The Optimization of the Effective Parameters of the Die in Parallel Tubular Channel Angular Pressing Process by Using Neural Network and Genetic Algorithm Methods

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Abstract
One of reasons that researchers in recent years have tried to produce ultrafine grained materials is producing lightweight components with high strength and reliability. There are disparate methods for production of ultra-fine grain materials,one of which is severe plastic deformation method. Severe plastic deformation method comprises different processes, one of which is Parallel tubular channel angular pressing. The aim of this study is optimizing parameters of the noticed process die just by utilizing neural network and genetic algorithm methods that at first for this purpose, by using ABAQUS finite element software, the numerical analysis of the die parameters is performed and the impact of each die parameter on the force of the process and the equivalent strain is examined. Finally, for gaining optimal parameters, MATLAB and neural network optimization methods and genetic algorithm are used. The use of neural network and genetic algorithm illustrated that to achieve the ideal possible situation in order to achieve a flawless super-fine tube, it is imperative to use the friction coefficient of 0.05, tube length of 40 mm, channel angle of 140 degrees and diameter increase difference of 1.5 mm. With such values, strain fluctuations reach 0.23, lowest value, and also the force reaches 0.49 KN and the amount of applied strain reaches its highest value to 2.37.

Keywords

1. Introduction
Nanostructure materials refer to materials that their appearance look like bulk, but their structures are in nano scale. Nanostructure materials are made with two major approaches (top-down), and (bottom to top). The aim of the first approach is changing the structure of the matter and bringing it to the nanometers dimensions. In the second approach, the target is creating the bulk material which is constructed just by ordering atoms or nanostructure components [1,2].

There are disparate methods in the top-down approach a bunch of which is applying mechanical force on workpieces and one of the main categories is severe plastic deformation method[3].

1.1.The definition of plastic deformation and severe plastic deformation

When a metal is deformed, depending on the amount of applied force, this deformation can occur in two forms in metal. Elastic deformation or elastic deformation is in conjunction with plastic deformation. Elastic deformation refers to that part of the transformation which is reversible and has spring state; in addition, if the applied force is removed, the deformed metal will return to its original state. In this type of deformation, the applied strain is proportional to the amount of applied stress; this means that the relationship between stress and strain is linear and the slope of the line is called the elastic modulus (E) [2]. This relationship can be considered equivalent to the spring Law (Hooke's Law). When the applied tension to the metal exceeds the elastic limit, the deformation process is transformed into the plastic range [3]. Plastic deformation which occurs after the elastic deformation is considered as an irreversible process and a permanent deformation. When a metal undergoes the plastic deformation in not so high temperatures, the resistance of the inner structure of the metal against deformation is increased; As a result, the amount of applied stress must be increased to continue the deformation process. This created state in the metal is called work hardening or strain hardening. As a matter of fact, the strength and the stiffness of the metal are increased because of the work hardening [4]. In contrast to this risen strength, the metal loses its ductility and its deformation ability will be declined. Therefore, this restriction causes limiting the metal strength increase with applying the mechanical work which is why the break of the material will occur [5].

Severe plastic deformation is actually a set of methods by which relatively large mechanical work can be applied to the metal without having failed and cracks. An important point about this severe plastic deformation method is that not only does it increase the strength of the metal, but also in many cases, it removes the loss of ductility and sometimes increases the softness. This is exactly what distinguishes this method and other methods of plastic deformation which is because of the special feature created in the metal nanostructure by using severe plastic deformation method. There is a combination of various methods for severe plastic deformation, one of which is Parallel tubular channel angular pressing (PTCAP) [1, 6].

1.2. The Background of Parallel tubular channel angular pressing

The experimental and numerical study of the mechanical effect of periodic increases and decreases in diameter method for producing resilient copper pipes were performed by Torabzadeh et al.[7]; a new method of severe plastic deformation was used by them. According to the statements, this method comprises two half-cycle; in the first half-cycle, the tube is pressed on the mandrel whose job is increasing the tube's diameter; So that in shear areas, tensile stress along with incision is created and the pipe's diameter is raised. In the second half of the cycle, the pipe is driven to the die which is responsible to reduce the pipe's diameter; so that at the same shear zones, the compressive stress in conjunction with incision is created to the point that the pipe's diameter reaches its initial value. After the experiments are carried out, the tensile strength from the initial state is grown by 50 percent, from 120 MPA to 180 MPA, and after the eleventh round, the hardness is increased, from 96 Vickers to 127 Vickers; as a result, it goes without saying that how valuable this method is in increasing the strength of the copper pipes.

The texture of 7075 aluminum alloy pressed at same angled channels in terms of annealing in various directions was investigated by Shaeri et al. [8]. After doing the heat treatment in 4 steps, the experiment was carried out at ambient temperature and in 3 directions. Considering that the 7075 aluminum has resilient texture, the first stage texture is highly dependent on the initial tissue. After the initial stage of the process, the strength of the tissue will be increased while the more the number of stages is increased, the more the strength of the tissue will be reduced.

The Parallel tubular channel angular presses (PTCAP) as a way to create severe plastic deformation for the production of cylindrical pipes was examined by Faraji et. al. [9]. Due to the fact that the tube will be between the mandrel and the die in this process and the diameter of the tube will be increased when the pressure is applied by the punch, this process is investigated just for manufacturing the copper pipes. After using ABAQUS finite element software and performing practical experiments in order to examine this process, the plastic strain was obtained equivalent to about $3 \pm 0/05$ in Parallel tubular channel angular pressing (PTCAP) whereas in Parallel tubular channel angular pressing, this value is obtained at a rate of $3 \pm 0/4$. Moreover, the fact that the amount of force in PTCAP is approximately 57% less than that in the tubular channel angular pressing was stated by them.

Tubular channel angular pressing was examined by Faraji et. al. [10] performed a method of severe plastic deformation in order to create tubular cylinders. This method was used since a large strain is occurred without any changes in dimensions; This experiment was performed on AZ91 Magnesium pipes and the results showed that the hardness was risen from 52 Vickers at a point to 80 Vickers at c point which is illustrated in Figure 1(a). Also in another study [11], the Friction Law in the Parallel tubular channel angular pressing was investigated. By using numerical, experimental and computational methods, it was figured out that the coefficient of friction has the greatest impression on the Parallel tubular channel angular pressing. Different friction coefficients with values of 0.025, 0/05, 0/075 and 0/1 were examined and according to the results, when the coefficient of friction is increased as much as three times, the third angle (shown in Figure 1(b)) is declined from 45 degrees to 40 degrees and also the strain is grown by the amount of 2/94 and the amount of force is risen by 2.5 times.
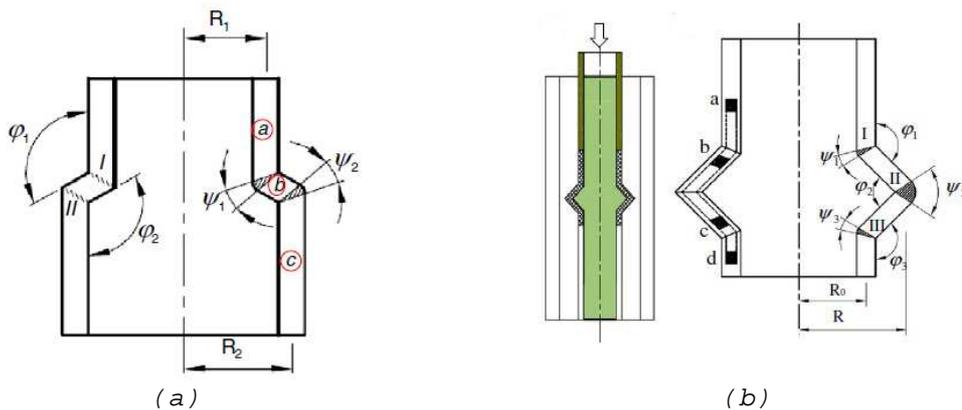

Figure1. Process Parameter (a) TCAP (b) PTCAP

2. The definition of parameters

Selecting appropriate input parameters plays an important role in improving the desired output parameters; therefore, controlling every listed factor controls the uniformity of the strain distribution which ultimately can be considered as controlling the process. Hence selecting every noticed input data properly is so important.

This process consists of two half-cycle. At first, the pipe is placed in the empty space between the mold and the mandrel. In the first cycle, due to applying the pressure with the first mandrel, the pipe enters the deformation zone and crosses two symmetrical shear zones which result in increasing the diameter of the pipe. In the second cycle, when the pressure is applied by the second mandrel, pipe crosses two shear zones and its diameter reaches the initial value. As a result, the pipe diameter at the end of two cycles has not changed which is why this process can be performed in several passes on the tube and large strains can be imposed on that; but as noted in this study, two half passes were used for applying the strain on the tube. As it was shown in Figure 1(b), the parameters related to the die are φ, R_1, R_2, ψ_1, ψ_2 and that the sufficient selection of these factors and controlling them are of utmost importance in advancing the ideal process to have uniform strain distribution. Each of parameters relating to the die is defined as shown in Table1.

Table1. Defined parameters

Row	Parameter	Value
1	channel angle (φ)	135 deg. 150 deg. 160 deg.
2	friction coefficient (f)	0 0.025 0.05 0.075 0.1
3	Tube Length (L)	40 mm 50 mm 70 mm
4	diameter increase difference ($K = R_2 - R_1$)	1.5 mm 2 mm 2.5 mm
5	Channel Curvature angles (ψ_1, ψ_2, ψ_3)	0 deg.

In order to obtain ideal process, values of channel curvature angles were Considered 0 deg in this study. The brass alloy is considered as the material of the pipe in the process and mechanical properties and its plastic behavior are defined as shown in Table2 [11].

Table2. The mechanical properties of the tube [11]

Elastic Properties		Plastic Properties		Density
Young's modulus	Poisson's ratio	Yield Stress(Gpa)	Plastic Strain (mm)	
100 Gpa	0.3	100	0	8.4 g/cm³
		103.35	0.02	
		150.24	0.03	
		175.6	0.05	
		205.3	0.07	
		233.4	1	
		270.5	0.12	
		289.2	0.15	
		325.4	0.18	

3. The procedure

3.1. Process modeling

ABAQUS finite element software is used to model the process; the explicit analysis of the ABAQUS software is utilized for analyzing which uses the explicit method with respect to the time for solving the motion equation; this method's calculations are entirely different with those in Abaqus/Standard. The present dynamic information in future calculations is used in this method like the following.

Abaqus-Explicit is a solver in which the global stiffness matrix is not formed for calculating displacements. In this solver, results (including position, speed and acceleration of nodes) are obtained directly from results of the last moment at any time and also there is no duplicated solution. In order to analyze the process by using explicit method, the whole model is plotted like the two-dimensional model for reducing the solution time.
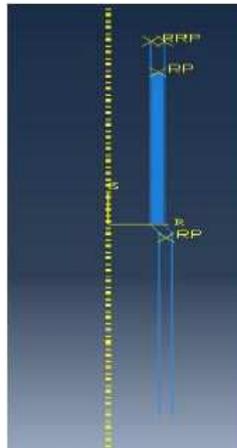

Figure2.Model plotted in ABAQUS Software

3.2. Validation of the study

For validating this research, it is necessary to compare the results obtained from the finite element simulation of the process with the analytical equation gained for Parallel channel angular pressing. For this Comparison, the values of the input parameters such as $\varphi=150°$, $\psi=0°$, $R_1= 10mm$ and $R_2=11.5mm$ were used to introduce them to the mentioned relationship just for obtaining the amount of the strain. The analytical equation.1 represents the resulted strain in the Parallel Tubular channel angular pressing which is extracted from the reference [12].

$$\bar{\varepsilon}_{PTCAP} = 2N \left\{ \sum_{i=1}^{2} \left[\frac{2\cot(\varphi_i/2 + \psi_i/2) + \psi_i \cosec(\varphi_i/2 + \psi_i/2)}{\sqrt{3}} \right] + \frac{2}{\sqrt{3}} \ln \frac{R_2}{R_1} \right\} \qquad (1)$$

The parameter N in the equation1 is the number of passes. By Taking into account presented input parameters and performing one pass of the process, the amount of the applied strain equals to 1.6. The strain value obtained from equation.1 is by assuming a uniform strain in the thickness direction, but in the experimental and numerical simulation of the strain is in the variable thickness direction. Strain changes in the thickness direction must be minimized; therefore, the homogeneity of strain to achieve the desired mechanical properties is so essential. Figure 3 shows the strain distribution at the end of one pass. According to results of the finite element simulation of Parallel channel angular pressing, the maximum applied strain is about 1.4.
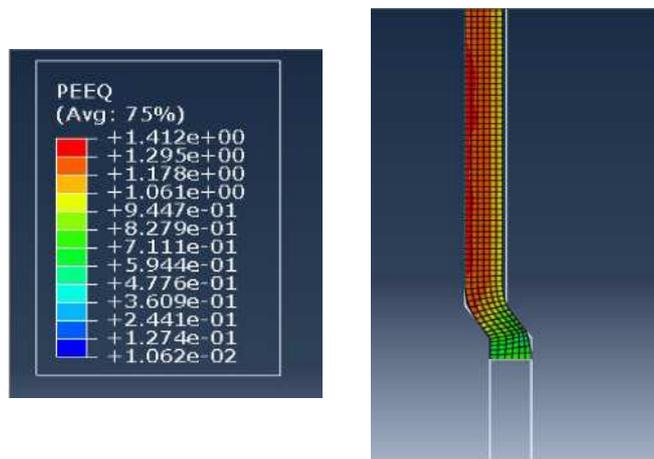

Figure3.The strain distribution at the end of a pass

Figure 4 illustrates the comparison between the strain obtained from the analytical equation and that gained from the process finite element simulation. The reason why there is an error between values of the theoretical strain and the strain obtained from finite element simulation of the process is ignoring the theoretical relationship of the tube length, material properties and the coefficient of friction effects.
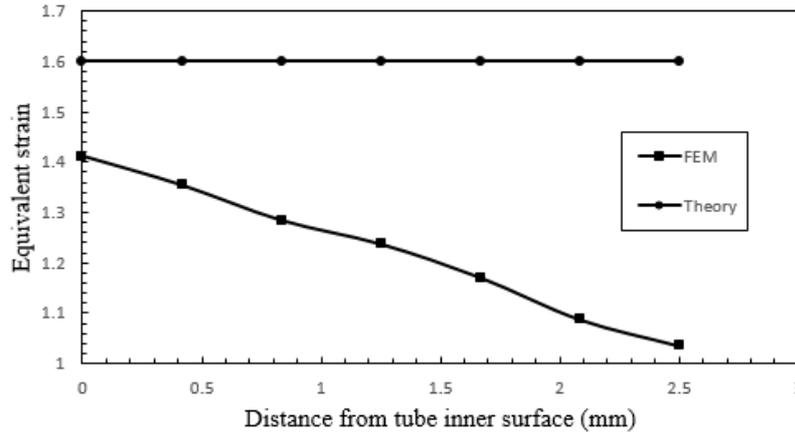
Figure4. Comparison between strain obtained from finite element simulation and strain obtained from analytical equation

4. Results

4.1. The effect of friction coefficient

A) The effect of friction on strain changes analysis

Equivalent strain changes for disparate friction coefficients are illustrated in the Figure5 As it was shown in this study, a homogeneous strain in the pipe's thickness direction was considered. For this reason, the analysis of effects of these entries on the uniformity of the strain distribution is of utmost importance. It can be seen easily that by increasing the friction coefficient, the homogeneity of the strain distribution has been raised. Therefore, it can be said that in order to achieve the ideal process, the friction coefficient as a key factor must be increased by a controlled rate for having uniform strain distribution.
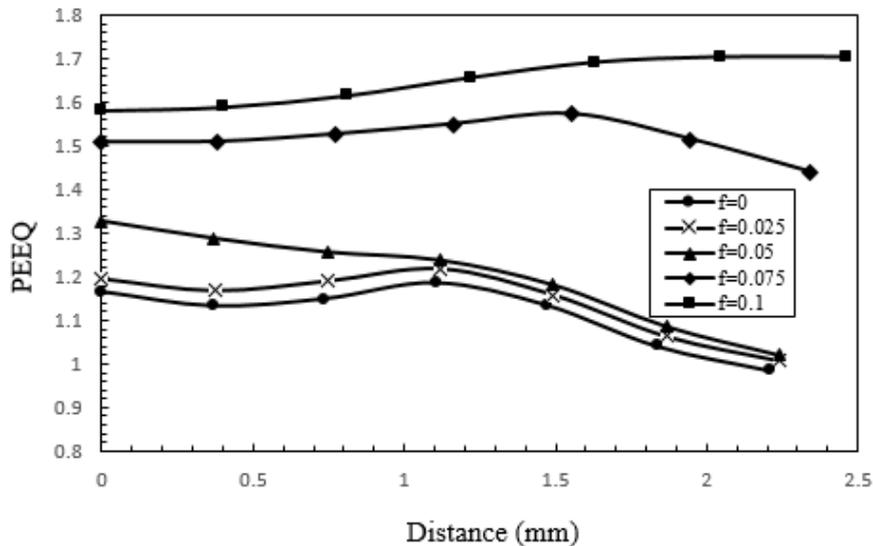

Figure5. Straining equivalent for different friction coefficients

B) The effect of friction coefficient on the process force analysis

The impression of friction on the force is shown in Figure 6. As can be seen, at a particular time, the more the friction coefficient raises, the more the shaping force will be increased. In other words, there is a direct linear relationship between the friction coefficient and the shaping force.
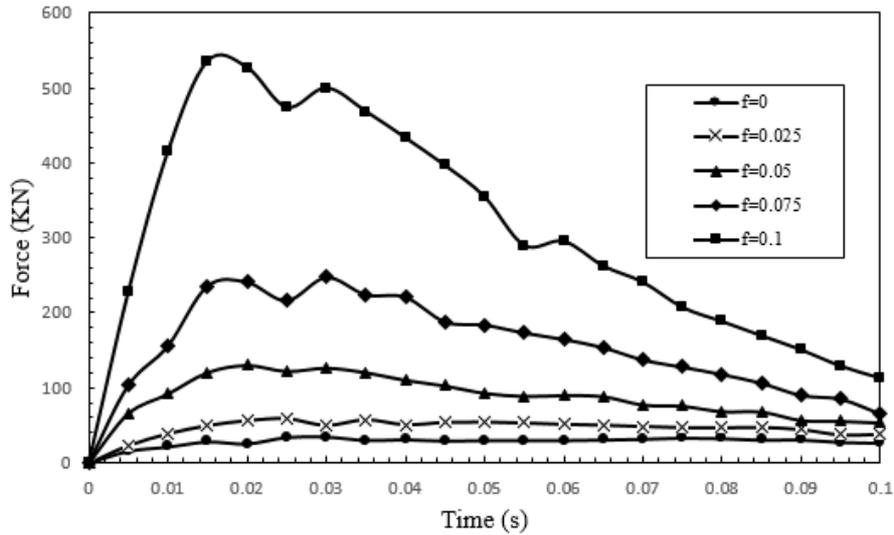
Figure6.The Process force for different friction coefficients

4.2. The effect of diameter difference analysis

A) The effect of the diameter difference increase on equivalent strain changes

Strain changes in the thickness direction for increasing different diameter differences (K) are shown in Figure 7. As far as the Figure 7 is concerned, changes in the diameter difference increase did not make a great impression on the homogeneity of the strain and strain distribution in the thickness direction for different (K) values has changed with an approximately uniform slope.
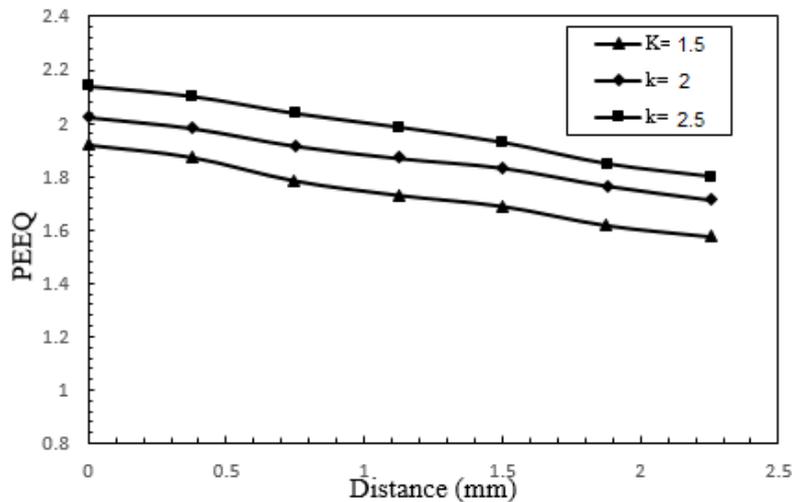

Figure7. Straining equivalent for different K parameter

B) The effect of the increase of the diameter difference on the force

The amount of the first half pass force changes because of K factor changes are illustrated in Figure8. According to the Figure, increasing in the amount of difference in diameter leads to an increase in the force at a certain time.
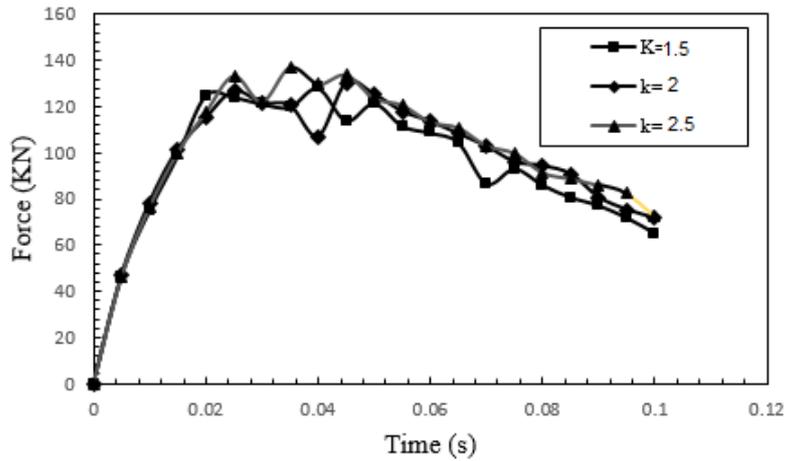
Figure8. The Process force for different K parameter

4.3. The effect of the channel angle analysis

A) The effect of the channel angle on equivalent strain changes

Strain changes in the thickness direction for different channel angles are shown in Figure9. According to the illustrated Figure, it can be seen that the channel angle will not have a great effect on the uniformity of the strain in a way that the homogeneity of the strain distribution for all channel angles has been changed with a slight slope. Therefore, it can be concluded that by altering this input data, it should not be expected to have an impact on the homogeneity of the strain distribution.
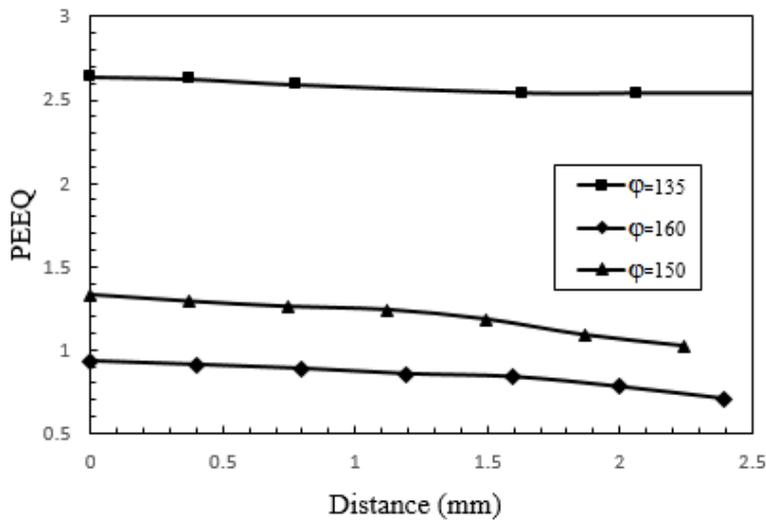

Figure9. Straining equivalent for different channel angle

B) The impression of the channel angle on the force

Changes in the first half pass force of the process caused by changes in the channel angle factor are shown in Figure10. According to the Figure, it can be anticipated that increasing the force will be caused by decreasing the channel angle. Therefore, needless to say, there is an inverse link between channel angle changes and the force of the process.
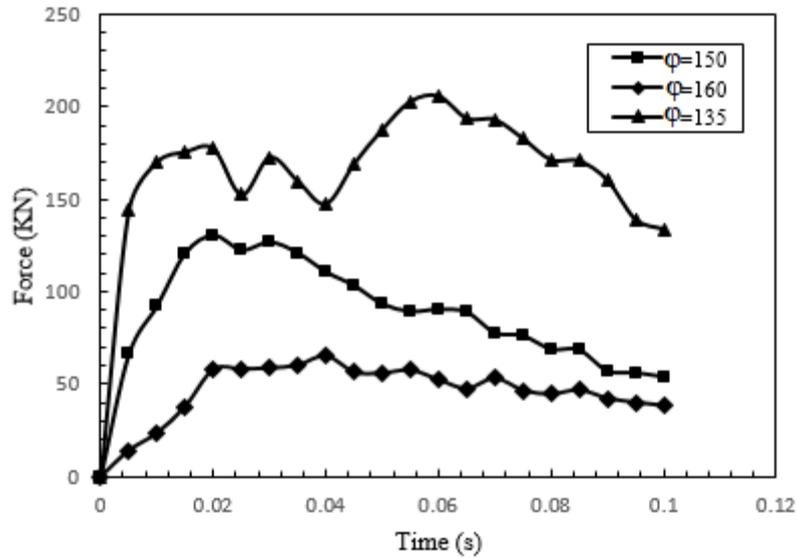
Figure10. The Process force for different channel angle

4.4. *The effect of the tube's length*

A) The influence of the pipe's length on equivalent strain changes analysis

Strain changes in the thickness direction for different pipes' lengths are demonstrated in Figure11. Considering the Figure, it is crystal clear that the homogeneity of the strain distribution is somehow affected by the low length of the tube. As a result, it is necessary to use pipes with lower lengths for achieving more homogeneity in the strain.
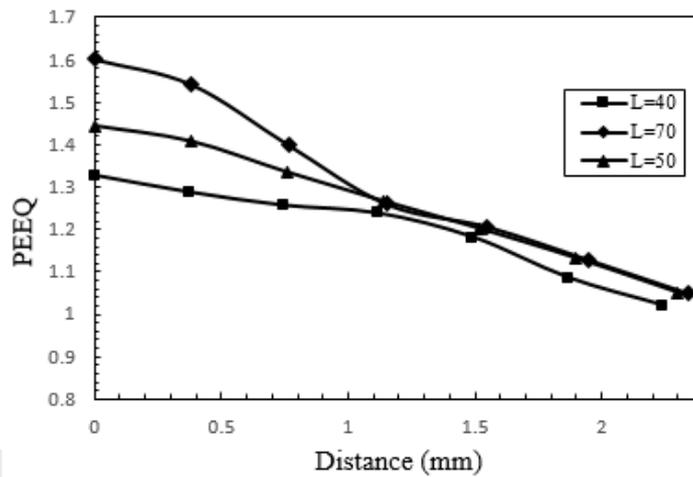

Figure11. Straining equivalent for different tube's length

B) The effect of pipe's length on the force of the process analysis

The first half pass force changes triggered by pipe's length changes (L) demonstrated in Figure12. It is clear that decreasing the pipe's length ends with dropping the shaping force.
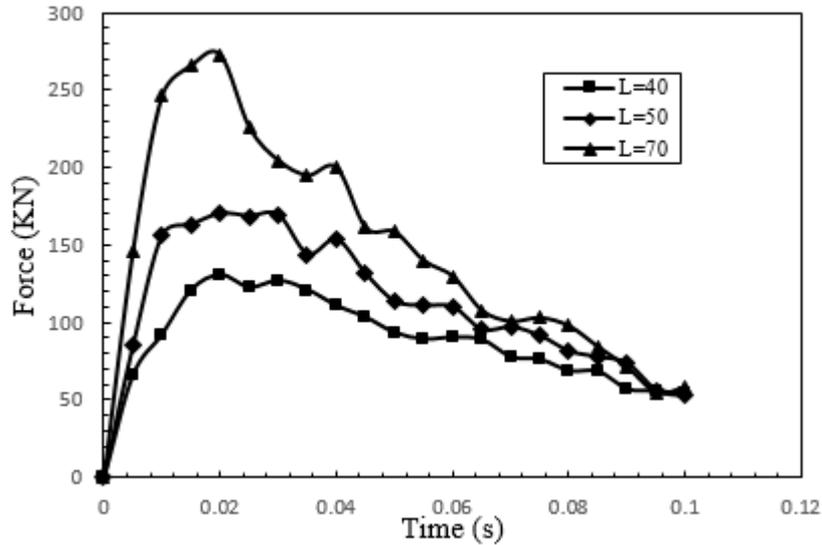
Figure12. The Process force for different tube's length

5. Optimization

5.1. Neural networks

An artificial neuron is in fact a computational model inspired from real human neural neurons. Natural neurons receive their input data through synapses. These synapses are located on dendrites or the nerve membrane. In a real neuron, the amplitudes of incoming pulses are changed by dendrites that the sort of this change will not be the same over the time and in terms; it can be learned by the nerve. If the received signal is strong enough (greater than a threshold value), the nerve will be activated and a signal along the axon will be released. This signal, in turn, can be imported into another synapse and consequently, other nerves can be stimulated by Dzung and Phuong [13].

In this study, the optimization of analyzed parameters in Parallel Tubular channel angular pressing process is performed just by using ABAQUS software. In the first place, neural networks are utilized for creating a relationship between input and output factors and making the objective function; Firstly, the input data including channel angle, length of pipe, the increase of the pipe diameter and the friction coefficient and then, the output data of the issue comprising strain distribution changes, force changes and the maximum applied strain are defined for the neural network. In the second place, a relationship between input and output parameters is established by neural networks which results in creating the objective function. In the third place, the objective function is optimized by using genetic algorithm optimization method and the optimal value of each input parameter is offered. The defined schematic of the neural network is shown in Figure13.
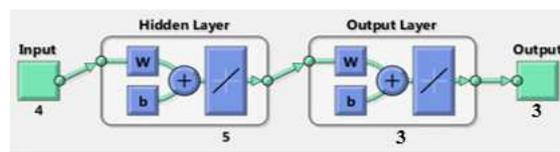

Figure13. Schematic of the neural network

Finally, after solving the neural network, its errors and regressions will be displayed as Figure14.
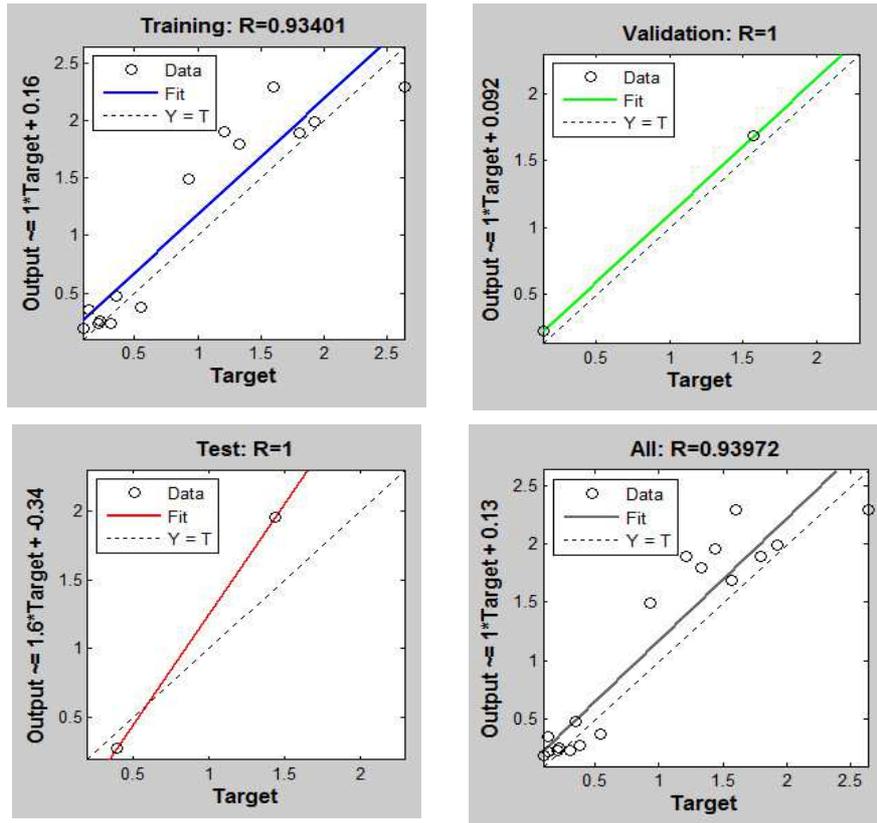
Figure14. Errors and regression of neural network

Additionally, the relations obtained by using neural network are shown as Equation2to4.

$$N_1 = (0.55108x_1) + (-0.30494x_2) + (1.0558x_3) + (0.50484x_4) + 0.81868$$
$$N_2 = (-0.93464x_1) + (-0.56413x_2) + (-0.33468x_3) + (-0.60872x_4) - 0.40777 \quad (2)$$
$$N_3 = (-0.10004x_1) + (-0.35363x_2) + (0.53122x_3) + (0.63117x_4) + 0.68111$$
$$N_4 = (-0.78879x_1) + (0.61911x_2) + (-0.39909x_3) + (0.16062x_4) - 0.97717$$
$$N_5 = (-0.29665x_1) + (0.17376x_2) + (-0.022358x_3) + (0.42406x_4) - 0.20155$$

$$Strain\ Hemogeneity = (0.13311N_1) + (-0.23809N_2) + (0.026836N_3) + \quad (3)$$
$$(0.14679N_4) + (0.68267N_5) + 0.16897$$

$$Max\ Strain = (0.38488N_1) + (-0.1473N_2) + (0.2357N_3) + \quad (4)$$
$$(-0.032853N_4) + (0.17925N_5) + 0.63963$$

In the above equation, x_1, x_2, x_3 and x_4 are input parameters which represent the friction coefficient, the pipe length, channel angle and the difference of the diameter increase.

5.2. *Genetic algorithms*

Search technique in computer science is for finding an approximate solution for the optimization and search problems. GA is a special kind of evolutionary algorithm which uses biology techniques such as inheritance and mutation. This algorithm was introduced firstly by Dzung and Phuong [13].

In fact, Darwin's natural selecting principles used for finding the optimal formula (for predicting or pattern matching) are utilized by GA; Genetic algorithms are usually good options for forecasting techniques based on regression. In artificial intelligence, the genetic algorithm is a programming technique which utilizes genetic evolution as a problem-solving model. A problem which needs to be resolved contains some input data that become solutions from genetic evolution through a modeled process. After that, solutions are evaluated as candidates by the evaluation function (Fitness Function) and if the exit condition is provided, the algorithm will be ended. In general, a genetic algorithm is an algorithm which is based on iteration and most of its sections are chosen like random processes [13].

Considering the fact that input and output parameters are available in neural networks, artificial neural networks for achieving the objective function were set for the problem. The relation (objective function) obtained from the neural network is optimized by using genetic algorithm in this section. For this purpose, firstly, a function is defined in MATLAB software and secondly, the desired function is called by using a genetic algorithm and finally, the optimization is done.

By opening the window of genetic algorithm in MATLAB software, the related function will be called. Also, 4 input variables are considered and ranges of variables are entered. Then, the genetic algorithm solves the problem by using MATLAB software and values of parameters by which the output will be optimized are provided. The convergence flow is shown in Figure 15 and optimized parameters are depicted in Table3.
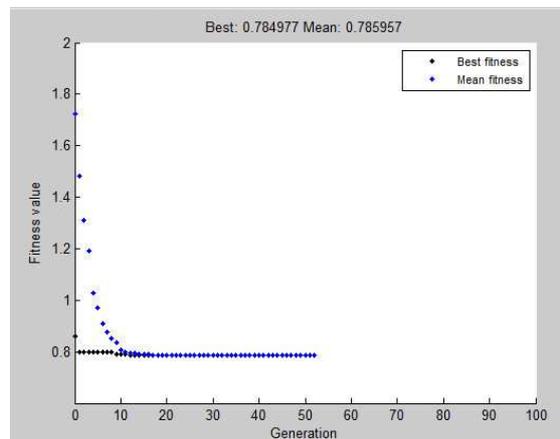

Figure15. The convergence of genetic algorithm

Table3. Optimized Parameters of PTCAP

Row	Position	Parameter	Best Level
1	Input	Channel Angle(φ)	140 deg
2	Input	Friction Coefficient (f)	0.05
3	Input	Tube Length (L)	40 mm
4	Input	Diameter Increase Difference (K)	1.5 mm
5	Output	Process Force	0.49 KN
6	Output	Straining Equivalent	0.23
7	Output	Maximum Strain	2.37

ABAQUS software is reused just in order to validate the results obtained fromoptimization which are depicted in Table 4 with error of 3 percent.

Table4. Validation Result

Row	Parameter	Validation Value	Error
1	Process Force	0.506 KN	3.26%
2	Straining Equivalent	0.24	4.78%
3	Maximum Strain	2.42	2.1%

6. Conclusion

After performing finite element simulation of Parallel Tubular channel angular pressing and extracting the results, it became clear that the control of input parameters of the mentioned process will make a great impression on the process improvement. In other words, in order to achieve a process with low defect or without flaw, it is necessary to select appropriate process input factors in the design of parallel channel angular pressing. According to results obtained from numerical experiment, it was obvious that each of the friction coefficient and examined pipe's length makes an impact on the homogeneity of the strain distribution separately; In a way that by increasing the defined friction coefficient and reducing the tested length of the tube, the distribution of the strain will lead to uniformity while the remaining two input parameters, the pipe's diameter difference increase and the angle of the die channel, will have little effect on improving the uniformity of strain distribution. On the other hand, increasing the friction coefficient, pipe's length and diameter, each of which leads to raise the force of the process while growing the angle of the die's channel ended with a reduction in the shaping force.

Additionally, according to results extracted from the optimization of parameters of parallel Tubular channel angular pressing, it was obvious that the most ideal state of the mentioned process for producing a product having the most homogenous strain distribution will occur when the friction coefficient is 0.05, pipe's length is 40 mm, channel angle is 140° and the diameter difference increase is 1.5 mm in the experiment's design. With such values, strain changes reach their lowest value, 0.23, and strain reaches the maximum value, 2.37 which means that the most uniform strain distribution will be achieved when the strain change will be the lowest value, 0.23.Additionally, values obtained from optimization were validated which had the error of 3 percent.

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