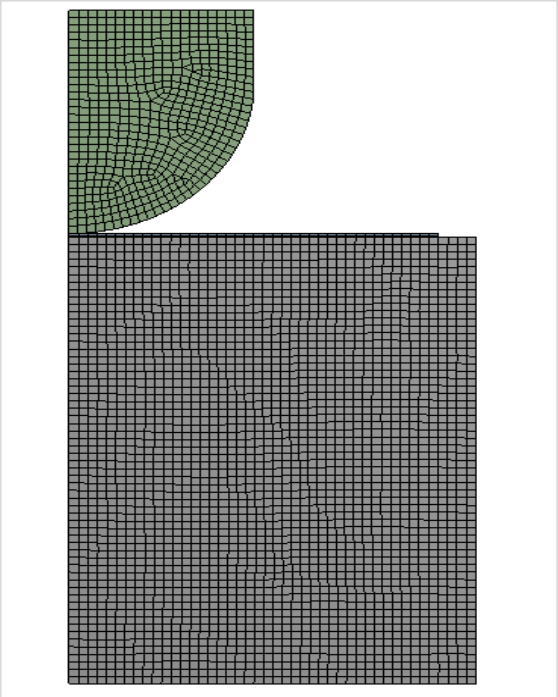


Figure 3.HFB model meshing.

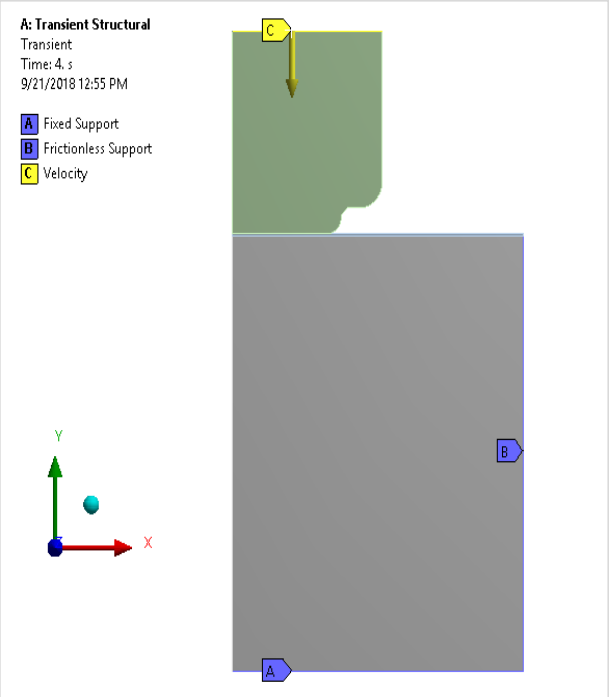


Figure 4.CFB model constraints.

3. Experimental Work

The RPSMF process largely depended on rubber pad geometrical and mechanical features, whereas the successful product result from an appropriate blend of these features. Huge experimental work required to accomplish the appropriate process parameters blend, so that the main objective of the adoption FEA work to lower the trial and error efforts which is no longer feasible because it is time consuming and expensive. The Experimental work of this research has based on the output of numerical models that established and executed in the previous section.

3.1. Sheet material characteristics

Low carbon steel has chosen to be drawn in RPSMF because it has a good drawability, which provides a good working space without failure due to wrinkling or tearing. Sheet with thickness (t_o= 0.5mm)

and circular test blanks of 80 mm diameter was cut out from the sheet. The tensile stress-strain curve of sheet material shows in figure 2.

3.2. Rubber material characteristics

A polyurethane (PU) is chosen to be the material for rubber pad, the choice of PU rubber because of it available in wide range of shore hardness as well as it can prepare through a chemical reaction of a diisocyanate and a polyol to obtain the required rubber pad with desired size and hardness. The compression test carried out according to ASTM D575, these experiment approaches involved two test systems for measuring the compression-deformation properties of rubber materials other than those normally divided as hard rubber and softer rubber. The compression test for rubber pad with hardness 50 ,60 and 70 shore A demonstrated in figure 5. In order to determine the hardness of elastomers the Shore test has used .The test is made with a measuring apparatus called durometer as shown in figure 6 and the Shore hardness is a number comprised between 0 and 100 defined in many standards such as ASTM D 2240.

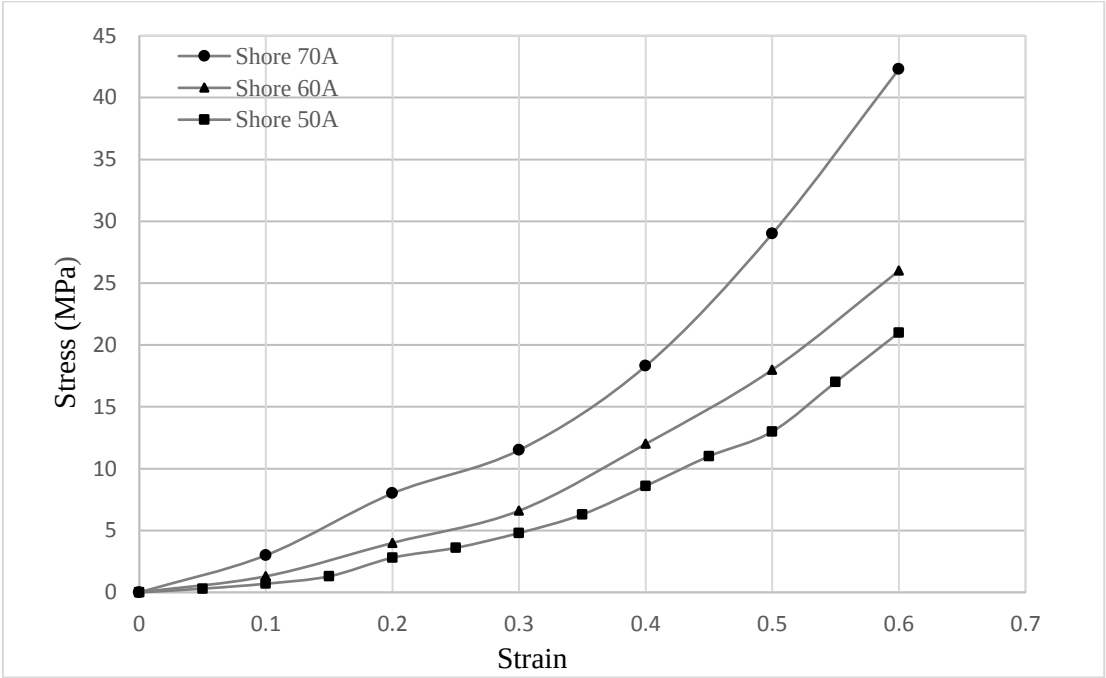


Figure 5. Compression stress–strain curve for rubbers with different hardness.

3.3. Experimental tools and equipment

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 7.
2. Two rubber containers with different height (40mm and 80 mm) As illustrated in figure 8.
3. Drawing die auxiliaries include upper plate, a lower plate, guides , spring and bolt.
4. Rubber pad with hardness (50,60 and 70) shore A and with thickness of 40 mm and 80 mm.

Drawing experiments are carried out to obtain cylindrical cups by mounted RPSMF die on the testing machine as shown in Figure 9. The testing machine type is (WDW-200E) has a capacity of (200KN) and stroke speed of 100 mm/min has used. The forming load and travel was directly measured on this testing machine.

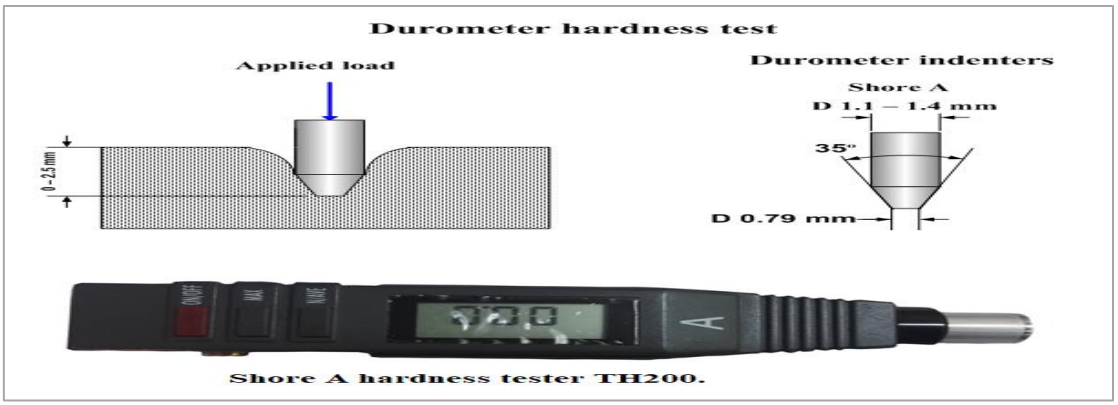


Figure 6. Durometer test details**.**

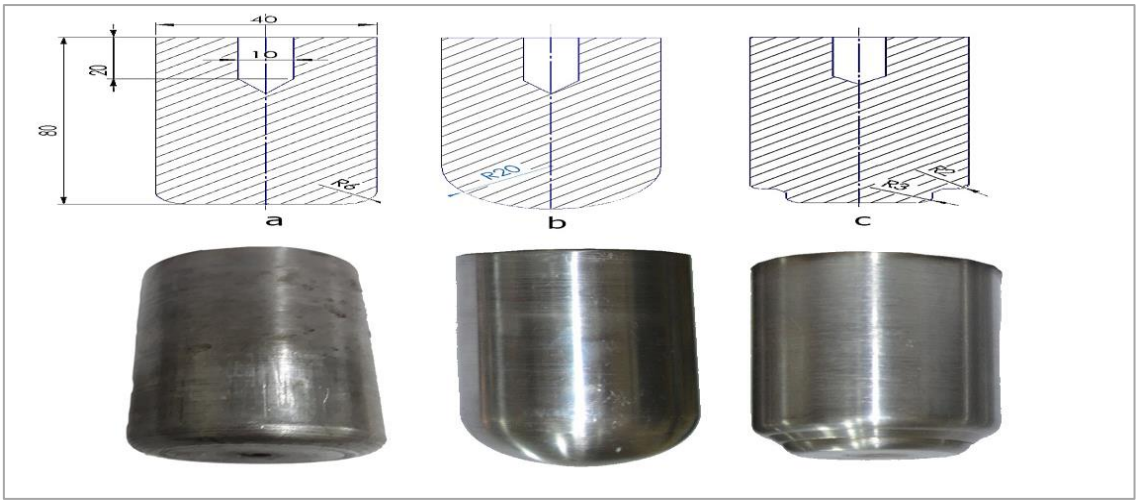


Figure 7. Cross sectional view and manufactured former block (a. Flat , b. Hemispherical and d. Complex).

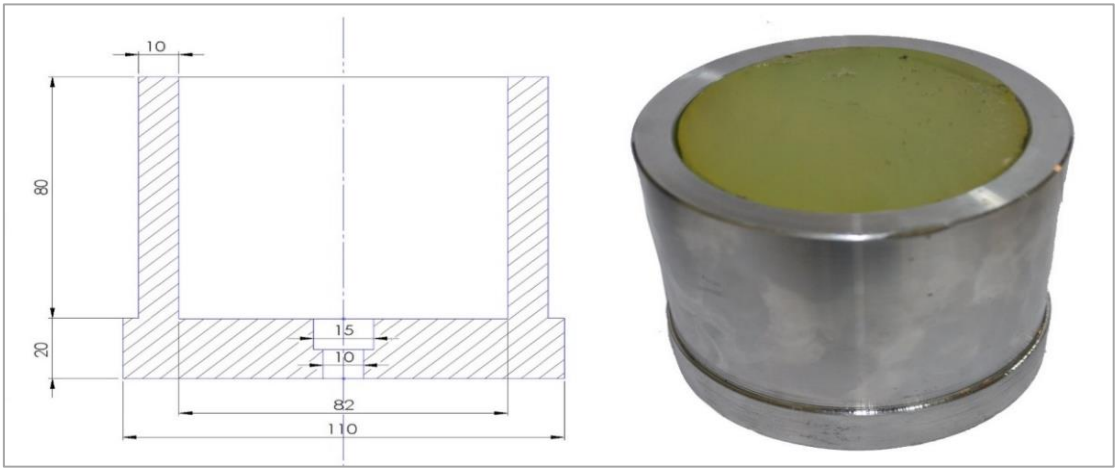


Figure 8. Cross sectional view and manufactured rubber container.



Figure 9. RPSMF die mounted to computerized testing machine.

4. Results and discussion

Allowable parameters range that obtained from numerical models has adopted in experimental tests. In this research, two process parameters affecting on forming load, rubber pad hardness and rubber pad thickness.

4.1. Results of rubber pad of thickness 40mm

The influence hardness of rubber when using Rubber Pad Thickness (RPT= 40mm) is illustrated in figure 10.As it is obvious from this figure, the forming load is strongly depended on Rubber Pad Hardness(RPH). Whereas the forming load varying from one former block to others based on deformation style.

For the same former block the forming load increase with an increasing rubber pad hardness , where the maximum load occurs with hemispherical former block (HFB) and reached 88.3 KN when RPH= 70A as shown in figure 10.b .That resulting from severe deformation style on the contact interface between the former block and blank material and that leads to high counter pressure induced in rubber especially if rubber pad with high hardness is used. On the other hand the minimum forming load occurs with complex former block (CFB) and reaches 43 KN when RPH= 50 A, as shown in figure 10.c. Lower forming loads in CFB explain the effect of deformation style on force required to achieve the forming.

Flat former block (FFB) represent average deformation state between HFB and CFB, where that reflected on maximum and minimum forming loads which were (44.8 and 81.7) KN when RPH of 50 and 70 A were used respectively as shown in figure 10.a.

The numerical simulation results demonstrate in figure 10.d, e and f. Where, these figures show good agreement with the experimental results. Although the maximum load in FEA results reach to 93.6 KN occurs using HFB and RPH= 70A.While the minimum forming load appears using CFB and RPH= 40A. Difference greater than 9% has observed between experimental and FEA results. This variation may cause by change of rubber and blank material properties through the progress of the process. The steps of numerical modelling were demonstrated in figure11.The completely drawn cups of experimental work were shown in figure 12.

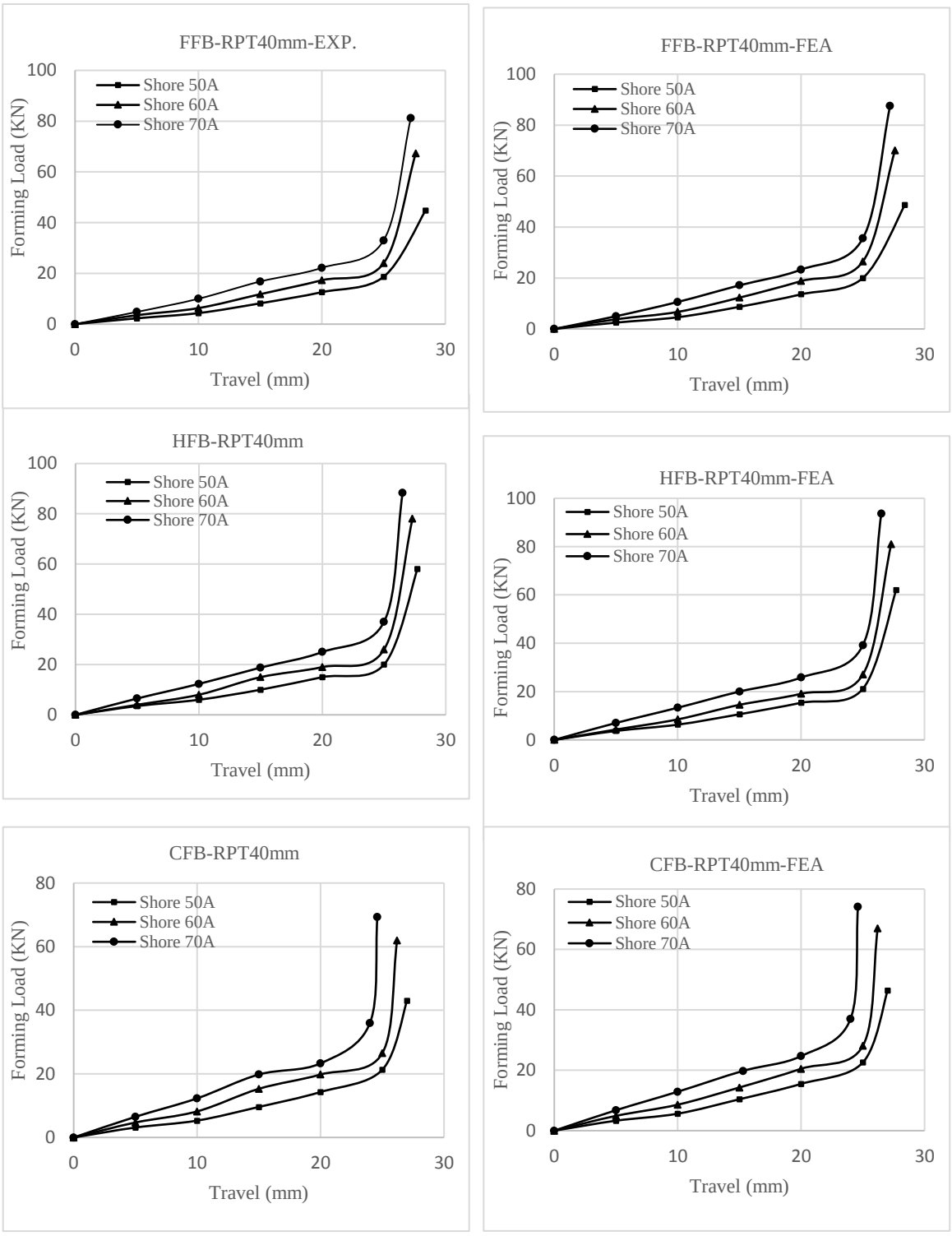


Figure 10. Effect of rubber pad hardness on forming load for flat, hemispherical and complex former block when using rubber pad with thickness 40mm (Experimental Results to the left, FEA results to the right).

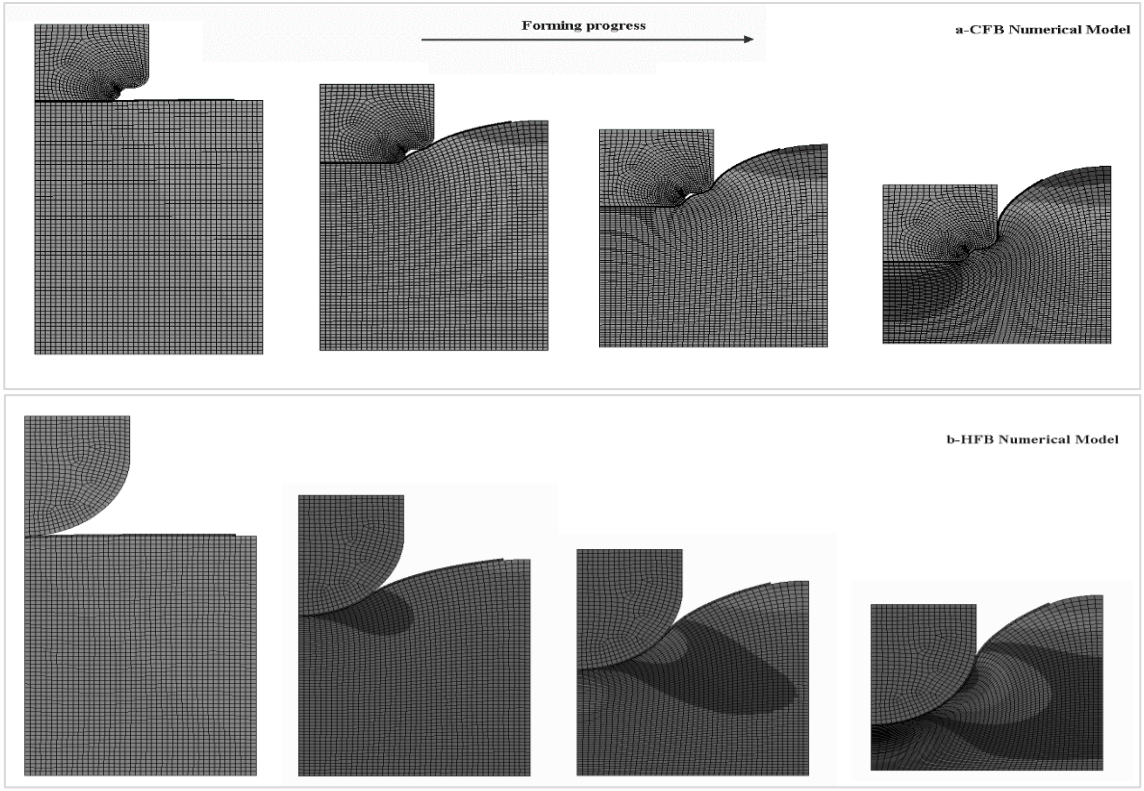


Figure 11. Sequences of rubber pad drawing FEM by ANSYS workbench with a-complex former and b- hemispherical former.



Figure 12. Samples of completely drawn cup of experimental work.

4.2. Results of rubber pad of thickness 80mm

The effect of rubber pad hardness when using (RPT= 80mm) is illustrated in figure 13. From the figures, it noted that longer forming travel achieved as compared with RPT= 40mm.Where the maximum forming travel which achieved in FFB and HFB which it equals to 51 mm when using RPH=50A, as shown in figure 13.a and b respectively. The improvement percentage in the forming travel reach 80% when rubber pad with thickness 80mm is used instead of that with 40mm.

Although of the increase in forming travel there is a considerable reduction percentage in forming the forming load reaches 12%, the decreasing in the forming load reflected in good product features. Improvement in forming travel and forming load vary from former block to other it depends on the deformation style as obvious in figure 12.

Difference up to 14% has observed between experimental and FEA results, resulting from an increase in cumulative error with longer forming travel as compared with RPT=40mm.

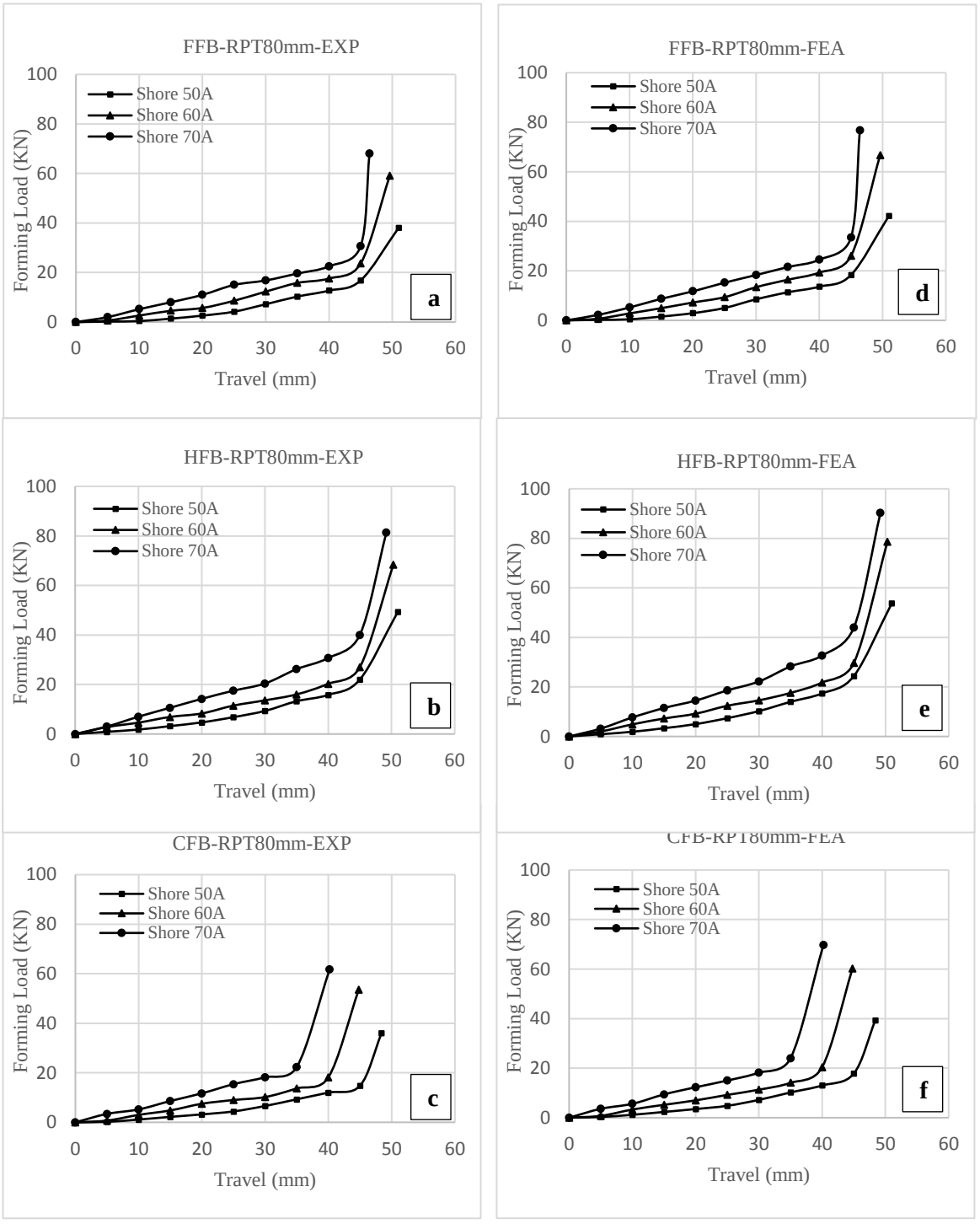


Figure 13. Effect of rubber pad hardness on forming load for flat, hemispherical and complex former block when using rubber pad with thickness 80mm (Experimental results to the left , FEA results to the right).

5. Conclusions

1. The study has shown that maximum forming load occurs in hemispherical former block (HFB) for both rubber pad thickness 40mm and 80mm, resulting from large bending radius on entire base of hemispherical deformation style. It has also shown that minimum forming load occurs

in complex former block (CFB) for both rubber pad thickness, as a result of shorter forming travel as compared with FFB and HFB.

2. It has found that generally the forming load increases with increasing the hardness of the rubber pad.
3. For all former block types, when the rubber pad thickness increases, the forming load decreases but the forming travel increases.

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