

PAPER • OPEN ACCESS

Fuzzy logic model analysis of shear force in aluminium / polyethylene lap joined by hot press

To cite this article: Mursal Luaibi Saad *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **518** 032007

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Fuzzy logic model analysis of shear force in aluminium/ polyethylene lap joined by hot press

Mursal Luaibi Saad¹, Mohammed Helan Sar², Osamah Sabah Barrak³, Sabah Khammass Hussein², Abbas Khammass Hussein⁴

¹Technical Institute - Suwaira, Middle Technical University, Baghdad, Iraq.

²Engineering Technical College, Middle Technical University, Baghdad, Iraq.

³Institute of Technology – Baghdad, Middle Technical University, Baghdad, Iraq.

⁴University of Technology , Baghdad, Iraq.

E-mail: ¹Mursal673@gmail.com, ²mheilan14@yahoo.com,

³Usamah.barrak@yahoo.com, ⁴sabah.kh1974@yahoo.com, ⁵abbas2000x@gmail.com

Abstract. Fuzzy logic is an optimization technique used to predict the behaviour of any problem. Polyethylene (PE) sheet of thickness 3 mm was joined by means of hot press method with aluminium (Al) of thickness 1mm using lap joint type. The inside surface of aluminium in the lap joint region was anodized to increase the size of surface pores and mechanical interlock between the melted polymers in the pores of anodized surface of aluminium. The anodizing process was performed by a solution of 15%wt. sulphuric acid with deionized water. The anodizing current density and time were 200A/m² and 60 min. respectively. The hot press process parameters were; temperature: 115, 125, 135 and 145 °C, pressure: 2, 4, 6, and 8 bar and the pressing time: 1, 2, 3 and 4 min. The hot press method was successfully joined the anodized Al with PE sheet. Shear tensile test was used to estimate the shear strength of lap joint. These data are optimized using a fuzzy logic concept which gives a good indication about the effect of input process parameters on the shear of joints. Increasing the applied pressure, decreasing the pressing time and increasing the temperature up to 80 °C resulted in increasing the maximum shear force of joint.

1. Introduction

Joining technology of lightweight dissimilar materials, particularly polymers and metals, has become important in the manufacturing of engineering hybrid structures [1]. Plastics-based materials are widely used in aerospace, automobile, and electrical industries due to their corrosion resistance, low weight, considerable strength, design flexibility, and electrical and thermal insulation [2,3].

The complex design of structures requires high-strength form of hybrid materials [4, 5]. The polymer sheet was joined with aluminium by several methods such as riveting and adhesive bonding [6, 7], clinching [8] and laser joining method [9,10].

Anodizing process was used to increase pores size at the oxide surface of aluminium [11] which increases the amount of molten polymer in the anodized surface and strengthened the joint [12]. AA 5052 was anodized and produced a thermo-mechanically affected zone from the friction stir welding (FSW) process [13]. FSW was used to weld Aluminium/ copper with intermediate foil of anodized copper. This foil improved the metallurgical and mechanical properties of joint [14]. The as- received and anodized aluminium alloy (AA2017) were



joined with high density polyethylene using friction lap joint. The process was failed with the as-received surface, while it succeeded with the anodized surface [15].

Real world problems (situations) are too complex, and the complexity involves the degree of uncertainty as uncertainty increases, so does the complexity of the problem. Traditional system modelling and analysis techniques are too precise for such problems (systems), and in order to make complexity less daunting, usually introduce appropriate simplifications, assumptions, etc. (i.e., degree of uncertainty or Fuzziness) to achieve a satisfactory compromise between the information we have and the amount of uncertainty we are willing to accept. In this aspect, fuzzy systems theory is similar to other engineering theories, because almost all of them characterize the real world in an approximate manner [16].

This paper aims to use a fuzzy logic model for the shear tensile test for aluminium/polyethylene lap joined by hot press method.

2. Theoretical Part Formatting the title, authors and affiliations

2.1 Fuzzy Logic (FL)

The term "fuzzy" was first used in University of California by Dr. Lotfi A. Zadeh, in journal of engineering, "Proceedings of the IRE", a leading engineering journal, in 1965 [17]. FL is a mathematical technique for dealing with uncertainty that handles problem that cannot be solved in traditional system. It is used to approximate the behaviour of any complex system which does not have analytic or numerical function. FL is a powerful problem-solving technique with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. Unlike classical logic, which requires a deep understanding of a system, exact equations, and precise numeric values [18]. Unlike classic strategy of control, the idea of FL is similar to human thinking. The classical control strategy is point to point where FL is range to range or ranges to point control. The crisp input value will be converted to different member of membership function based on its value. FL unit consist of fuzzification, membership function, fuzzy rule base, inference engine and difuzzification. Figure 1 shows the fuzzy and crisp [19].

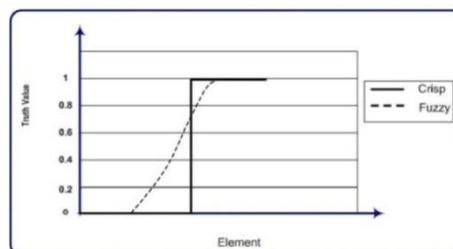


Figure 1. Fuzzy and crisp set

2.2 Fuzzy Logic System (FLS)

FLS is main success and development of FL and fuzzy set. FLS is rule base system that implemented mapping between outputs and inputs Figure 2 show the FLS structure [20].

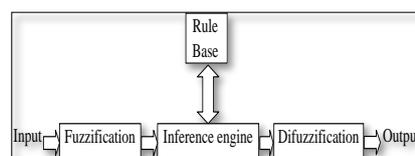


Figure 2. FLS structure

There are four characterized modules for FLS:

2.2.1 Fuzzification

The first step in FLS, which involves converting of each input data to degrees of membership by a lookup in one or several membership functions. Data input always crisp value limited to the universe of discourse of input variable (the interval between 0 and 1) and output is fuzzy degree of membership in the qualifying linguistic set [21,22].

2.2.2 Fuzzy Rule Base

Mapping of input data to the output for FL is in part characterized by set of conditions - action rules (if-then) form [19, 20]. The inputs of FL are related with the premise, and the outputs are related with consequent. These rules can be represented in many forms the standard form is, multi-input Single Output (MISO) is considered in this research. The MISO form of a linguistic rule is:

If U1 is A1 and U2 is A2 then y is B

It's entire set of linguistic rules of this form that the expert specifies on how to control the system. Note that if U1 = "hardness" and A1 = "high" then U1 is A1 a single term in the premise of the rule, means "hardness is high" it can be easily shown that the MISO form for a rule can be decomposed into a number of MISO rules using simple rules from logic [17-20]. It is linguistically (logically) equivalent to the four rules:

Rule 1 If X1 is A1 X2 is B1 X3 is C1 and X4 is D1 then y is E1
 Rule 2 If X1 is A2 X2 is B2 X3 is C2 and X4 is D2 then y is E2
 Rule n If Xn is An Xn is Bn Xn is Cn and Xn is Dn then y is En

2.2.3 Fuzzy Inference Engine

The inference engine defines mapping from input-output fuzzy sets. Inference engine determine the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may use at same time. Outputs for all rules are then aggregated. During aggregation, fuzzy sets that represent the output of each rule are combined into a single fuzzy set [17-20]. In this research Mamdani Fuzzy Inference system (FIS) was used.

2.2.4 Defuzzification

Mathematical process used to convert a fuzzy set to a real number. The result of FL operations with fuzzy sets is invariably a conclusion in the form of a fuzzy set. Defuzzification is an interface unit between the process and the decision making which converts the fuzzy set output to crisp output, which converts the conclusions of the interface mechanism into actual inputs for the process. There are three methods to transfer a fuzzy set into a single value for obtaining the defuzzification:

1. Center of Gravity Method: is the most widely used, researches use this defuzzification method, and is the weighted average of the output membership function and this method is relatively simple. center of gravity method was used in this research.
2. Composite maximum method, this method involves two kinds, including the center of maximum method (COM) and mean of maximum method (MOM). This method considers the general tools in defuzzification.
3. Peak Method, the peak method takes into account the high points in membership function [21]. In this study centroid defuzzification method was adopted to transform the multi-

response output y_{μ_c} (y) refer in to a non-fuzzy value y_o which is expressed in equation (1). Center of gravity method (centroid) shown in Figure 3.

$$y_o = \frac{\sum y_{\mu_c}(y)}{\sum \mu_c(y)} \quad (1)$$

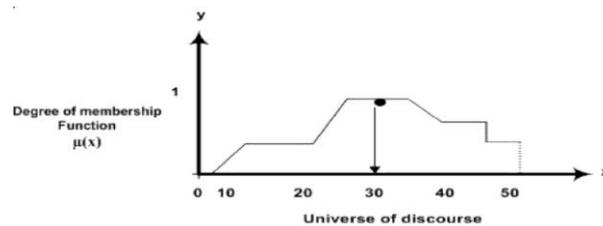


Figure 3. Centre of gravity method (centroid) [21]

3. Experimental setup

A lap joint was achieved from two types of materials; aluminium (AL.) and Polyethylene (PE.).

The specific chemical compositions of Al AA6061-T6 and mechanical properties of Al & PE were listed in tables (1 and 2). The dimensions of aluminium sheet were 25x100x1 mm, while the PE sheet has 25x100x3 mm dimensions as shown in figure 4. Those dimensions were selected according to the standard specification of AWS spot welding C1.1M/C1.1:2012 with a lap joint of 25x25 mm²[22].

Table 1. Chemical Composition of AA6061-T6

Element wt %									
Material	Si	Mn	Mg	Ti	Cr	Cu	Fe	Zn	Al
Nominal value	0.4-0.8	0.15	0.8-1.2	0.15	0.04-0.35	0.15-0.4	0.7	0.25	Remainder
Actual value	0.65	0.11	1	0.12	0.156	0.298	0.45	0.052	Remainder

Table 2a. mechanical properties of AA6061-T6

Material	Tensile strength σ_u (MPa)	Yield strength σ_y (MPa)	Elongation%
Nominal value	290	240	10
Actual value	325	264	12.1

Table 2b. mechanical properties of PE

Material	Tensile strength σ_u (MPa)	Yield strength σ_y (MPa)	Elongation%
Actual value	11.5	9.5	51.5

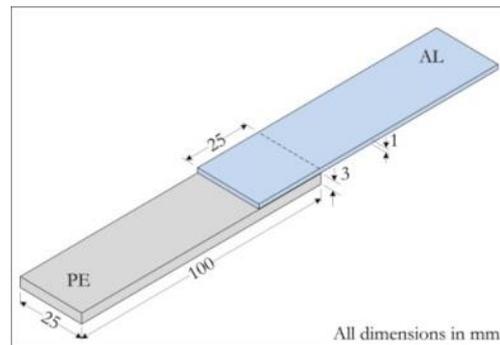


Figure 4. Schematic dimensions a lap joint for Al-PE specimens.

3.1 Anodizing of aluminium specimen surface

The anodizing rig was built containing three parts; power supply, multi-meter and container as shown in Figure 5. The DC current is produced and recorded by supply and multi-meter respectively. The container consists of cathode, anode and anodizing solution. A lead material was used as cathode in order to increase the electron transmission density due to its higher density as compared with the anode (aluminium specimen). This process was used to remove the Al_2O_3 oxide layer from the aluminium surface and build a new layer. The anodization was done for the metal surface which is joined for polymer to improve the shear strength by improve the surface morphology. The anodization is rebuilding the pores at the surface of the AA6061-T6 to be more uniform (size and shape) than the original. The uniformity of the pores at the anodized surface of the metal will increase the penetration of the polymer into the pores. Therefore, the shear strength will increase.

A cleaning process has been done before starting the anodizing process. In which, the rust, oil layer... etc. was removed by mechanical and chemical methods. Initially, the samples were grinded by emery papers. In the chemical method, a solution of NaOH was prepared by dilution of (10% wt.) with (90% wt.) of the deionized water. A stirring of this mixture was performed until reach the homogenous state and then heated to 50 °C during 15 min. the samples were cleaned by this solution during 15 min.

The solution of anodizing process was prepared by adding 15% wt. sulphuric acid to a deionized water. The current density and anodizing time were 200 Amp/m² and 60 min. respectively. This process was performed according to ASM [23].

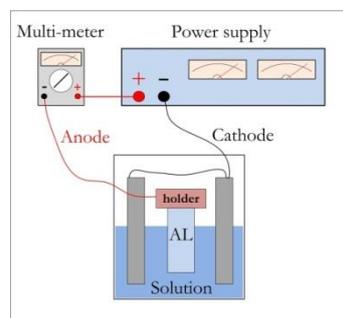


Figure 5. Schematic diagram of anodizing cell.

3.2 Hot press method

The joint was performed using a hot press rig which consist of heating device ($T_{\text{max}}=300$ °C) , hydraulic press (12 Ton capacity), specimens fixture die, pressure gauge and controller arm as shown in Figure 6. The heating device was designed using three layers; upper, lower plate and intermediate heater. A K-type thermocouple was used to record the temperature.

The location of thermocouple was in the centre of lap joint and at the bottom surface of the aluminium sample.

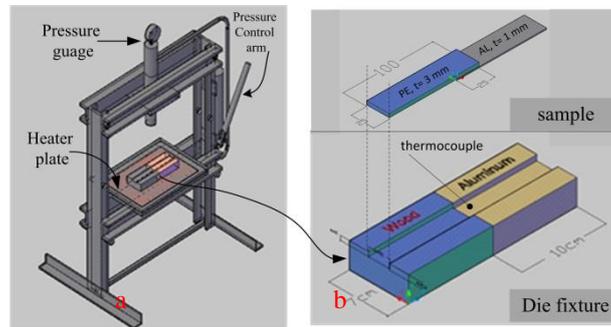


Figure 6. Schematic of hot press equipment, a) The hot press assembly b) Die fixture

The hot press process was achieved by applying pressure (P) on the sample at particular temperature (T) and time (t). The experiments were performed using specific ranges of temperature (115-145 °C) because the melting point of the PE (118-139 °C), pressure (2-8 bar) and duration time (1-4 min.) as listed in table 3. The number of tests to be conducted was decided by the Taguchi experimental design method [(L9 (3^3))] orthogonal array A jointed sample was shown in figure 7. Taguchi method was used to the design of experiments and analysis of data results.

Table 3. Experimental input data

No.	Temperature °C	Pressure (bar)	Time (min.)
1	135	2	1
2	135	4	2
3	135	6	3
4	135	8	4
5	125	2	2
6	125	4	1
7	125	6	4
8	125	8	3
9	115	2	3
10	115	4	4
11	115	6	1
12	115	8	2
13	145	2	4
14	145	4	3
15	145	6	2
16	145	8	1



Figure 7. PE-Al jointed sample

3.3 Tensile Shear test

In order to determine the maximum shear force of the jointed specimens, a tensile shear test was executed according to AWS spot welding C1.1M/C1.1:2012. Two opposite shims were placed at the ends of specimen to prevent bending and slipping during the test as shown in figure 8.

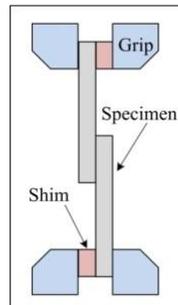


Figure 8. Tensile Shear test assembly

4. Results and Discussion

In this work, many trials were conducted on the joints. For conducting the test, three input parameters like temperature, pressure and time are divided into three categories like all the values are low, medium and high. From these three different input parameters, it get one output i.e. shear force as shown in table 4.

Table 4. Fuzzy matrix for input parameters and output response

Input1	Input2	Input3	Output
Low	Low	Low	Low
Medium	Medium	Medium	Medium
High	High	High	High

In Fuzzy Inference System (FIS) mamdani system is used. In FIS editor, all input and output parameters are entered as given in table 3. These values are shown in Figure 9. For input parameters, Gaussian curve is selected and for output parameters triangular parameters is selected. The value of three input parameters are filled in membership function.

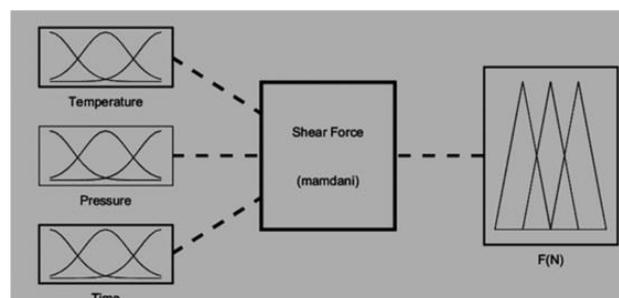


Figure 9. FIS editor for inputs and output

Rules were applied by taking the information from table 4. Three rules were applied. The rules can be viewed in rule viewer and the surface can be seen in Figure 10. The output parameters are checked from rule viewer by changing the three input parameters from low to high values matching with the output parameters. From this, the information is obtained by keeping the three input parameters at different levels and hence, the output can be getting in the three levels like “Low”, “medium” or “high”.

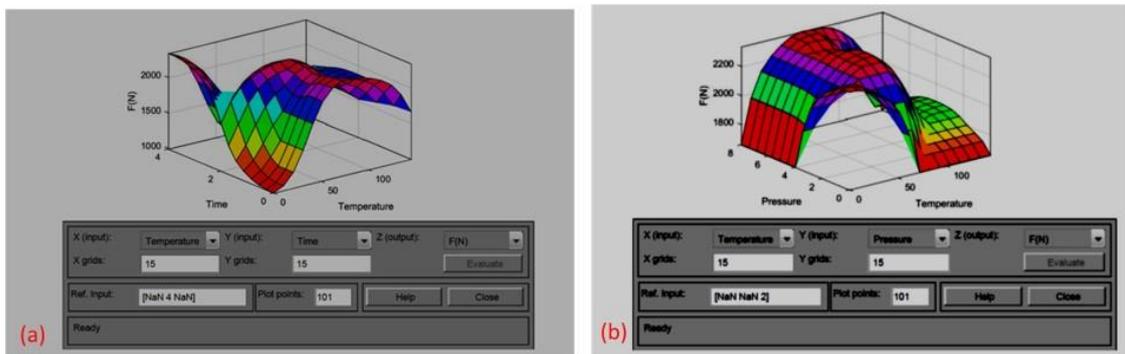


Figure 10. Surface viewer of shear force as a function for (a) time & temperature (b) pressure & temperature

The graph between three parameters can be viewed from the surface viewer as shown in Figure 10. A 2-D graph was plotted between input and output parameters as shown in Figure 11.

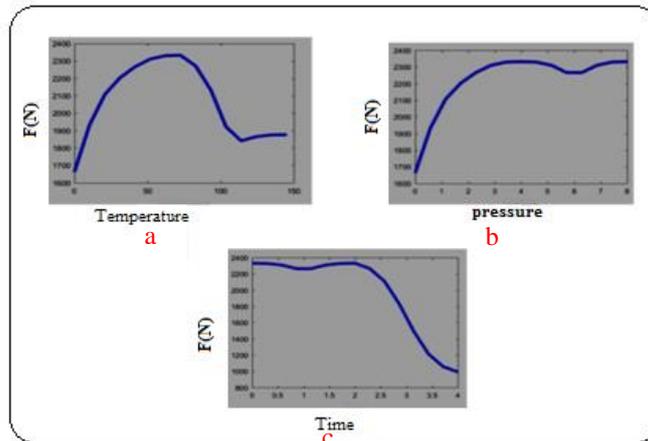


Figure 11. Shear force versus temperature(a), pressure (b) and time (c)

Figure 11 indicates that as temperature increases shear force up to 80°C and beyond that it decreases. Also, shear force increases with pressure and decreases with time. The output values were divided in the symmetrical way. The output shear force can be grouped in three categories like “Low”, “medium” or “high”. The predicted values are shown in table 5.

Table 5. Comparison between experimental and predicted data of shear force

No.	Temperature °C	Pressure (bar)	Time (min.)	Experimental force (N)	Predicted force (N)
1	135	2	1	832	Medium
2	135	4	2	1280	High
3	135	6	3	1280	High
4	135	8	4	2624	High
5	125	2	2	1248	High
6	125	4	1	960	High
7	125	6	4	512	Low
8	125	8	3	1312	High

9	115	2	3	992	High
10	115	4	4	960	High
11	115	6	1	544	Low
12	115	8	2	576	Low
13	145	2	4	960	High
14	145	4	3	1152	High
15	145	6	2	768	Medium
16	145	8	1	507	Low

5. Conclusions

Fuzzy logic is an important tool to find optimum parameters for shear tensile test. Different output parameters are checked by changing the three input parameters like temperature, pressure and time. The readings are matching with the experimental values. As maximum shear tensile test is expected, fourteen trials are giving satisfactory results. The process parameters effect on the shear force of joint which increased when the applied pressure and time is increased and decreased respectively.

6. References

- [1] K. Martinsen, S.J. Hu and B.E. Carlson, 2015 Joining of dissimilar materials, *Journal of CIRP Annals - Manufacturing Technology* **1404**, pp.1-21.
- [2] Huang, Zhequn, Sumio Sugiyama, and Jun Yanagimoto, 2014 Adhesive-embossing Hybrid Joining Process to Fiber-reinforced Thermosetting Plastic and Metallic Thin Sheets, *Procedia Engineering* **81**, 2123-2128.
- [3] Ye, Lin, Ye Lu, S. Zhongqing and M. Guang, 2005 Functionalized composite structures for new generation airframes: a review, *Composites Science and Technology* **65** (9), 1436-1446.
- [4] A.B. Abibe, M. Sônego, JF. D. Santos, L.B. Canto and S.T. Amancio-Filho, 2016 on the feasibility of a friction-based staking joining method for polymer-metal hybrid structures, *Materials & Design* **92**,632–642.
- [5] S.M. Goushegir, J.F. Dos Santos and S.T. Amancio-Filho, 2014 Friction spot joining of aluminum AA2024/carbon-fiber reinforced poly (phenylene sulfide) composite single lap joints: microstructure and mechanical performance, *Materials & Design* **54**, 196–206.
- [6] P. Kah, R. Suoranta, J. Martikainen, C.Magnus, 2014 Techniques for joining dissimilar materials: metals and polymers152, *Rev. Adv. Mater. Sci.* **36**, 152–164.
- [7] E. Rodríguez-Vidal, I. Quintana and C. Gadea, 2014 Laser transmission welding of ABS: effect of CNTs concentration and process parameters on material integrity and weld formation, *Opt. Laser Technol.* **57**,194–201.
- [8] Francesco Lambiase, Dae-Cheol Ko, 2017 Two-steps clinching of aluminum and Carbon Fiber Reinforced Polymer Sheets, *Composite Structures*, **164**, 180–188.
- [9] Z. Zhang, J.G. Shan, X. H.Tan , J. Zhang, 2016 Effect of anodizing pretreatment on laser joining CFRP to aluminum alloy A6061, *International Journal of Adhesion & Adhesives*,**70**, 142–151.
- [10] N. Pagano, G. Campana, M. Fiorini and R. Morelli, 2017 Laser transmission welding of polylactide to aluminium thin films for applications in the food-packaging industry, *Optics & Laser Technology*, **91**, 80–84.
- [11] L. Zaraska, G. D. Sulka and M. Jaskuła, 2010 The effect of n-alcohols on porous anodic alumina formed by self-organized two-step anodizing of aluminum in phosphoric acid, *Surface & Coatings Technology* **204**, 1729–1737.
- [12] Z. Zhang, J.-G. Shan, X.-H. Tan, and J. Zhang, 2016 Effect of anodizing pretreatment

- on laser joining CFRP to aluminum alloy A6061, *International Journal of Adhesion and Adhesives*, **70**, 142-151.
- [13] T.-S. Shih, Y.-J. Jhou, J.-W. Wang and L.-R. Hwang, 2011 Anodisation of friction stir welds in AA 5052-O alloy, *Science and Technology of Welding and Joining*, **16** (5).
- [14] M. Akbari, P. Bahemmat, M. Haghpanahi and M.-K. Besharati Givi, 2013 Enhancing metallurgical and mechanical properties of friction stir lap welding of Al–Cu using intermediate layer, *Science and Technology of Welding and Joining*, **18** (6).
- [15] T. Okada, S. Uchida & K. Nakata, 2017 Effect of anodizing on direct joining properties of aluminium alloy and plastic sheets by friction lap joining, *Welding International*.
- [16] S.N. Sivanandam, S. Sumathi and S. N. Deepa, 2007 “*Introduction to Fuzzy Logic using MATLAB*,” Springer-Verlag Berlin Heidelberg.
- [17] D. Dumitrescu, B. Lazzerini and L.C.Jain, 2000 “*Fuzzy Set and their Application to clustering and Training*,” 1st Edition, (Library of Congress), USA: The CRC Press LLC.
- [18] Hung T. Nduyen and Elbert A. Walker, 2000 “*A First Course in Fuzzy Logic*,” 2nd Edition, (Library of Congress), USA: Chapman and Hall/CRC.
- [19] MATLAB R2013b, 2013 “*Fuzzy Logic Toolbox™ User’s Guide*,” the math works, Inc., 3 Apple Hill drive, <http://www.mathwork.com>.
- [20] U. H. Hanna, 2005 “*Optimization of Die Geometry in Tube Sinking by Using Fuzzy Logic*,” M.Sc. Thesis, University of Technology, Department of Production and Metallurgy Engineering, Baghdad.
- [21] M. A. Abdulrazzaq, 2011 “*Utilizing Quality Function Deployment with Fuzzy Logic for Enhancing Product Planning*,” Ph.D. Thesis, Department of Production Engineering and Metallurgy in the University of Technology, Baghdad.
- [22] ANSI/AWS C1.1M/C1.1:2012, “*Recommended Practices for Resistance Welding*”, American Welding Society.
- [23] American Society for Metals, “*Surface Engineering*”, *ASM handbook*, vol **5**, 01 Sep. 2005.