Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Provide a Modeling Algorithm for Mechanical Properties of Friction Stir Welding of 5 Series Aluminum and Pure-Copper Based on Fuzzy Logic

M. R. Maraki[1]*, H. Tagimalek[2], B. Pasoodeh[3]

[1] *Department of Materials and Metallurgy Engineering, Birjand University of Technology, Birjand, Iran*
[2] *Faculty of Mechanical Engineering, Semnan University, Semnan, Iran*
[3] *Department of Mechanical Engineering, Urmia University, Urmia, Iran*

P A P E R I N F O

Paper history:
Received 26 January 2022
Accepted in revised form 30 March 2022

Keywords:
5 series aluminum
Friction stir welding
Fuzzy logic
Microhardness
Pure copper

A B S T R A C T

The copper/aluminum composite is very important and practical due to its light weight, optimal thermal and electrical conductivity. The high weight resistance ratio, along with its inherent properties, makes it attractive for new applications. In this regard, the use of composites with high mechanical properties has significantly increased. In this research, 5000 series aluminum and pure copper samples in 1st, 2nd, 3rd, and 4th passes have been subjected to friction stir welding (FSW) and then the mechanical and metallurgical properties of the welded samples have been compared with the original samples. In order to further study the results of tensile tests, metallography and microhardness tests have been performed. Microstructural evaluation of welded samples showed that the mixing zone of the samples was determined by combining aluminum and copper layers. The results showed an increase in yield strength in the welding zone and ultimately an improvement in hardness and ultimate strength in the weld zone compared to the prototype. Compared to stretched samples, the greater the distance from the nugget weld, the less the improvement in mechanical properties and microhardness. By changing the parameters and increasing the inlet temperature, the mixing and uniform dispersion of the particles is performed more appropriately and ultimately increases the tensile strength. Finally, in the research, experimental data were modeled using fuzzy logic method and considering that the presented model was obtained in two indices R-Sq (pred) and R-Sq (adj), 96 and 99%, respectively. The comparison between the experimental data and the model data indicated an acceptable error in the experimental data.

doi: *10.5829/ijee.2022.13.02.08*

INTRODUCTION

As one of the basic industries itself, welding has played an important role in industrial development and is recognized as one of the best and oldest industry-used methods [1]. The technique of welding can be used to permanently attach metallic, ceramic, polymeric, composite parts to each other and etc - whether using a melting or non-melting method, with or without pressure, applying or not applying fillers and for similar or dissimilar samples [2]. The Friction Stir Welding/Processing (FSW/P), invented in 1991 by the British Welding Association, is a solid-state bonding process that has been used to colligate the metallic and polymeric materials [3]. Using a non-consumable rotational tool in this method, the base parts are heated by friction and then the workpieces are pressed to each other, which causes them to be conjoined [4]. No workpiece melting and solid-phase linking is the main advantages of this method [5]. The FSW process is involved in mechanical and thermal interactions and is widely used in welding heterogeneous sheets in the automotive industry [6]. In this method, the attaching process is emanated from the friction between workpieces and the heat-proof tool [7]. The intricacy of performing high-strength welding, with a fracture and fatigue resistance used in the

*Corresponding Author Email: Maraki@birjand@ac.ir (M. R. Maraki)

Please cite this article as: M. R. Maraki, H. Tagimalek, B. Pasoodeh, 2022. Provide a Modeling Algorithm for Mechanical Properties of Friction Stir Welding of 5 Series Aluminum and Pure-Copper Based on Fuzzy Logic, Iranian (Iranica) Journal of Energy and Environment, 13(2), pp.169-175. Doi: 10.5829/ijee.2022.13.02.08

aerospace industry, has restricted the widespread utilization of welding in adjoining spatial structures. The diminution of mechanical properties, which leads to the fracture of a substance or a component under cyclic loads, is defined as fatigue. It is estimated that about 90% of motion failures in metal components are along of fatigues [8].

Karrar et al. [9] have investigated the influence of the tool rotational speed and forward speed on dissimilar friction stir butt welds (FSBW) on 5083 aluminums to pure copper samples. Complex microstructures were formed in the thermal-mechanically affected zone (TMAZ), in which a vortex-like pattern and lamellar structures were found. The highest ultimate tensile strength of 203 MPa and joint efficiency of 94.8% were achieved at 1400 rpm tool rotational speed and 120 mm/min traverse speed. Placing the softer material (aluminium) on the advancing side produced an excellent metallurgical bond with no requirement for tool offsetting. Aliha et al. [10] have investigated to mixed mode I/II fracture resistance of dissimilar aluminum alloy. The AA7075-T6 / pure copper butt joints welded by the friction stir welding (FSW) is experimentally and theoretically investigated. First, a novel semi-circular bend shape specimen was proposed for conducting mixed mode I/II fracture tests. da-Silva et al. [11] have investigated localized electrochemical methods supported by surface analytical characterizations that were employed to investigate galvanic coupling effects and local electrochemical activity developed along the welded zones in Friction Stir Welded 2098-T351 Al-Cu-Li alloy.

According to the background of our research in the process FSW the existence of research to correlate the significant relationship between input and output parameters of expression is quite felt that the authors paid more attention to this issue.

RESEARCH METHODOLOGY

Material and method

Figure 1 shows the schematic of the butt turbulent friction stir welding process discussed in this work. The metal sheets with a thickness of 3 mm made of 5000 aluminum and pure-copper were used. The mechanical properties of base metals are shown in Figure 2. For rotation and advancement, an FP4M milling machine made in Tabriz was used. Table 1 summarized the turbulent friction stir welding process parameters. In order to design the experiments and reach an acceptable algorithm, an attempt has been made to study and apply the Taguchi experiment design process step by step. Numerous tests must be performed to perform complete experiments in order to achieve proper process control. One of the main goals of test design methods is to select the best possible test mode, which can be used to evaluate the process in the most desirable way while justifying the number of tests, which is used to design experiments from mini software. Fever is used. In this range, input variables have been studied and the maximum and minimum theoretical limits and practical limitations have been determined. Using Taguchi method, the design of experiments with L8 experiments is shown in Table 2.

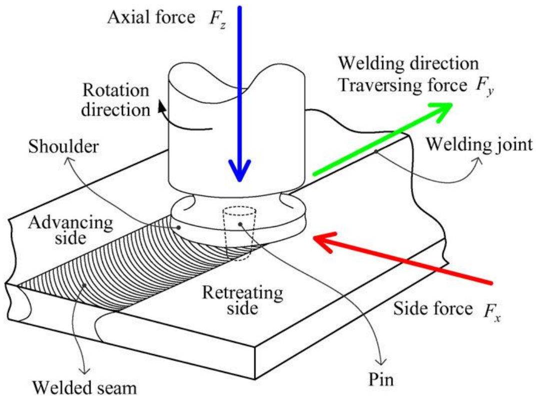

Figure 1. Schematic of the butt turbulent friction stir welding process [12]

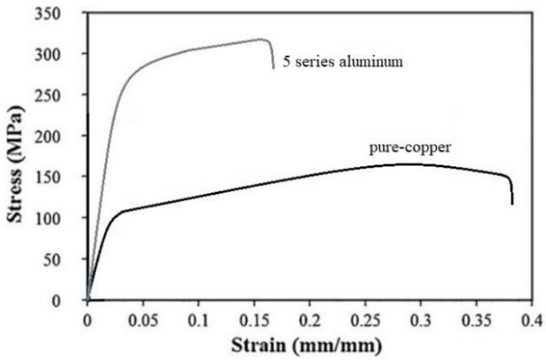

Figure 2. Stress and strain diagram of base metals

Given the importance of the issue and being there some constraints in the field of magnesium alloys welding, it would seem necessary to conduct a disquisition in this matter using two similar materials. Using an H13 stainless steel tool with a hardness of 52 Hardness Rockwell-C (HRC), the welding operation was handled at the ambient temperature. As well, the tool's height and the shoulder's diameter were 100 mm and 50 mm, respectively. Choosing parameters is based on their

Table 1. Turbulent friction stir welding process parameters

Row	Test input parameters	Working range	Quantity of measurement
1	Tool deflection angle	2-3	Degree
2	Rotational speed	700-850-1000-1150	rpm/min
3	Forward speed	22-40	mm/min

Table 2. Design of experiments and obtained model with effective parameters

Exp.	Laboratory settings			Code
	Rotational speed	Forward speed	Tool deflection angle	
1	700	22	2	P1
2	700	40	3	P2
3	850	22	2	P3
4	850	40	3	P4
5	1000	22	3	P5
6	1000	40	2	P6
7	1150	22	3	P7
8	1150	40	2	P8

effectiveness and also the choice ranges according to the previous research and the laboratorial facilities. An SEM microscope was employed to shoulder and pin the flow behavior and surface structure of welded 5000 aluminum magnesium alloy casts. For the heavy deformation and frictional calefaction, resulting from the collision between the sheet's surface and the tool's shoulder during the FSW, the stir zone is wide and close to the sheet's upper surface. According to the applied parameters, the incoming heat, or required time at high temperature, the lack of defects in the turbulence zone indicates that the local increment of material's temperature around the possible zones of plastic deformation causes the material to be completely circulated around the pin. The cylindrical welding tool made of hot steel working with a square pin is shown in Figure 3.

Fuzzy logic

Fuzzy logic was officially introduced by Shehabeldeen et al. [13]. It was stated that classical theory emphasizes too much on accuracy and is therefore not very compatible with complex systems and the real world [13]. Classical logic represents anything based on a binary system (true or false, zero or one), but in fuzzy logic everything is represented by the degree of membership; the value of which is between zero and one [14]. In this research, MATLAB software has been used to model the stiffness and tensile test results. Figures 4 and 5 show the fuzzy model designed in MATLAB software. Figure 4 shows the creative model for input and output parameters using Mamdani inference in fuzzy logic. Also, Figure 5 demonstrates the graphical representation of the fuzzy inference to predict the thickness of the layer.

The fuzzy process includes the following steps:

1. Selecting the inference system to make the connection between the input space to the output space
2. Fuzzy inputs through operators Fuzzy, for numerical data to fuzzy sets through membership function.
3. Applying fuzzy operators when the number of inputs is more than one.
4. Applying a conceptual method for assigning a given unit number from a fuzzy role to a fuzzy set.
5. Integration of outputs to combine the outputs of each role into a single fuzzy set.
6. Converting a fuzzy set by assigning an exclusive value [15].

The number of rules used to model 8 rules has been applied. In this research, Mamdani inference motor is used and the values of fuzzy inputs are converted to fuzzy outputs after entering the inference motor and applying the existing fuzzy rules. Finally, the fuzzy outputs are converted to surface roughness output values using the

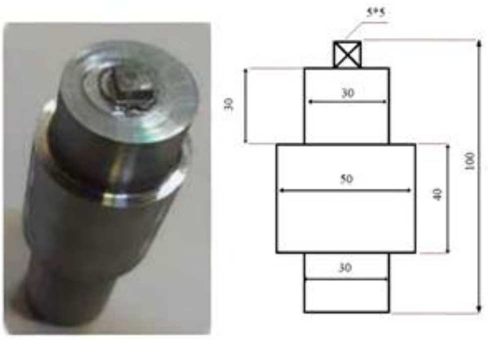

Figure 3. Cylindrical welding tool made of hot steel working with a square pin

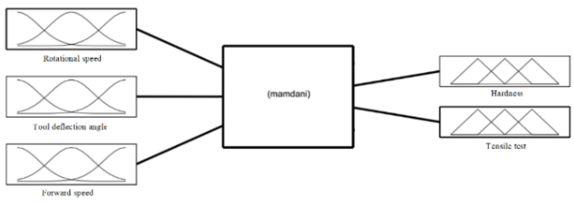

Figure 4. Creative model for input and output parameters using Mamdani inference in fuzzy logic

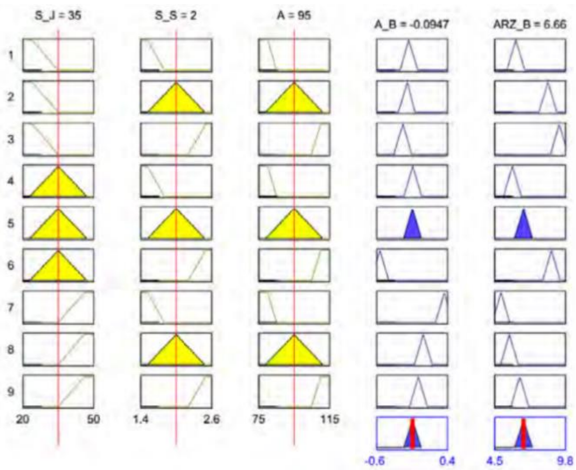

Figure 5. Graphical representation of the fuzzy inference to predict the thickness of the layer

non-fuzzy method of calculating the center of mass. After presenting and analyzing the experiments performed in this paper, the modeling of the results is investigated by the fuzzy region and the error rate of the method.

The experiments were performed in the same laboratory conditions based on Taguchi with different parameters. As can be seen in Figure 6, using the eye test, sample No. 7 is in a good condition with regard to cracks and surface cavities, and after polishing and grinding operations, it is selected as the desired part.

RESULTS AND DISCUSSION

Pass number effects

The microhardness of different welding zones in different number of passes is shown in Figure 7.

Figure 8 shows the anion model light microscope image of the welded sample from the desired sample cross section. Metallography was performed according to ASTM-E3-01 standard by polishing machine and to etch the structure of the samples, a solution containing 82 ml of alcohol and 18 ml of nitric acid was used. In turbulent friction stir welding process, the process is accompanied by severe deformation and increase in temperature, which causes dynamic recrystallization in the weld zone, changes in the microstructure of the turbulence zone, fuzzy deposits and coarse grains around the turbulence zone. In the present image, three regions of turbulence, the region affected by heat and the region affected by the thermomechanical process are formed. These three regions occur based on strain and thermal gradients during the process.

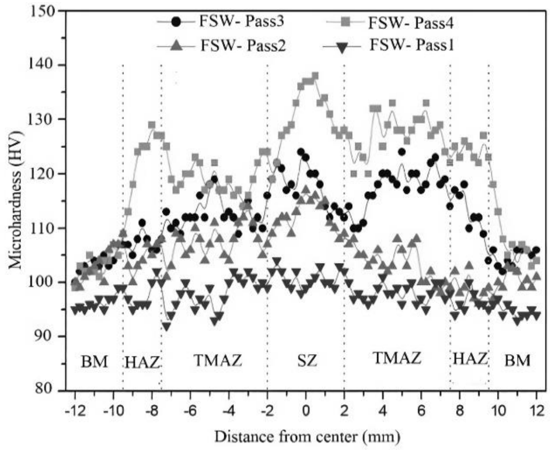

Figure 7. Microhardness of different welding zones in different number of passes

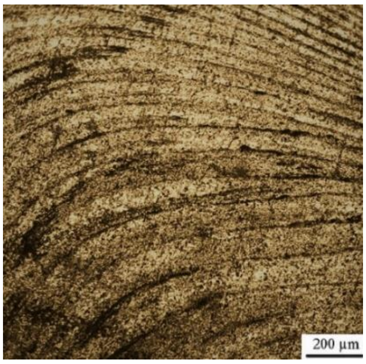

Figure 8. Light microscope image of the onion ring zone between the weld line zone and the thermodynamic zone

Mechanical properties

The test pieces were prepared according to ASTM E8-04 standard for tensile test and the test was performed at a constant speed of 1 mm/min and a strain rate of 0.003 at room temperature for all welded samples by the SANTAM STM-150 tensile machine of Semnan University. The comparison of experimental tensile test results with generated fuzzy model in terms of stress are illustrated in Figure 9. Also, comparison of experimental Vickers hardness test results from cross section with fuzzy model are depicted in Figure 10.

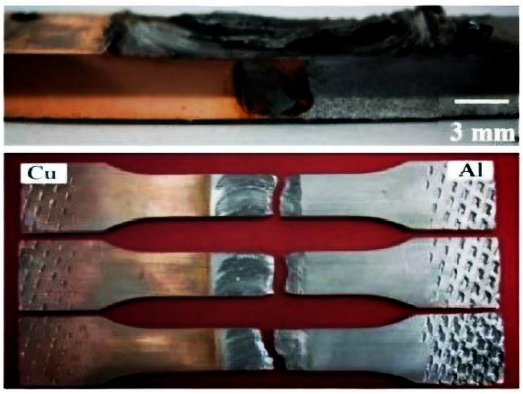

Figure 6. Optimal sample of weld number 7 after surface finishing operation

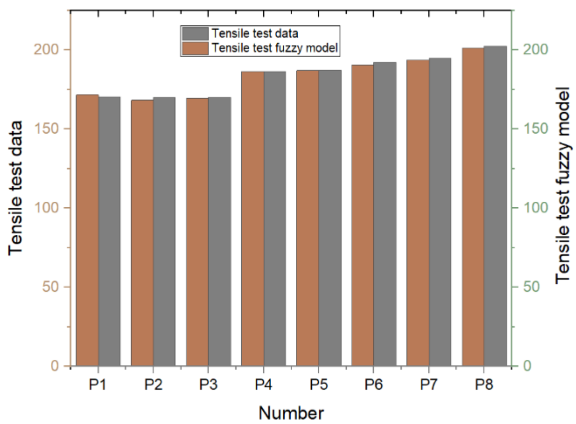

Figure 9. Comparison of experimental tensile test results with generated fuzzy model in terms of stress

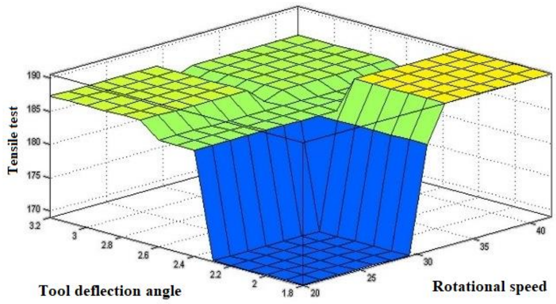

Figure 10. Comparison of experimental Vickers hardness test results from cross section with fuzzy model

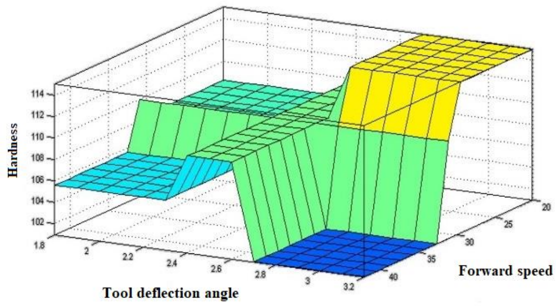

Figure 12. Comparison of Vickers hardness experimental cross-sectional results with fuzzy model

Hardness

The hardness of the welded sample is based on metallography according to ASTM-E384 standard by Vickers hardness test method by Bohler machine with a force of 250 g for 10 seconds. Hardness was measured at five points at a distance of 2 mm on the cross section of the welded sample. According to the experimental results, the amount of stiffness in the forward part is more than the backward part and the reason for this difficulty is the same in the forward side for the rotation and the speed of the tool, but in the backward side they work in the opposite direction. As a result, the heat generated by the leading side increases and the material removed by the tool undergoes a severe deformation in the turbulence region, which increases the driving force of dynamic recrystallization. As the driving force increases, there are more corrections on the forward side than on the backward, and the stiffness of the forearm increases.

Figure 11 shows the comparison of Vickers hardness experimental cross-sectional results with fuzzy model; while the comparison of Vickers hardness experimental cross-sectional results with fuzzy model are illustrated in Figure 12. The hardness results and tensile tests for several samples are summarized in Table 3.

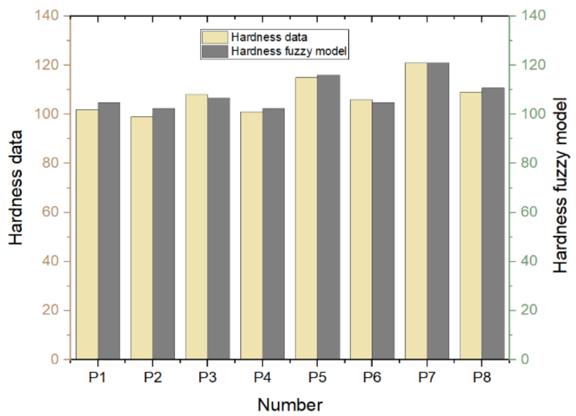

Figure 11. Comparison of Vickers hardness experimental cross-sectional results with fuzzy model

Table 3. Summary of Hardness results and tensile tests

Exp.	Hardness Results (Vickers)		Tensile test results (MPa)	
	Hardness data	Hardness fuzzy model	Tensile test data	Tensile test fuzzy model
P1	102	104.9	171.7	170.5
P2	99	102.5	168.3	169.9
P3	108	106.8	169.5	170.1
P4	101	102.3	186.5	186.6
P5	115	116.1	187	187.3
P6	106	104.9	190.5	192.2
P7	121	120.9	193.5	195
P8	109	110.8	201.3	202.5

CONCLUSION

In this study, the effect of sinking depth and tool retention time in the connection of 5000 aluminums alloy/ pure copper using the FSW welding method of the FSW was examined. The most important results of this research can be seen as follows Title:

1) The high quality of the appearance of the weld and the absence of depressions in Welding Surface The main advantage of using this method over Other methods are similar.

2) Increasing the parameters of the welding process increases the depth The tool is inserted into the part and the material is removed from the connection Which reduces the effective thickness of the top sheet.

3) An increase in the parameters increases the depth of the agitated zone and the length of the connection is due to the production of heat Friction as well as greater agitation of the material.

4) The maximum weld strength in this study is related to sample No. 8 is equal to 211 Newton's. This sample to reason for peripheral failure mode and proper connection in the joint has a high failure force.

5) Increase both parameters due to more heat generation and helps to grow seeds as well as sediments, reduce hardness is following.

6) Two situations of environmental failure and a common chapter in the samples were observed. Common chapter failures are common in samples with low process parameters occurred which could be due to lack of proper mixing in the common season.

ACKNOWLEDGMENTS

The authors are very much thankful to the unknown reviewers for their valuable and constructive suggestions which improved the readability of the paper.

FUNDING

The authors received no financial support for the research, authorship, and publication of this article.

REFERENCES

1. Rafiee, A., Nickabadi, S., Nobarian, M.A., Tagimalek, H., and Khatami, H., 2022. Experimental Investigation Joining Al 5083 and High-density Polyethylen by Protrusion Friction Stir Spot Welding Containing Nanoparticles using Taguchi Method. *International Journal of Engineering, Transactions C: Aspects*, 35(06), pp.1144–1153. Doi: 10.5829/ije.2022.35.03c.06
2. Ghazvinloo, H.R., 2020. Impact Energy of Weld Metal in CK45 Carbon Steel. *Iranian (Iranica) Journal of Energy and Environment*, 11(2), pp.152–156. Doi: 10.5829/IJEE.2020.11.02.09
3. Tagimalek, H., Maraki, M.R., Mahmoodi, M., Moghaddam, H.K., and Farzad-Rik, S., 2022. Prediction of mechanical properties and hardness of friction stir welding of Al 5083/pure Cu using ANN, ICA and PSO model. *SN Applied Sciences*, 4(4), pp.1–17. Doi: 10.1007/s42452-022-04989-y
4. El-Wazery, M.S., Mabrouk, O.M., and El-Sissy, A.R., 2022. Optimization of Ultrasonic-assisted Friction Stir Welded using Taguchi Approach. *International Journal of Engineering, Transactions A: Basics*, 35(01), pp.213–219. Doi: 10.5829/ije.2022.35.01a.20
5. Heidarzadeh, A., Testik, Ö.M., Güleryüz, G., and Barenji, R.V., 2020. Development of a fuzzy logic based model to elucidate the effect of FSW parameters on the ultimate tensile strength and elongation of pure copper joints. *Journal of Manufacturing Processes*, 53, pp.250–259. Doi: 10.1016/j.jmapro.2020.02.020
6. Heidarzadeh, A., Mironov, S., Kaibyshev, R., Çam, G., Simar, A., Gerlich, A., Khodabakhshi, F., Mostafaei, A., Field, D.P., Robson, J.D., Deschamps, A., and Withers, P.J., 2021. Friction stir welding/processing of metals and alloys: A comprehensive review on microstructural evolution. *Progress in Materials Science*, 117, pp.100752. Doi: 10.1016/j.pmatsci.2020.100752
7. Heidarzadeh, A., Saeid, T., Klemm, V., Chabok, A., and Pei, Y., 2019. Effect of stacking fault energy on the restoration mechanisms and mechanical properties of friction stir welded copper alloys. *Materials & Design*, 162, pp.185–197. Doi: 10.1016/j.matdes.2018.11.050
8. Tagimalek, H., Maraki, M.R., Mahmoodi, M., and Mohammad Zadeh, P., 2021. Investigation Experimental and Finite Element Method of Mechanical Properties of Hot Forging on Ti6Al4V Alloy. *Iranian (Iranica) Journal of Energy and Environment*, 12(2), pp.149–154. Doi: 10.5829/IJEE.2021.12.02.07
9. Karrar, G., Galloway, A., Toumpis, A., Li, H., and Al-Badour, F., 2020. Microstructural characterisation and mechanical properties of dissimilar AA5083-copper joints produced by friction stir welding. *Journal of Materials Research and Technology*, 9(5), pp.11968–11979. Doi: 10.1016/j.jmrt.2020.08.073
10. Aliha, M.R.M., Kalantari, M.H., Ghoreishi, S.M.N., Torabi, A.R., and Etesam, S., 2019. Mixed mode I/II crack growth investigation for bi-metal FSW aluminum alloy AA7075-T6/pure copper joints. *Theoretical and Applied Fracture Mechanics*, 103, pp.102243. Doi: 10.1016/j.tafmec.2019.102243
11. da Silva, R.M.P., Izquierdo, J., Milagre, M.X., Betancor-Abreu, A.M., de Oliveira, L.A., Antunes, R.A., Souto, R.M., and Costa, I., 2021. On the local corrosion behavior of coupled welded zones of the 2098-T351 Al-Cu-Li alloy produced by Friction Stir Welding (FSW): An amperometric and potentiometric microelectrochemical investigation. *Electrochimica Acta*, 373, pp.137910. Doi: 10.1016/j.electacta.2021.137910
12. Tagimalek, H., Maraki, M.R., Mahmoodi, M., and Azargoman, M., 2022. A Hybrid SVM-RVM Algorithm to Mechanical Properties in the Friction Stir Welding Process. *Journal of Applied and Computational Mechanics*, 8(1), pp.36–47. Doi: 10.22055/JACM.2019.31017.1811
13. Shehabeldeen, T.A., Elaziz, M.A., Elsheikh, A.H., and Zhou, J., 2019. Modeling of friction stir welding process using adaptive neuro-fuzzy inference system integrated with harris hawks optimizer. *Journal of Materials Research and Technology*, 8(6), pp.5882–5892. Doi: 10.1016/j.jmrt.2019.09.060
14. Kebria, I.A., and Hogland, W., 2019. Sustainable Storm Water Management by Predicting Climate Change Using Fuzzy Neural Network and GIS. *Iranian (Iranica) Journal of Energy and Environment*, 10(1), pp.65–71. Doi: 10.5829/IJEE.2019.10.01.10
15. Mathew, J., Griffin, J., Alamaniotis, M., Kanarachos, S., and Fitzpatrick, M.E., 2018. Prediction of welding residual stresses using machine learning: Comparison between neural networks and neuro-fuzzy systems. *Applied Soft Computing*, 70, pp.131–146. Doi: 10.1016/j.asoc.2018.05.01

Persian Abstract

چکیده

کامپوزیت مس/آلومینیوم به دلیل سبک بودن، رسانایی بهینه حرارتی و الکتریکی بسیار مهم و کاربردی است. نسبت مقاومت به وزن بالا، همراه با ویژگی‌های ذاتی، آن را برای کاربردهای نو جذاب می‌کند. در این راستا اخیراً استفاده از کامپوزیت‌های با خواص مکانیکی بالا افزایش چشمگیری داشته است. در این تحقیق نمونه آلومینیوم سری ۵۰۰۰ و مس خالص در پاس‌های ۱، ۲، ۳ و ۴ تحت فرآیند جوشکاری اصطکاکی اغتشاشی قرار گرفته و سپس خواص مکانیکی و متالورژیکی نمونه‌های جوش داده شده با نمونه‌های اولیه مقایسه شده است. به منظور مطالعه و بررسی بیشتر نتایج آزمون‌های کشش، متالوگرافی و میکروسختی سنجی انجام شده است. ارزیابی ریزساختاری نمونه‌های جوش داده شده نشان داد که ناحیه اختلاط نمونه‌ها با ترکیب لایه‌های آلومینیوم و مس تعیین شد. نتایج نشان‌دهنده افزایش استحکام تسلیم در ناحیه جوشکاری و در نهایت بهبود سختی و استحکام نهایی در ناحیه جوش نسبت به نمونه اولیه است. در مقایسه نمونه‌های کشیده شده، هر چه فاصله از ناگت جوش بیشتر باشد، بهبود خواص مکانیکی و ریزسختی به تدریج کمتر می‌شود. با تغییر پارامترها و افزایش دمای ورودی، عملیات اختلاط و پراکندگی یکنواخت ذرات به نحو مناسب‌تری انجام و درنهایت استحکام کششی را افزایش می‌دهد. در نهایت در پژوهش، داده‌های تجربی با استفاده از روش منطق فازی مدل‌سازی شده و با توجه به اینکه مدل ارائه شده در دو شاخص R-Sq(pred) و R-Sq (adj) به ترتیب ۹۵/۹۹٪ و ۹۸/۹۹٪ بدست آمد. مقایسه بین داده‌های تجربی و داده‌های مدل به بیان خطای قابل قبولی در داده‌های تجربی اشاره کرد.