JCAMECH

Vol. 47, No. 2, December 2016, pp 129-136
DOI: 10.22059/jcamech.2017.119753.63

Numerical study and genetic algorithm optimization of hot extrusion process to produce rectangular waveguides

M. Sharififar *, S. A. A. Akbari Mousavi

School of Metallurgy and Material Engineering, College of Engineering, University of Tehran, Tehran, Iran

Received: 9 Dec. 2015 , Accepted: 18 Oct. 2016

Abstract

Rectangular waveguide is one of the earliest types of transmission lines. Rectangular waveguide can be produced by hot extrusion process. In this paper, the hot extrusion process of CuZn5 rectangular waveguide was investigated by Finite Element Method (FEM). In addition, Genetic Algorithm (GA) was used to optimize the die geometry and process conditions to achieve the lowest magnitude of extrusion force. Die geometry was introduced in terms of die length and billet hole diameter under various frictional conditions. It was found that die length and billet hole diameter had contradictory effects on the extrusion force. The experimental study was also carried out to verify the accuracy of estimated results.

Keywords: *Extrusion, Finite element method, Genetic algorithm, Optimization, Rectangular waveguide*

1. Introduction

Rectangular waveguide is one of the earliest types of the transmission lines that is used for microwave frequencies between 1 to above 220 GHz. Typically waveguide is made of brass, copper, silver, aluminum, or any metal that has low bulk resistivity. ASTM B372 [1] gives comprehensive information about the metallurgical characteristics of rectangular waveguides. Besides some advantages of waveguide such as transmission of high peak powers and its very low loss in microwave frequencies, the high cost is its disadvantage. Rectangular waveguide has low mass production, and waveguide materials such as copper and silver are relatively expensive. Rectangular waveguide can be produced by hot extrusion process. Simulation of the manufacturing process and optimizing their effective factors to achieve the minimum forming force is the logical method to reduce manufacturing costs.

Many researchers studied the influential factors affecting the hot extrusion process for various alloys. Chanda et al. [2] studied the effect of reduction of area on the stress and strain distributions for AA1100 extrusion process using FEM. They showed that the product temperature for 20:1 reduction ratio with circular die was more than that with square die whereas for 60:1 reduction ratio the product temperature for square die was more than that for circular die. The reason was attributed to severe shear deformation produced in the square die and high velocity of product in 60:1 ratio. In another study [3], Lee et al. reported that the highest temperature zone lies near the die exit through hot extrusion process of Al alloys. The region near the die corner was found to be the dead metal zone and the highest mean stress zone was close to the corner of the container in the longitudinal cross-section of the minor axis of symmetry. Kumar et al. [4] showed that temperature rise was more for higher reductions in FE simulation of Al6061 extrusion process. It was also found that variations in temperatures of billet were less at higher billet initial temperature whereas variations

* Corresponding Author. Tel.: +9831-32601074, Fax: +98-31-32601074
Email Address: m.sharififar@ut.ac.ir

in temperatures of billet were more at lower billet initial temperature. Malpani and Kumar in their study [5] about hollow shape extrusion of Al2024 showed that with increase of reduction of area, the optimum die length initially decreased to a minimum value and again increased for a given friction factor. They also found that the die angle decreased with increase of friction factor at a given reduction. The decrease in die length with friction factor increment was due to diminishing frictional power at lower die length that minimized the total power consumption.

In [6], the FE simulation of AZ31 extrusion process showed a 100°C increase of billet temperature from 350℃ to 450℃ and led to a 46% decrease in the extrusion pressure from 700MPa to 375MPa. Mao et al. [7] also studied the hot extrusion process of Inconel 690 super alloy for Φ63.5×5.5mm tubes. It was shown that for the die angle of about 30°, the extrusion force approached a minimum. The reason is that by decrease of die angle, the contact area of billet and cone die and so friction force increased. Moreover, the heat transfer of billet and cone die accelerated, and as a result, the billet temperature reduced and deformation resistance increased. The extrusion force approached minimum when the three above mentioned factors reached a balance.

In recent years genetic algorithms have been successfully applied to die design problems [8,9]. The basic difference of GAs with most of the traditional optimization methods are that the GA uses a coding of variables instead of variables directly, a population of points instead of a single point, and stochastic operators instead of deterministic operators. The advantage of using GA over other gradient-based methods is that the latter can be mapped on local minima whereas GA predicts global minima, which may be hidden between several local minima [10]. In 2002, Wu et al. [11] used GA to obtain the optimal shape of an extrusion die. In their study, the profile curve of the extrusion die was optimized to obtain the lowest amount of extrusion force. Moreover, in 2005, Yan et al. [12] used FE and GA to optimize extrusion die factors to balance the metal flow velocity in the aluminum L-shape extrusion process. In 2009, Pathak et al. [10] optimized die conditions and ram velocity by using FEM and GA to obtain the maximum production speed and minimum left out material in the die cavity.

In this paper, design and simulation of hot extrusion process to produce the CuZn5 rectangular waveguide was carried out using FEM. In addition, GA was used to optimize the die and process conditions to achieve the lowest amount of extrusion force.

2. Experiment

The material used in this study was alpha brass alloy known according to UNS standard C21000 [13]. Die design and simulation of extrusion process to produce rectangular waveguide according to standard ASTM B372 [1] was carried out with ABAQUS 6.9.3. The outer dimensions of the waveguide were 76×38mm with 2mm thickness that was used for microwave frequencies between 2.6 to 3.95 GHz. To provide necessary mechanical properties of the alloy, tensile tests were carried out at the temperatures 250, 350 and 450℃ and strain rate of 0.01 1/s (Table 1).

250℃			350℃			450℃		
Young Modulus (MPa)	Plastic strain	Flow stress (MPa)	Young Modulus (MPa)	Plastic strain	Flow stress (MPa)	Young Modulus (MPa)	Plastic strain	Flow stress (MPa)
	0.0000	138		0.0000	121		0.0000	99
	0.0656	158		0.0652	139		0.0668	117
	0.1272	176		0.1316	155		0. 1280	134
570	0.1888	189	489	0.1964	166	465	0.1936	148
	0.2560	198		0.2580	173		0.2548	156
	0.3220	204		0.3196	178		0.3216	162
	0.3832	207		0.3812	180		0.3872	165

2.1. *Design*

The die contained 3 components: a) Die-container: Dimension size of die exit was 76×38mm and die length was considered as variable (Fig. 1a). b) Mandrel-press: Dimension size of mandrel was 72×34mm and the length of conic section was 150mm (Fig. 1b). c) Cylindrical billet: The billet was considered as a 100mm diameter cylinder with a variable diameter hole in the center to reduce the extrusion force. Because of symmetry in cross section of the billet and product and to save time, the billet was considered as 1/4 in section for ABAQUS simulation (Fig. 1c).

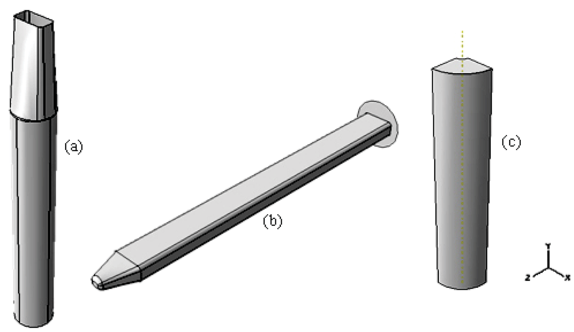

Fig. 1. a) Die-container; b) Mandrel-press; c) Solid billet.

Type and size of elements have main effects on the results. In this study, elements of die-container and mandrel-press were considered as E3D4 (4-node 3-D bilinear rigid quadrilateral) and elements of billet were C3D8T (8-node thermally coupled brick, trilinear displacement and temperature). The die-container and mandrel-press were considered as rigid bodies and the billet was considered as deformable and homogenous solid body. In this study, the coupled temperature and displacement analysis through explicit solver was used and the contacts between die components were considered as surface to surface contacting conditions. The die-container was fixed and displacement was applied to the press. Extrusion force was the force that billet imposed to the press. In addition, the mass scaling of 10000 was used to save time in the simulation process. Among many significant factors affecting die design and process, die length, diameter of billet hole, friction coefficient and billet initial temperature were considered to analyze the extrusion force. Because of negligible strain rate sensitivity of the alloy [14], study of strain rate was ignored. In addition, the initial die temperature was 100°C similar to experiments. The analyzed factors and their levels were:

Die length (l): 20, 25, 30, 35 and 40 cm.
Diameter of billet hole (d): 1, 1.5, 2, 2.5 and 3 cm.
Friction coefficient (μ): 0.025, 0.05, 0.075 and 0.1.
Billet initial temperature: 250, 300, 350, 400 and 450 °C.

2.2. *Genetic algorithm*

The FE data obtained from ABAQUS software were used as input data for the execution of GA model. A mathematic equation was obtained using GA with MATLAB R2014a software. Then, the effects of factors were analyzed and the optimum conditions of die design were found in order to obtain minimum extrusion force.

3. Results and discussions

In the preliminary simulation results, it was found that use of billets without hole led to element distortion due to high reduction of area (about 1800%), (Fig. 2). Therefore, a cylindrical hole was designed in the center of billet. Any change in the diameter of the cylindrical hole (d) led to changes in the extrusion force.

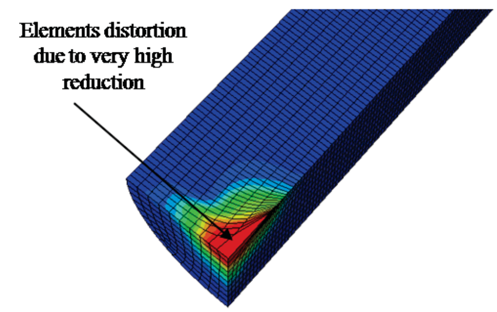

Fig. 2. Element distortions for the billet without hole.

3.1. *Velocity distribution*

Fig. 3 shows the axial velocity distribution along the extrusion direction for the die with l=20cm, d=1cm, μ=0.05 and T=450°C when the billet is attached to the die exit. It is known that non-uniform distribution of velocity in the billet section indicates dead zone forming [3]. Fig. 3 shows uniform axial velocity distribution. The figure shows no dead metal zone. Similar results were obtained at other conditions.

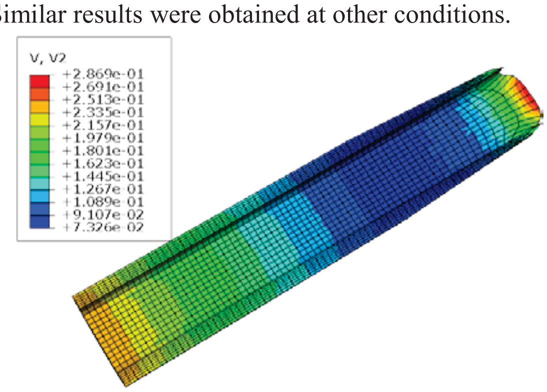

Fig. 3. Axial velocity distribution at *l*=20cm, *d*=1cm, *μ*=0.05, and Temperature=450°C.

3.2. *Temperature effect*

Fig. 4 shows the temperature-force curve at l=30 and d=2cm under different frictional conditions. As expected, the minimum extrusion force occurred at the maximum billet initial temperature. Increase of temperature from 250°C to 450°C decreases extrusion force around 20% at different frictional conditions. Such a trend obtained in this study was also verified in other study [6]. The reason for reduction of extrusion force with temperature is attributed to the reduction of flow stress with increase of temperature at any hot deformation process.

Fig. 5 show the effective stress distribution at 250 and 450°C at given conditions for the case that the top of billet passed ¾ of die length. It can be seen that at any given element, the effective stress at 250°C is more than that at 450°C. At 250°C, the maximum and minimum effective stresses are 206.6MPa and 81.39MPa and at 450 °C are 165.1MPa and 60.14MPa, respectively.

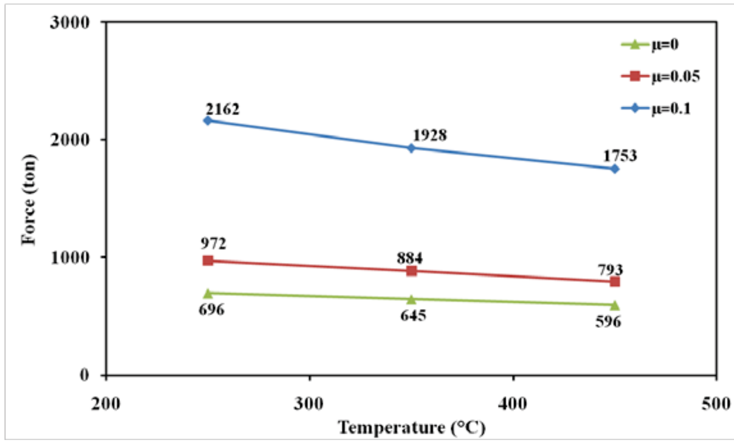

Fig. 4. Temperature-force curve at *l*=30cm and *d*=2cm under different frictional conditions.

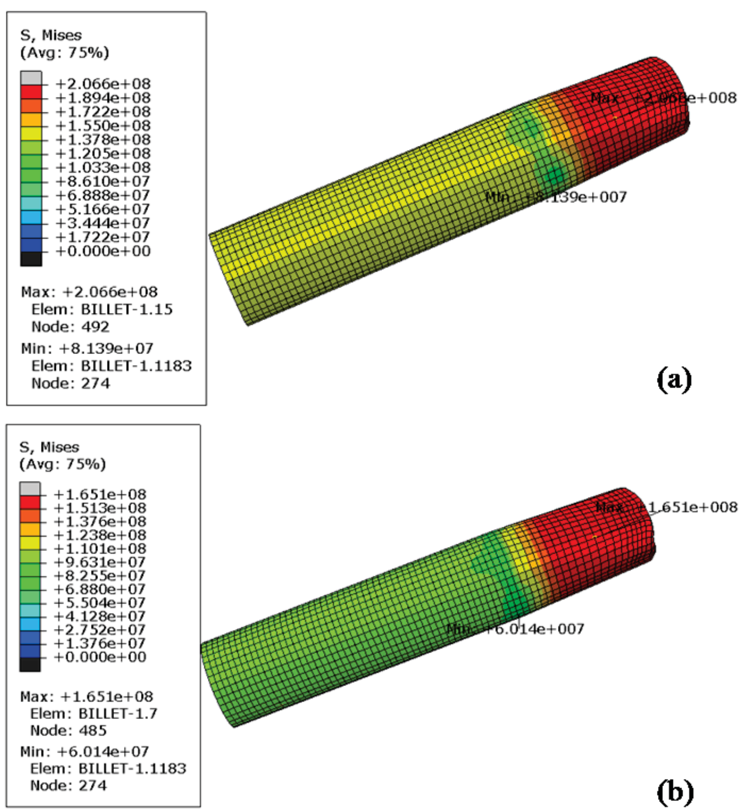

Fig. 5. Effective stress distribution at *l*=20cm, *d*=1cm, *μ*=0.05 and a) Temperature=250°C; b) Temperature=450°C.

3.3. *Friction effect*

A major concern in all metalworking processes is the amount friction force between the deforming workpiece and the tools or dies which may act as constrained and affect the shape change. The existence of friction force increases the magnitude of deformation force, which in turn increases the propensity for fracture. Fig. 4 shows that the maximum extrusion force occurs at maximum friction coefficient. Increase of friction coefficient from 0.05 to 0.1 results in 120% increase of extrusion force at given conditions. Friction also affects the effective stress distribution. Fig. 6 show the effective stress contours for μ=0.05 and μ=0.1 at given conditions when the top of billet attaches to the die exit. It can be seen that for any given element, the magnitude of effective stress at μ=0.1 is more than that for μ=0.05. For μ=0.1, the maximum and minimum effective stresses are 157.5MPa and 84.37MPa and for μ=0.05, are 145.7MPa and 61.94MPa, respectively

3.4. *Genetic algorithm*

An absolute error type function (Eq. (1)) was used as fitness function in this study [15]. The fitness function is the basis of the survival of the fittest premise of genetic algorithms. It is responsible for evaluating the parameter set, and choosing which parameter sets mate. In Eq. (1), f(x) is the fitness function, j is a fitness case out of n cases, EF is the extrusion force where subscripts FEM and GA stand for finite elements methods and genetic algorithm methods, respectively.

$$min\ f(x) = \sum_{j=1}^{n} \left| (EF_{FEM})_j - (EF_{GA})_j \right| \qquad (1)$$

The GA model, proposed in this work, attempted to capture an optimized model by randomly selecting the set of weighting factors and evolved them to create the best model for l and d under minimized error. The suggested GA model for extrusion force (GAEF) takes the following form [15]:

$$GAEF = w(1) + w(2)d + w(3)l + w(4)dl + w(5)d^2 + w(6)l^2 + w(7)dl^2 + w(8)d^2l + w(9)d^2l^2 \qquad (2)$$

Where w(1), w(2), w(3),…, w(9) are the weight factors. The FE data obtained from ABAQUS software was used as input data for the execution of GA model. Following parameters were used for running the algorithm:

Population size: 1500
Generation: 1500
Elite children: 20
Crossover probability: 0.8

.

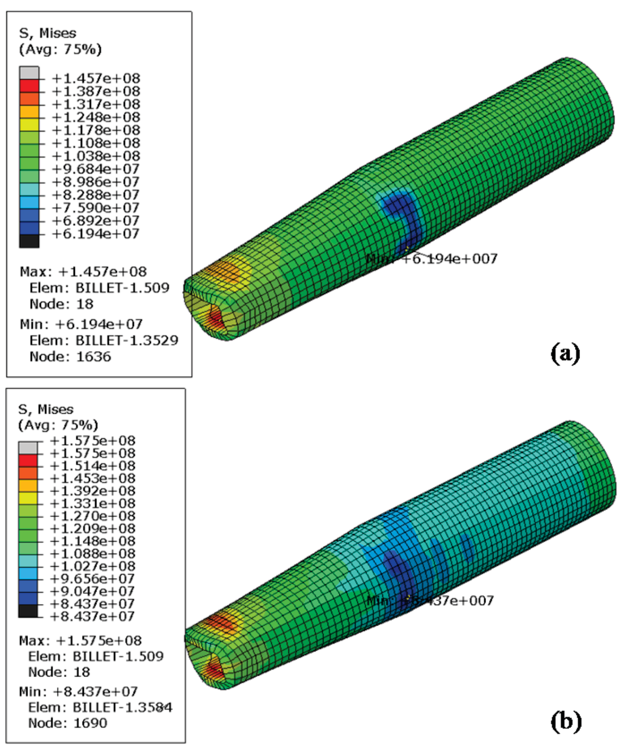

Fig. 6. a) Effective stress distribution at *l*=30cm, *d*=2cm, Temperature=450℃ and a) μ=0.05; b) μ=0.1.

After running of the program, GA returned numerical values of weight factors (w(1), w(2), w(3), ... w(9)) which were found by minimizing the difference between FE values and estimated values with GA using Eq. (1). The resultant weight factors obtained from the GA program for different friction coefficients and Temperature=450°C are given in Eqs. (3)–(6).

$$GAPF_{\mu=0.025} = -6893.962625 + 7481.93d + 587.6311l - 583.598dl - 2071.814d^2 - 10.47663l^2 + 10.8206dl^2 + 161.0203d^2l - 2.99166d^2l^2 \quad (3)$$

$$GAPF_{\mu=0.05} = 1283.6 - 533.93d + 21.28l + 5.62dl - 410.8d^2 - 0.83l^2 + 1.03505dl^2 + 38.6337d^2l - 0.9671d^2l^2 \quad (4)$$

$$GAPF_{\mu=0.075} = 738.62 - 975.3d + 62.2l + 66.53dl - 87.2d^2 - 1.203l^2 - 0.4337dl^2 + 7.586d^2l - 0.32732d^2l^2 \quad (5)$$

$$GAPF_{\mu=0.1} = -5557.5 + 4933.7d + 466.5l - 289.06dl - 1198.4d^2 - 7.131l^2 + 4.51413dl^2 + 69.78d^2l - 1.1089d^2l^2 \quad (6)$$

Comparison between FE and predicted extrusion force by the proposed GA model is shown in Fig. 7. The correlation coefficient (R) of the model is 0.995. Also the maximum relative error |(GA-FEM)/FEM| is 5.53%. Therefore, the proposed GA model can be efficiently utilized to predict the extrusion force of rectangular waveguides with reasonable accuracy and reliability.

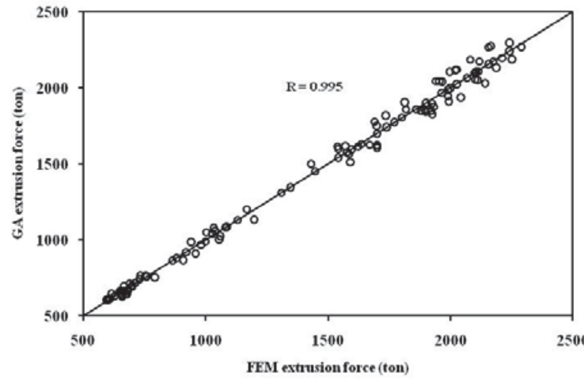

Fig .7. Comparison between FEM and extrusion force predicted by GA model.

Fig. 8a-d compares extrusion force for different frictional conditions at Temperature=450°C. The maximum and minimum extrusion forces obtained are shown in Fig. 9. The maximum extrusion forces are 1109, 1911, 2205 and 2304 T (ton) for friction coefficients of 0.025, 0.05, 0.075 and 0.1, respectively. In addition, the minimum extrusion forces are 442, 1130, 1449 and 1577 T for the above mentioned frictional conditions, respectively.

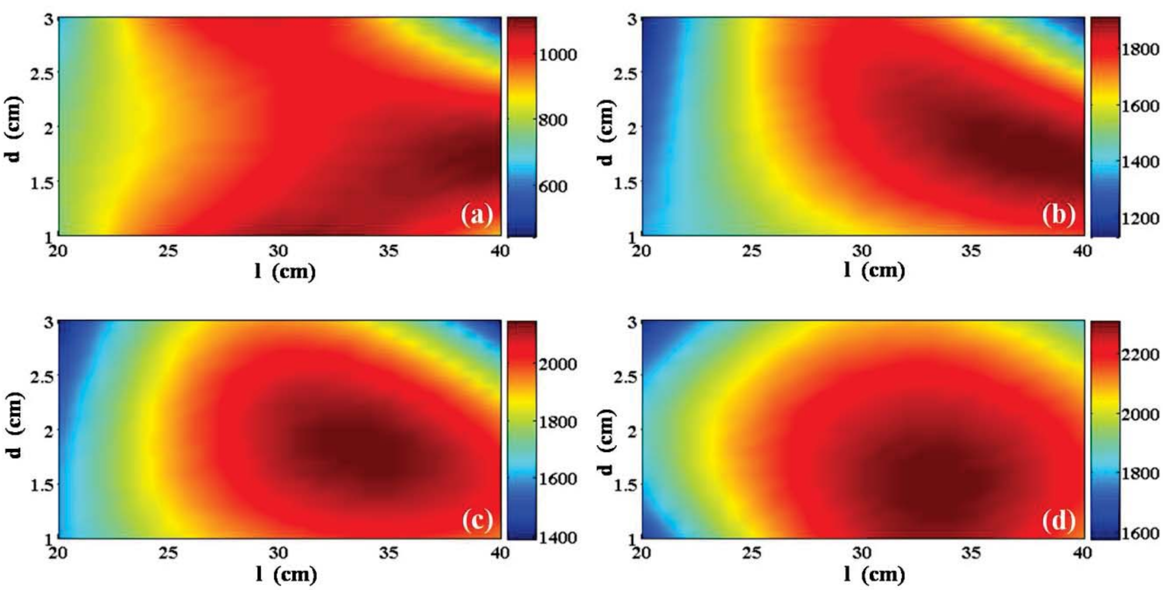

Fig. 8. Extrusion force distribution at 450°C and a) μ=0.025; b) μ=0.05; c) μ=0.075; d) μ=0.1

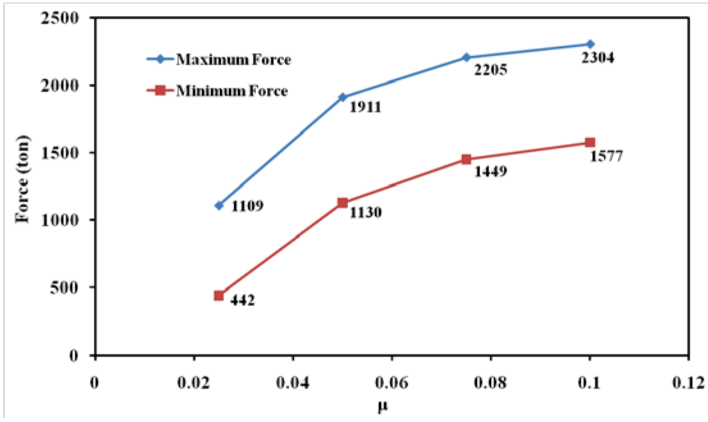

Fig. 9. Maximum and minimum extrusion force at different frictional conditions

3.5. *Die length effect*

Die length has contradictory effect on the extrusion force. Material shows smaller plastic deformation for large die length in comparison with small die length and so extrusion force decreases at large die length [5]. On the other hand, increase of die length results in more friction forces between billet and die, which in turn results in increase of extrusion force [16]. Fig. 8b-c show that the extrusion force for d=3cm, l=20 and 40cm has no significant difference. It shows that the effect of die length to facilitate the material flow at l=40cm is equivalent to that of friction force decrease at l=20cm. For μ=0.025 (Fig. 8a), the minimum extrusion force occurs at l=40cm. It means that the ease of material flow is the dominant factor affecting the extrusion force, while in Fig. 8d (μ=0.1), increase of friction is the influential parameter affecting the extrusion force and the minimum extrusion force occurs at l=20cm.

3.6. *Hole diameter effect*

Fig. 8a-d show that the diameter of billet hole has also a contradictory effect on the extrusion force. For l>26cm, increase of d from 1 to 3cm shows that the extrusion force first increases and then decreases. Reduce of extrusion force with increase of hole diameter was reported in other study as well [17]. Increase of hole diameter is equivalent to the reduction of extrusion ratio or reduction of area that results force decrease. It is reported in the forming process that if the shape is held constant while reducing the size of an object, the ratio of total surface area and volume increases with size decrease. That is because the volume of a part is proportional to the third power of its size r3 while the surface is comparative with the second power of r2. Change of the size r results in a change of the relation of surface to volume by 1/r. In this study, with increase of hole diameter, the volume of the billet decreases and the surface area of the billet increases. Hence, the ratio of surface to volume and so the friction force increases. From Fig. 8a-d, it can be seen that for l>26cm and d<1.8cm, the effect of surface to volume ratio is the dominant factor affecting the extrusion force while for d>1.8cm, the effect of reduction of area is the dominant factor. However, for l<26cm and the whole range of d from 1 to 3cm, the above mentioned contradictory effects are equivalent, so that for l<26cm the change of d has no significant effect on the extrusion force.

3.7. *Optimization*

It was found that d=3cm to be the optimum hole diameter for all frictional conditions. It means that despite the contradictory effect of hole diameter, the reduction of extrusion ratio is an important parameter on the extrusion force changes for all conditions considered. However, the optimum die length for μ=0.025 was different from other frictional conditions. The optimum die length l=40cm was obtained for μ=0.025 and l=20cm was achieved for μ=0.05, 0.075 and 0.1.

3.8. *Experimental procedure*

The experimental procedure was carried out to verify the accuracy of results. The extrusion force of 1600 T was obtained from experiment for the friction coefficient of μ≈0.1. The estimated force of such a condition with GA is 1577 T which has a good agreement with experimental result. Fig. 10 shows the produced profile. It is obvious that the use of cold drawing process is unavoidable to achieve the closed tolerances mentioned in ASTM-B372 standard [1]. This process was not studied in this paper.

4. Conclusion

Simulation and optimization of hot extrusion process were carried out to produce the rectangular waveguide and the following results are obtained:

Fig. 10. The produced profile at optimized conditions

- Temperature increase from 250℃ to 450℃ leads to force decrease about 20% at different frictional conditions.
- Die length has contradictory effect on the extrusion force. Therefore, there is an optimum die length in which the force is minimized. For $\mu=0.025$ the optimum length is 40cm and for other frictional conditions is 20cm.
- Diameter of billet hole has also contradictory effect on the extrusion force. However, d=3cm is obtained as optimum diameter for all frictional conditions.

References

[1] ASTM B372, 2003, Standard Specification for Copper Sheet and Strip for Building Construction. ASTM International, West Conshohocken, PA.
[2] Chanda T., Zhou J., Duszczyk J., 2000, FEM analysis of aluminum extrusion through square and round dies, MATER DESIGN 21: 323-335.
[3] Lee C.M., Yang D.Y., 2000, A three-dimensional steady-state finite element analysis of square die extrusion by using automatic mesh generation, INT J MACH TOOL MANUF 40: 33-47.
[4] Kumar S., Prasad S.K., 2004, Feature-based design of extrusion process using upper-bound and finite element techniques for extrudable shapes, J MATER PROCESS TECHNO 155: 1365-1372.
[5] Malpani M., Kumar S., 2007, A feature based analysis of tube extrusion, J MATER PROCESS TECHNO 190: 363-374.
[6] Gang L., Jie Z., Duszczyk J., 2008, Process optimization diagram based on FEM simulation for extrusion of AZ31 profile, TRANS NONFERR METAL SOC 18: 247-251.
[7] Mao Y., Zhang Q., Sun C., 2010, Study on extrusion forming of superalloy tube under different dies, ADV MAT RES 145: 380-385.
[8] Chung J.S., Hwang S.M., 1997, Application of a genetic algorithm to the optimal design of the die shape in extrusion, J MATER PROCESS TECHNO 72: 69-77.
[9] Narayanasamy R., Venkatesan R., Ponalagusamy R., 2005, Extrusion die profile and extrusion pressure optimization using genetic algorithm, J. ADV INSTR ENG 45: 52-63.
[10] Pathak K.K., Lomash S., Jain N., Jha A.K., 2009, Tube extrusion design for some selected inner profiles, INT J PHYS SCI 4: 69-75.
[11] Wu C.Y., Hsu Y.C., 2002, Optimal shape design of an extrusion die using polynomial networks and genetic algorithms, INT J ADV MANUF TECHNOL 19: 79-87.
[12] Yan H., Xia J., 2005, An approach to the optimal design of technological parameters in the profile extrusion process, SCI TECHNOL ADV MAT 7: 127-131.
[13] UNS Standard. ASTM B36 / B36M - 08a, 2003, Standard Specification for Brass Plate, Sheet, Strip, and Rolled Bar. ASTM International, West Conshohocken, PA.
[14] Naka T., Youshida F., Ohmori M., 1995, Flow stress and ductility of brass with various Zn-contents at wide range of strain rate, J SOC MATER SCI, JAPAN 4: 591-596.
[15] Zain-ul-abdeina M., Nélias D., Jullien J.F., Wagan A.I., 2010, Thermo-mechanical characterization of AA6056-T4 and estimation of its material properties using Genetic Algorithm, MATER DESIGN 31: 4302-4311.
[16] Ebrahimi R., Reihanian M., Kanaani M., Moshksar M.M., 2008, An upper-bound analysis of the tube extrusion process, J MATER PROCESS TECHNO 199: 214-220.
[17] Venkata N.R., Dixit P.M., Lal G.K., 1996, Analysis of axisymmetric tube extrusion, INT J MACH TOOL MANUF 36: 1253-1267.