Comparison of Tube Formability in Electromagnetic Forming and High Speed Hydroforming

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Abstract: Tube forming is a common forming process in industry. There are several methods in tube forming, whereas industries are looking for best methods with low cost and high speed. For this reason, industries need new modern forming methods. Electromagnetic forming and tube hydroforming are two modern processes which are used in manufacturing of hollow complex parts. These two processes are considered as high speed forming methods in automotive industries. In this paper, the processes of electromagnetic forming of tubes and high speed hydroforming of tubes have been investigated by numerical simulations and empirical method. Firstly, the results of numerical solutions by ABAQUS software are compared with empirical tests. At last these two forming methods have been compared in terms of displacement, stress distribution and thickness distribution. The results of deformation and thickness of the tip of the bulged tubes in empirical tests are in good agreement with the results of numerical simulations of this research. The results show that formability and bulge height in electromagnetic forming process are higher than high speed hydroforming. However, high speed hydroforming may be used in applications such as shirring fitting of parts and rings on tubes instead of electromagnetic forming.

Keywords: Electromagnetic Forming, High Speed Hydroforming, Finite Element Analysis

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1 INTRODUCTION

One of the most widely used processes in industry is tube forming. There are many ways to form a tube. The industry is always looking for the best way with the lowest cost and highest speed. That is why the industry approach is towards new ways of forming. Two new methods for this purpose are electromagnetic forming and high speed hydroforming. These methods are considered as fast forming methods that have many applications in forming low density materials where their forming is difficult such as aluminum. Al-Hassani studied the behavior of aluminum thin-walled tubes and rings under pressure with electromagnetic shock devices [1].

Urakoshi et al. studied forming into the aluminum tubes experimentally and numerically [2]. Thomas et al. obtained Forming Limit Diagram (FLD) of a deformed aluminum by EMF. They have investigated the improvement of formability in this method compared to the conventional methods [3]. Correa et al. obtained electromagnetic forces by numerical solution for flat plate geometries [4]. Ebrahimi et al. expressed applications, advantages and disadvantages of EMF [5]. They also, simulated bulging of aluminum tubes in EMF process by ANSYS software. Shahrokh studied the inward electromagnetic bulging of tubes in a symmetrical die by the finite element method [6]. In this study, a decoupled analysis was used in simulation of electromagnetic and deformation process. Fach used Hydrostatic pressure in tube forming processes [7].

Loh-Mousavi et al. simulated T-shaped tube hydroforming process using three-dimensional finite element method [8]. Belhaj et al. examined the wall thickness distribution in T-shaped tube hydroforming using neural network approach [9]. As mentioned, much work has been done on hydroforming and electromagnetic forming. Nevertheless, there is not any article or report to compare the important parameters of forming (e.g., thickness distribution, displacement, etc.) in hydroforming and EMF. These two tube forming processes have many advantages and drawbacks, thus comparing these two forming methods, may help to choose the best forming method for a specific application.

In this study, electromagnetic tube forming process is compared with a high speed tube hydroforming process by numerical and experimental methods. The tube is hydroformed by water jet to increase the speed of process which make similar conditions for EMF and hydroforming of tubes. Both forming processes are used to form tubes in a simple die after free expansion process. In this research, firstly, applications, advantages and disadvantages of two methods are discussed. Then, the results of numerical solution of electromagnetic forming process by ABAQUS software were compared with experimental tests of this research and Ref. [10]. Finally, these two forming methods have been compared in terms of displacement, stress distribution and thickness distribution.

1.1. Electromagnetic Forming

The main applications of this technique include tube compression, tube expansion, contour forming and magnetic pulse welding [11]. According to the small size of electromagnetic forming, one of its applications are posing and fitting of components on tubes in assembling and montage of parts. This method has many advantages in comparison with conventional forming methods [11].

1. The high speed forming leads to improvement of formability especially for lightweight metals that are difficult to form.

2. Low friction due to less contact between the die surfaces and the work piece.

3. Reduction of wrinkles in tube forming due to less compression stresses.

4. Reduction of spring back.

5. High quality.

6. A relatively clean environment and free of oil and grease.

The main limitation of electromagnetic forming process is that forming part must be a good conductor of electricity. Other limitation of this approach is that they have not been able to produce complex and three-dimensional parts.

1.2 High speed Hydroforming

Hydroforming advantages compared to conventional methods of forming are as follows [6]:

- Reduced parts weight
- Improvement of strength and stiffness
- Reduction of spring back
- Improvement of dimensional tolerances
- Decreasing welding process
- Reduced steps and time of production
- No need to multiple dies

In hydroforming, the increase in pressure resulted in the bursting of the workpiece, and the pressure reduction brings about wrinkle. There is a possibility of buckling in long tubes with relatively high thickness. Another problem in this method is sealing the piece during hydroforming.

2 FINITE ELEMENT SIMULATION

Simulation of electromagnetic forming and high speed hydroforming processes were performed using finite element method. The numerical simulation of electromagnetic forming process consists of two stages. The first stage is calculation of body forces caused by electromagnetic and the second stage is tube forming caused by body forces. Due to small deformation of the tube in this process, these two stages were not analyzed as a coupled simulation.

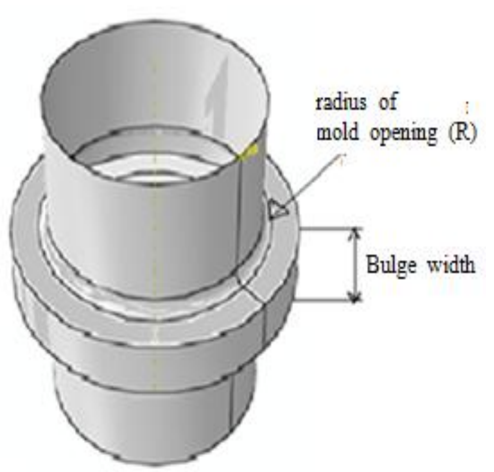

Fig. 1 Geometric model of mold in Abaqus software

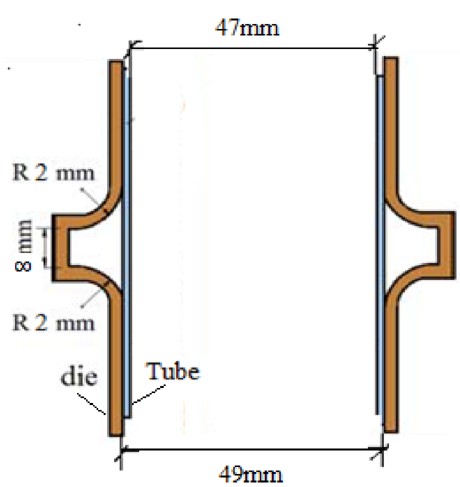

Fig. 2 Schematic of tube and mold with dimensions

For both processes, the mold is considered as a three-dimensional rigid analytic body. Mold openings (bulge width) and radius of mold opening (R) are specified with the dimensions of mold in Fig. 1. Also, according to the tube diameter to thickness ratio that is 47, model geometry is intended as a shell and only a quarter tubes is modeled due to its symmetry. S4R elements are used to mesh the tube, where the used work piece was made of aluminum 7075 which is the most common aluminum alloys used in aerospace industry. The aluminum alloy was heat treatable and had high corrosion resistance with good formability. Mechanical properties of the work piece have been defined in Table 1 and Fig. 3.

Table 1 Physical and mechanical properties of work piece

Material	AL7075-T0
Density	2790 kg/ m^3
Young's modulus	70GPa
Poisson's ratio	0.33
Elongation percent	11%

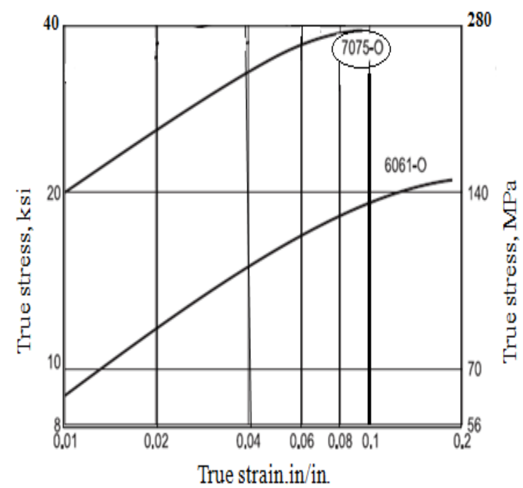

Fig. 3 Stress-strain diagram of aluminum 7075 [12]

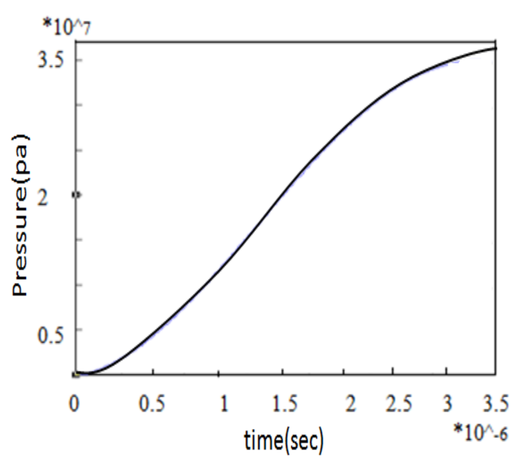

Fig. 4 Pressure graph obtained from solving electromagnetic part

For the simulation of contact, the penalty method was used with friction coefficient of 0.15. The analyses performed in this study were done in one step and explicit dynamic method was used due to fast forming. In this study, deformation was caused through applying pressure on inner surfaces of the tube. As it was explained, for the simulation of electromagnetic forming stage, electromagnetic body forces were calculated by electromagnetic analysis and then, obtained body forces, were imported in deformation analysis of the tube by Abaqus software. Here, electromagnetic pressure was calculated using the computer program provided in reference [6] with boundary conditions of the current study. Tabular pressure and one millisecond time were used for high speed hydroforming modeling. Here, the maximum pressure of high speed hydroforming process is 25 MPa and process time is one millisecond. In electromagnetic forming process, the most common applied pressure is 35.6 MPa and the process time is 35 microseconds which corresponds exactly to the graph obtained from solving MATLAB software (Fig. 4).

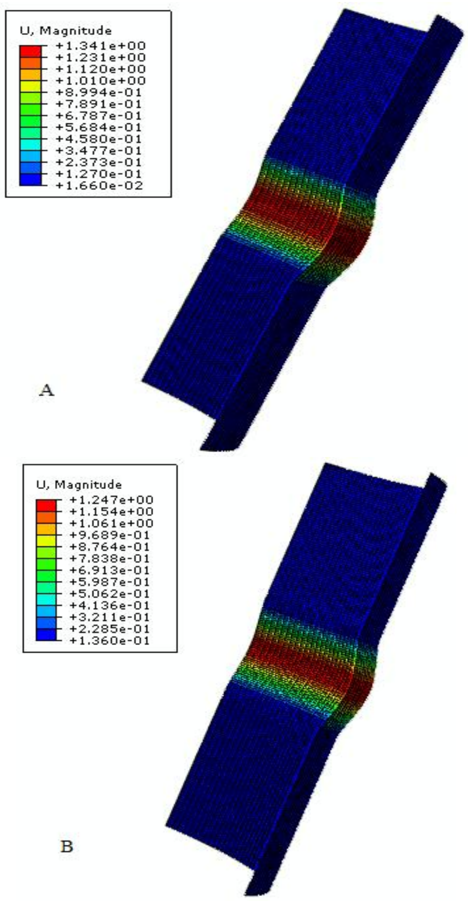

Fig. 5 Distribution of tube displacement (a) EMF process (b) high speed hydroforming process

3 RESULTS AND DISCUSSION

3.1. Displacement

Fig. 5 shows the displacement distribution at the end of two investigated forming processes. According to this figure, the maximum displacement of EMF process is 1.341 mm and the maximum displacement of high speed hydroforming is 1.247 mm which occurs in the tube.

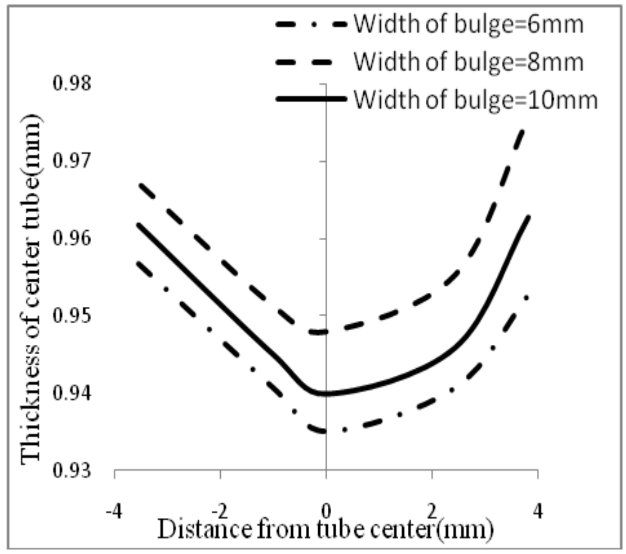

Fig. 6 The thickness of center tube from distance of center tube for different bulges' width of EMF process

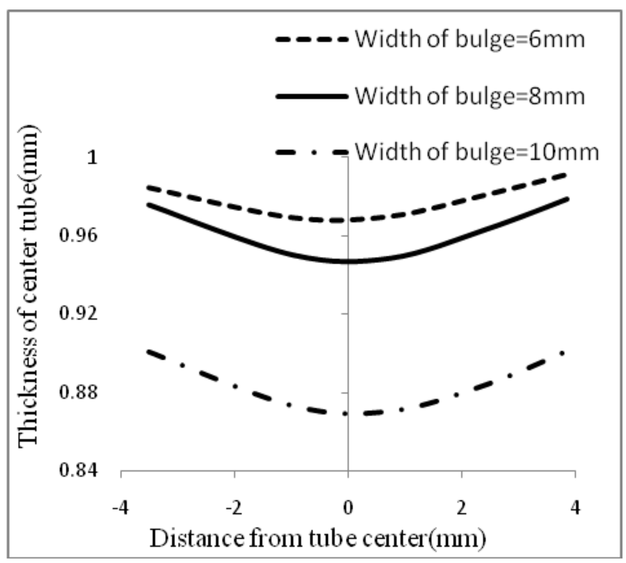

Fig. 7 The thickness of center tube from distance of center tube for different bulges' width of high speed hydroforming

3.2. Studying the effects of bulge width on thickness

In this section, the effects of bulge width on tube thickness is studied. According to Fig. 6 and Fig. 7, for both EMF and fast hydroforming processes, increasing bulge width leads to reduction of tube thickness.

3.3. Studying the effects of bulge width on bulge height

According to Fig. 8 and Fig. 9 for both processes, increased bulge width will result in increased bulge tip height. The reason for this may be expressed from the fact that if the tube is assumed to be a restrained beam, increasing the distance of bearing result in increased beam deflection (bulge height).

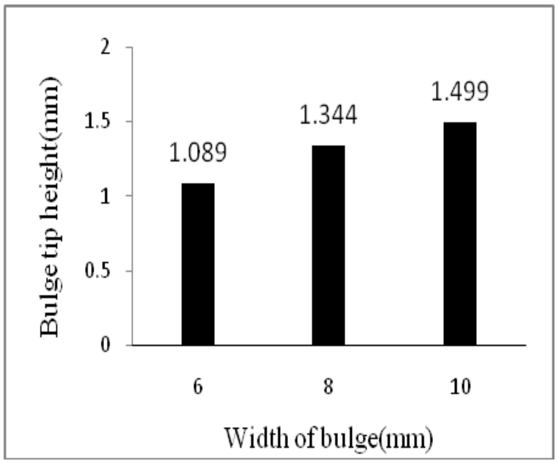

Fig. 8 Bulge tip height for width of various bulges in EMF

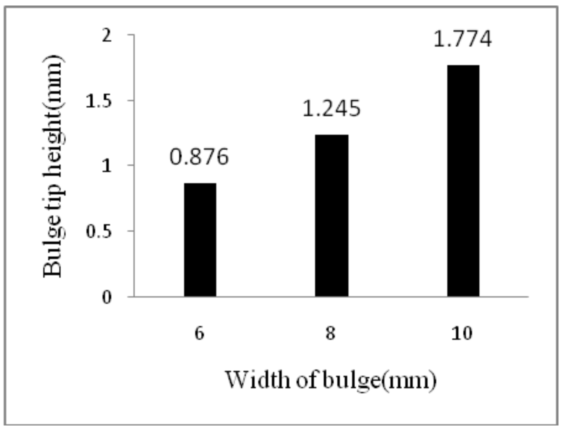

Fig. 9 Bulge tip height for width of various bulges in high speed hydroforming process

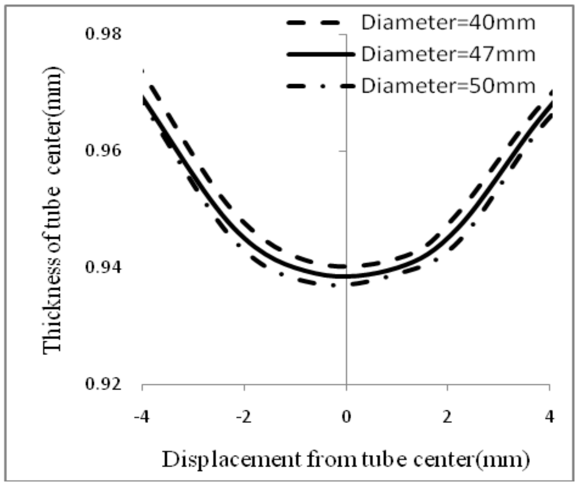

Fig. 10 The thickness of central tube for tube different diameters in EMF

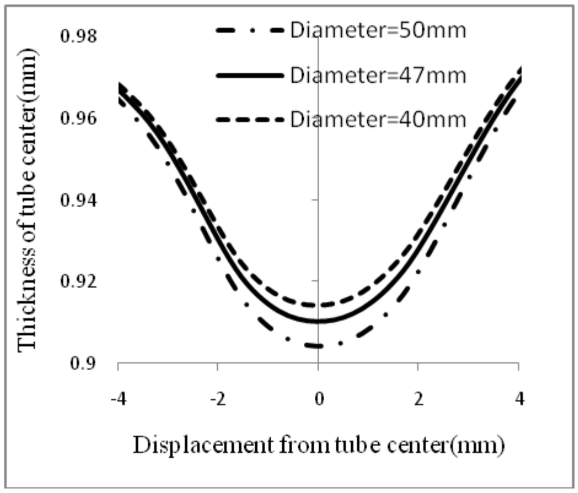

Fig. 11 The thickness of central tube for tube different diameters in high speed hydroforming

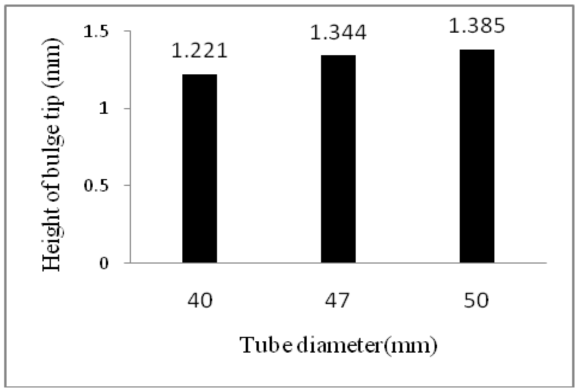

Fig. 12 Height of bulge tip against tube diameter in EMF process

3.4. Studying the effects of tube diameter on thickness

According to Fig. 10 and Fig. 11, for both high speed hydroforming and EMF processes, increasing tube diameter will result in reduced tube thickness.

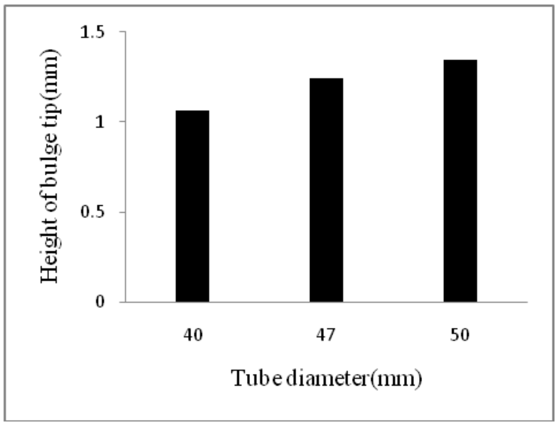

Fig. 13 Height of bulge tip against tube diameter in high speed hydroforming process

Fig. 14 The final formed work piece

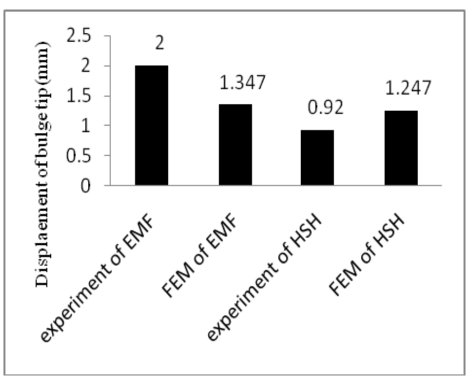

Fig. 15 Displacement of bulge tip in experimental tests and finite element models

3.5. Studying the effects of tube diameter on bulge height

As can be seen in Fig. 12 and Fig. 13, for both high speed hydroforming and EMF processes, increasing tube diameter increase the bulge height.

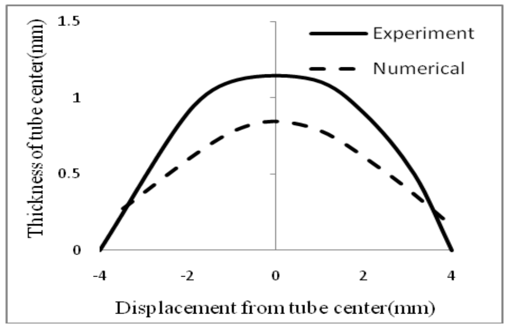

Fig. 16 Displacement of central tube in high speed hydroforming process

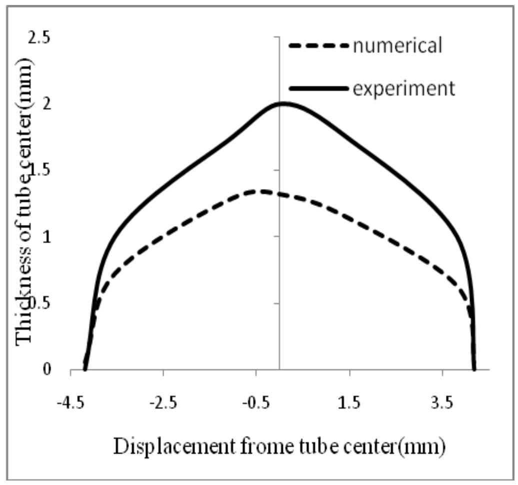

Fig. 17 Displacement of central tube in EMF process

4 VALIDATION OF NUMERICAL RESULTS WITH EXPERIMENTAL TEST

In this study, high speed hydroforming (HSH) with water jet equipment which has easier settings compared to conventional hydroforming, was carried out in order to verify the simulation results. Validation of electromagnetic forming results was performed according to reference [8].

Results of bulge tip displacement obtained by experiment and finite element method, using Abaqus software are given in Fig. 15.

Fig. 16 and Fig. 17 compare the displacement of central tube in experimental tests and finite element solution. According to these figures, there is a good agreement between finite element results and experimental tests.

5 CONCLUSION

Simulation of two high speed hydroforming (HSH) and EMF processes was performed by applying Abaqus software and the results were compared with the experimental results. The following results may be concluded based on this study.

The central bulge of tube in high speed hydroforming is smaller than values obtained from EMF method. It was found that, due to higher speed of EMF, the more stress is applied to different areas of bulge and bigger bulge is formed without thinning and bursting. It was found that, for both high speed_hydroforming and EMF processes, increasing tube diameter will result in reduced thickness. In addition, accordingly increasing bulge width leads to reduction in tube thickness.

REFERENCES

[1] Al-Hassani, S. T. S., "The Plastic Bukling of Thin Walled Tubes Subject to Magneto motive Forces", J. Mechanical Engineering Science, Vol. 16, No. 2, pp. 59-70, 1974.

[2] Urakoshi Y., Takahashi M., Toshio, Hanada K., and Negishi H., "Inside bead forming of aluminum tube by electro-magnetic forming", Journal of Materials Processing Technology, Vol. 80–81, pp. 695–699, 1998.

[3] Thomas, J. D., Seth, M., Daehn, G. S., Bradley, J. R., and Triantafyllidis, N., "Forming limits for electromagnetically expanded aluminum alloy tubes: Theory and experiment", Acta Materialia, Vol. 55, 2007, pp. 2863-2873.

[4] Correia, J. P. M., Siddiqui, M. A., Ahzi, S., Belouettar, S., and Davies, R., "A simple model to simulate electromagnetic sheet free bulging process", International Journal of Mechanical sciences, 2008, pp. 1466-1475.

[5] Ebrahimi, H., Fallahi, A. R., Farzin, M., Attaran, M., and Tavangar, M., "Investigation of Electrical and Mechanical parameters on Forming Process", 6th International Conference on Electromagnetic Processing of Materials, Germany, 2009, pp. 719-722,

[6] Shahrokh, R., Farzin, M., Ebrahimi, H., Fallahi Arezoodar, A., and Fadaii Tehrani, A., "Numerical Solution of the Governing Equations for Electromagnetic Inward Tube Forming", 20th Annual International Conference on Mechanical Engineering-ISME2012.

[7] Fuch, F. J., "Hydrostatic pressure-in role in metal forming Mech", Eng. April 1996, pp. 34-40.

[8] Loh-Mousavi. M, Mori. K, Hayashi. K, Maki. K. S, and Bakhshi. M, "3Dfinite element simulation of pulsating T-shape hydroforming of tube", Key Engineering Materials. Vol. 340, 2007, pp. 353-358.

[9] Belhaj, T., Abbasi, F., Mistou, S., and Zghal, A., "Numerical Analyses Tube Hydroforming Problem Using Artificial Neural Network", Int J Mater Form, Vol. 3, 2010, pp. 295-298.

[10] Ebrahimi, H., Fallahi, A. R., Farzin, M., Attaran, M., Tavangar, M. and Toroqi, S., "Electromagnetic forming method", Proceedings of Eighth Annual Conference (International) Iranian Aerospace SocietyIAS2009, Isfahan, Shahin Shahr, Malek Ashtar University, 2008, pp. 213-214.

[11] Psyk, V., Risch, D., Kinsey, B. L., Tekkaya, A. E. and Kleiner, M., "Electromagnetic forming-A review", Journal of Materials Processing Technology 211, 2011, pp. 787-825.

[12] Moosbrugger, C., "Atlas of stress-strain curves", 2nd ed., ASM international, Ohio, 2002, pp. 299.