Numerical and Experimental Investigation of Thickness Variation in the Spinning Process of Al-1060 Alloy

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Abstract
Metal spinning as a kind of manufacturing process has capability to shape hollow components. In present work shear spinning process is used to formplates into conical shapes. Moreover, the aim of this research is to demonstrate the impact of the process parameters (i.e. feeding rate and spindle speed) on wall thickness. This approachwas done by experimental and finite elements method. The results illustrated that wall thickness decreases while feeding rate increases in spinning process. The experimental results confirm the Finite element analysis (FEA) results during thickness evaluations so this shows that FEA results are reliable for this specific case. The results of analysis reveals that the best condition for spinning is for feeding rate of 40 mm/min and spindle speed of 50 rpm in which highest thickness of 1mm is obtained. In consequence, the findings also illustrated that by decreasing the feeding rate and spindle speed, higher thickeners can be observed during shear spinning process.

Keywords
Spinning, Thickness variation, Rotational Speed, FEM, Al-1060

1. Introduction

Metal spinning is a type of sheet metal forming which allows to produce symmetric and asymmetric sheet metal hollow components.This is done byforming the blank over a rotating mandrel to create a round hollow shape. Sheet metal spinning can be categorized in two general groups: conventional spinning and shear forming spinning. In the first one, the roller during several steps form the plateover the mandrelwhile thickness remain unchanged. Conversely, in shear forming process tool or roller moves over mandrel in one pass while thickness is changing. The schematic of the conventional and the shear spinning processes illustrated in Figure 1.

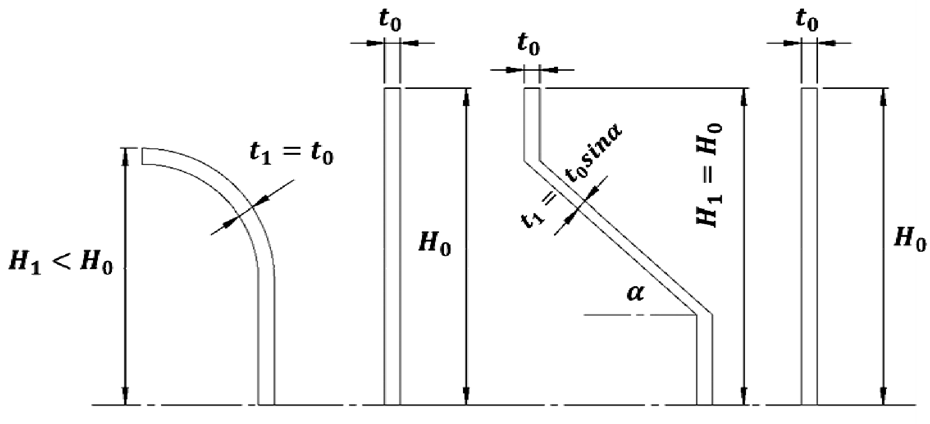

Figure1. a) conventional spinning b) shear spinning

In shear forming final wall thickness of the spun sheet, t_1, can be calculated by sine law:

$$t_1 = t_0 \sin\alpha \tag{1}$$

Where t_0 is the initial thickness of the blank, α is the incline angle of the conical mandrel. The process is capable of forming components of diameters ranging from 3 mm to 10 m, and thicknesses of 0.4–25 mm [1].

Many researches have been performed in conventional spinning [2-6] and modern one like incremental forming [7] while some of them are numerical and experimental studies. However in case of shear spinning, Kim et al. [8] proposed a lower upper-bound solution for shear spinning of cone shaped components. Hot shear spinning process has been developed by Mori et al. [9] in order to eliminate casting defects and obtain excellent thickness distribution. Series of experimentation have been carried out in order to investigate the effect of the roller nose radius, mandrel rotational speed and feeding rate on surface roughness by Chen et al. [10]. Mechanical characterization and microstructure of AlMg6Mn alloy during shear spinning process were investigated by Radović et al. [11].An experimental study was conducted by Kawai et al. [12] in order to determine possibility of the shear spinning processfor truncated hemispherical shells. Lexian and Dariani [13] demonstrated the impact of roller geometry on profile of the components using proposed finite element code in the hot rolling process.In a research, carried out by Zoghi et al. [14], deformation behavior of Tube spinning for dome forming was investigated with help of experiments and finite element analysis. Hashemi et al. [15] proposed a modified method based on Marciniak-Kuczynski technique for calculation of an extended strain-based forming limit curve. This method was provided based on material flow direction and equivalent plastic strains after deformation.

Aforementionedbrief literature and authors investigations reveal that there are limited works on shear spinning process from thickness aspect. In this study Shear forming process as virtually novel version of spinning is employed in order to investigate final thickness by finite element and experimentaltechniques. Moreover, following objectives are achieved in this research:

1. Thefinite element method is employed to predictions thickness or the desired results.
2. Evaluation of wall thickness for the several rotational speeds of the mandrel using experimental and FEA techniques,
3. Evaluation of wall thickness for several feeding rates using experimental and FEA techniques.

2. Experimental Procedure

In this study blanks of aluminum1060 alloy is prepared in 100mm diameter (As seen in Figure 2a). Initial thickness of blank plates is equal to 5 mm. A conical mandrel is machined from low carbon steel bar. Mandrel has minor diameter of 30mm, major diameter 150mm and height of 200mm. As it can be seen in figure as Figure 2c roller has outer diameter 42.5mm and thickness of 15mm. Mandrel is subjected to spindle and blank plates are fixed between tailstock quill and mandrel tip Figure 2d. Moreover, roller is set on the Apron of the lath machine. Therefore, once spindle starts to spin as constant speed mandrel and blank rotate as it rotates.

Experiments are done for different feeding rates and rotational speeds. Velocities of 40, 50 and 60mm/sec are chosen for feeding rates of roller and 50, 100, 150 rpm for spindle speed. Furthermore, before doing shear forming blank is pre deformed by conventional spinning as shown in Figure 2d.

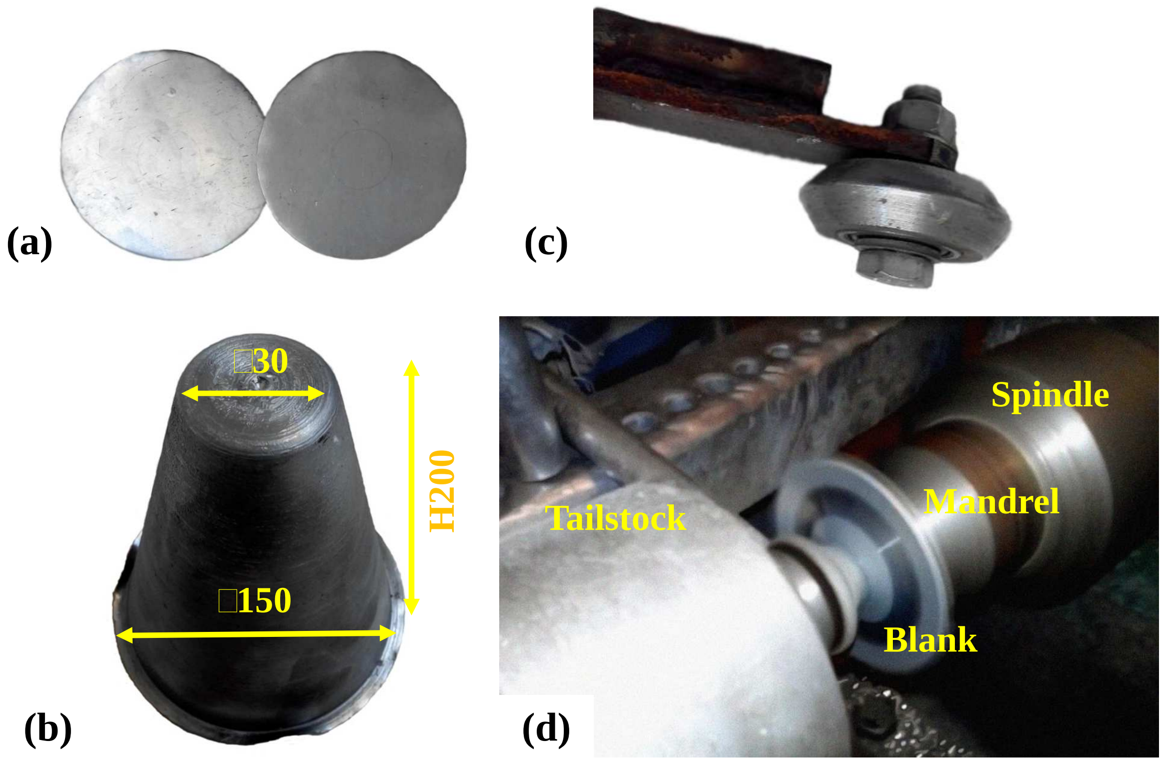

Figure2. a) aluminium blanks b) mandrel and its dimentions c) roller tool d) experimental ssetup

3. Finite Element Analysis

3D finite element analysis was carried out by ABAQUSE 6.14-2 to predict final thickness of components. The model consists of three components: mandrel, blank and roller such thatmandrel consists of 1098 linear quadrilateral elements of type R3D4, blank contains 7175 linear hexahedral elements of type C3D8R and roller tool comprises of 790 linear quadrilateral elements of type R3D4. Furthermore, general friction is assumed with friction coefficient 0.3 to simulation become more realistic.

The blank is tied to the tip of mandrel so that it is rotated by rotation of conical mandrel. A coordinate system is defined along adjacent edge of the cone as shown in Figure 3. Roller is constrained along y and z axis with zero displacement however roller can move along x axis with velocities of 30, 40 and 50mm/sec. moreover, mandrel can rotate along x axis with constant rotational speed of 50, 100 and 150rpm. The behavior of the stress-strain of Al-1060 alloy is modeled by the Figure 4. Figure 5 demonstrates stress distribution, during shear spinning process, which is uniform for case of spindle speed of 50rpm and feeding rate of 30mm/min.thickness can be extracted from it by reading distance from nod to node along it.

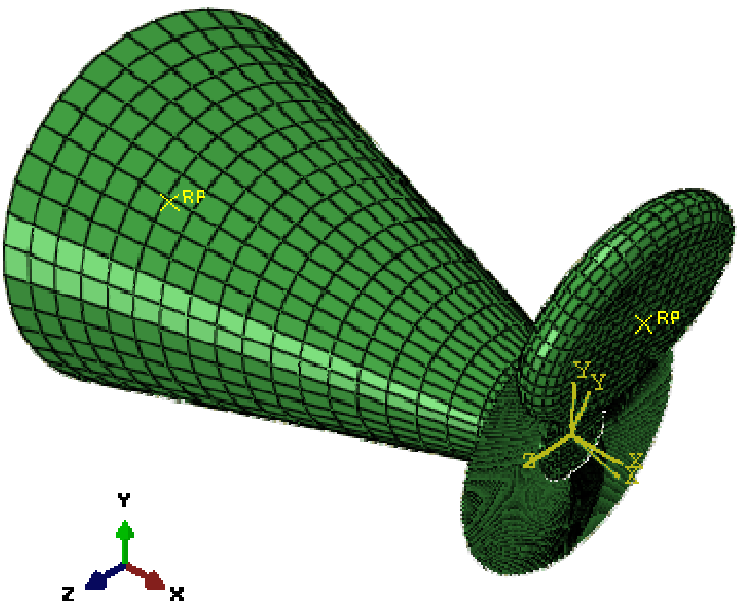

Figure3. 3D model of FEA model

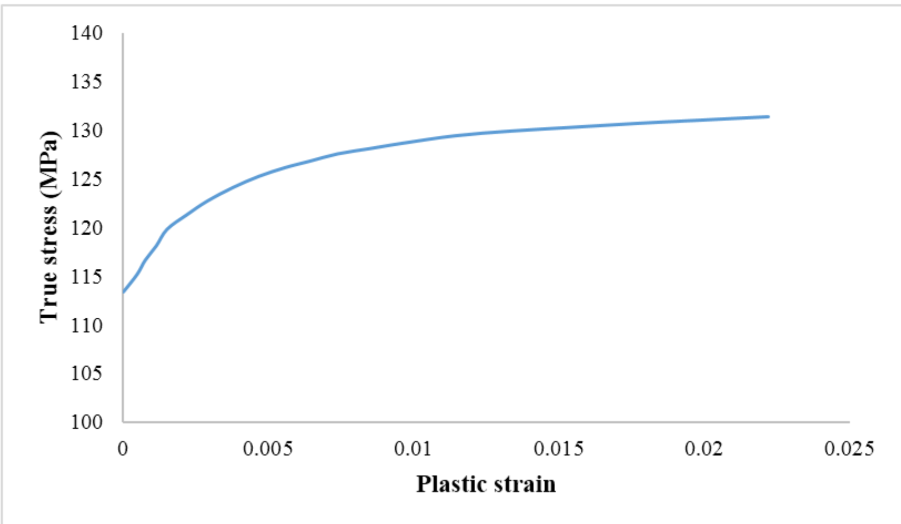

Figure4. The true stress-plastic strain curves of Al-1060 [16]

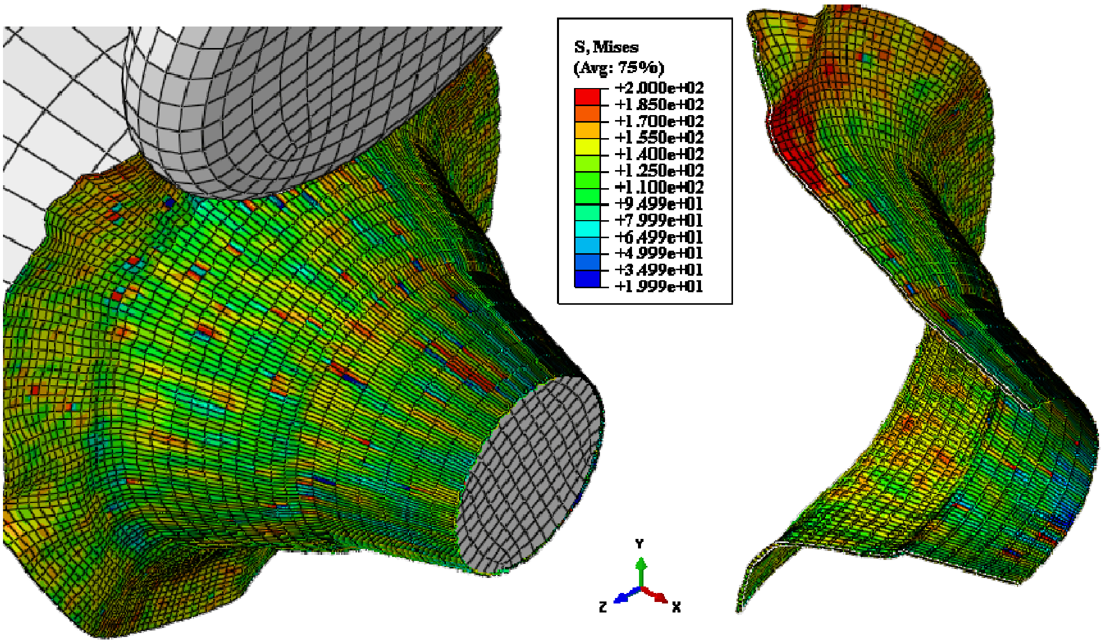

Figure5. Deformed blank during shear spinning

4. Results and discussion

Thickness of deformed component is extracted from finite element analysis and experiments. Figure 6 illustrates final thickness regarding to rotational speed as it can be seen in both FEA and experiment graph when rotational speed increases, thickness decreases which is not desired. On other hand, at low speeds higher thickness can be produced. Moreover, it is inferred that FEA results are matched with experiments by small deviation so FEA results in this type of cases are reliable. Figure 7 shows samples which are produced in experiment attempts in order to measure final wall thickness. In this Figure spindle speed for sample numbers 1, 2 and 3 are 50, 100 and 150RPM respectively.

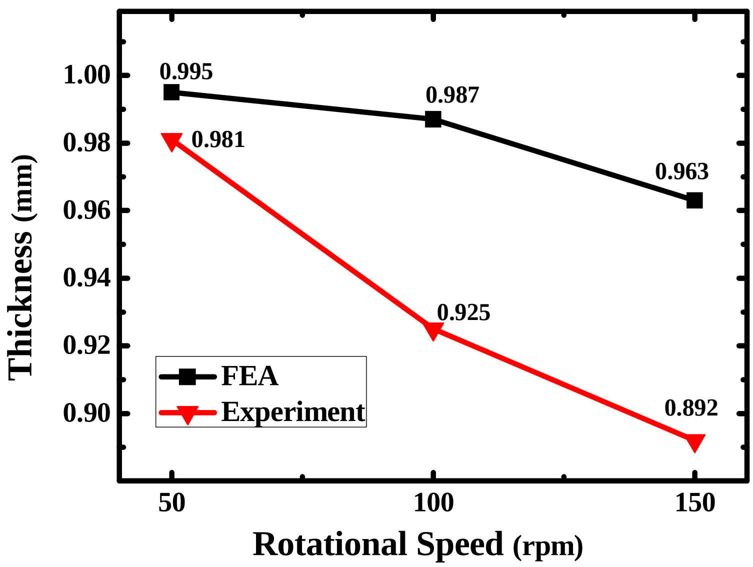

Figure6. Experimentaly and numerically comparison of the wall thickness versus spindle speed

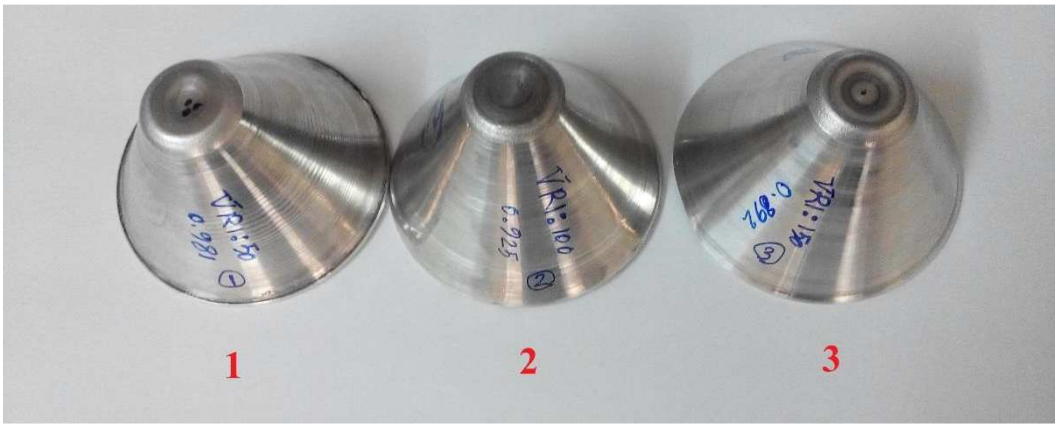

Figure7.Deformed samples produced under various spindle speeds

Illustration of thickness variation regarding to feeding rate of roller has been depicted in Figure 8. As it can be seen, two graphs represent the results obtained from FEA and Experimentation. Regarding to experiment graph, it is concluded that increasing velocity or feeding rate decreases thickness whereas FEA graph implies there is no significant changes in thickness according to velocity changes. Figure 9 shows samples which are produced with various feeding ratesof the roller. In this figure, spindle speed for sample numbers 1, 2 and 3 are 40, 50 and 100 mm/min respectively.

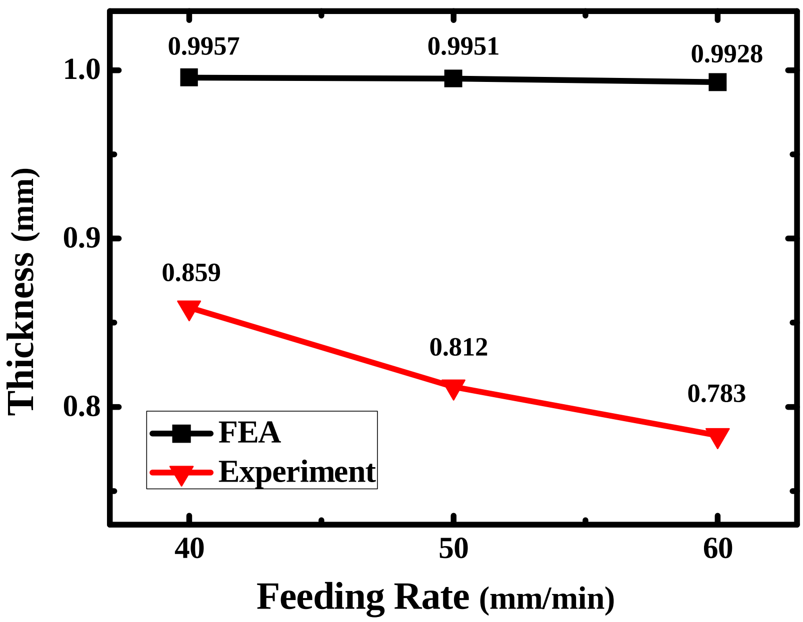

Figure8. Experimentaly and numerically comparison of the wall thickness versus feeding rate

Figure9.Deformed samples produced under various feeding rates

5. Conclusion

Metal spinning process can be categorized in two groups of conventional spinning and shear forming spinning where each of them has particular specification. In conventional one, thickness is not changing,although in shear forming wall, thickness of components is changing during the process. Moreover in conventional spinning the process, is done by multi pass movement of tool along mandrel whereas in shear spinning process, forming is accomplished by one pass movement of tool along mandrel. In this research, experimental and finite element study of shear spinning process were carried out in order to evaluate final thickness for different rotational speed and feeding rate. Moreover in this study, conical mandrel was employed to form blanks into conical hollow shape. Based on results, following conclusion may be drawn:

1. The findings indicated that increasing rotational speed decreases wall thickness of the component.
2. The results illustrated that wall thickness decreases while feeding rate increases in spinning process.
3. The experimentally findings confirmed the validity of obtained FEA results. This claims the reliability of finite element results in shear spinning process.
4. The best condition for spinning is for feeding rate of 40 mm/min and spindle speed of 50 rpm in which results highest possible thickness of 1mm.

6. References

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