Investigations on effect of FSP parameter on hybrid Mg MMC using Taguchi approach

Dr. Sujit Kumar Khuntia
College of Engineering Bhubaneswar, BPUT, Odisha, India

Abstract:

In this study, the stir casting method was used to create a hybrid aluminum composite with variable percentages of bagasse ash (4, 8, and 12 wt%) and a constant weight percentage of boron nitride (2 wt%). For the weldability analysis, the friction stir welding process was used. The welding speed and tool rotation speed are chosen as inputsparameter and the weld nugget's impact strength were chosen as the output response. The Taguchi method was used to plan the experiment and investigate how input parameters affect the final result.The results showed that an increase in the percentage of reinforcement showed negative trends on impact strength; tool rotation speed contributed significantly (48.5%) to the output response. The results of the ANOVA show that every input parameter significantly affects the output response.

1. Introduction

Metal matrix Composite materials are widely used in various industries due to its high strength to weight ration. Among them, aluminium based composite materials are mainly used in automobiles and aerospace application [1–4]. Aluminium based composite are fabricated by addition hard ceramic particles and solid lubricating materials such SiC, TiC, graphite, MoS2 etc. Addition of these reinforcement materials increases the basic and functional properties of base material without affecting its existing properties [5–9]. However usage of these reinforcement particles increase the fabrication cost of composite fabrication due its higher cost. To overcome this fact, agriculture waste such as rice husk ash, bagasse ash and industrial wastes such as rock dust and fly ash are used as reinforcements [10–15]. These agro wastes consist of silicon as the major constituents. In application point of view, developing larger size automobile component using composites; metal joining process is consider as the better way instead of using large size mould and dies. Generally squeeze casting and stir casting are followed to fabricate these composites [16–28]. Fusion welding processes are widely used in welding of metals and alloys. Conversely these processes have several problems like porosities, thermal stresses that reduce welding strength. To overcome this fact solid state welding processes such as Friction Stir Welding (FSW) are prefer in this joining of two metal take place by means of frictional force. Tool angle, tool rotational speed, axial force, welding speed, etc., are major parameters that govern strength of the welded materials. In order to attain high quality of welded joint. These control parameters must be optimized, since improper selection to control factor results in tool failure and reduce the welding quality and production timing. Advancement in computational technology results in formation various optimization methods such as ANN, Taguchi, RSM, PSO, ANFIS etc. usage of this optimization tools well assist in attaining proper control parameter with improved welding quality [29–32]. In this research, an attempt has been made to understand the weldability of aluminium composite. Aluminium based hybrid composite was developed by stir casting method and FSW process was adopted for weldability analysis. Tool rotational speed and welding speed was selected as input parameter and impact strength of weld nugget was selected as output parameter. Taguchi method was adopted for experiment plan and L9 orthogonal array was designed using the control factors.

2. Materials and method

2.1 Materials

The base material selected for developing the aluminium composite is aluminium 7075 which is known for its hardness and yield strength due to the existence of stronger precipitates in the material. The bagasse ash is prepared from the crushed sugar cane stems which are collected from the nearby sugarcane processing industries. The collected crushed sugarcane is kept in a furnace and the temperature is increased to burn. Then the ash is collected from the furnace and sieved to get uniform sized particles and to remove the unwanted particles. The secondary reinforcement Boron nitride is purchased from the marker directly.

2.2. Composite fabrication

The weight percentage of the bagasse ash is varied as 4, 8 and 12% in the aluminium matrix in the view of analysing the effect of reinforcement over the properties of aluminium matrix. As minimal as only 2% Boron nitride is added with the Al7075 as the soft nature of reinforcement will decrease the composite properties when it is added in higher amount. The fabrication methodology chosen in stir casting in which the small pieces of Al7075 material is kept in the furnace. Then the temperature is increased to 700℃ to melt the material completely [32]. On the other hand the primary and secondary reinforcements are preheated separately for a period of one hour at 200℃. Then the preheated reinforcements are added to the molten material and stirred continuously with the aid of mechanical stirrer to get uniform reinforcement distribution. Then the molten mixture is poured into the rectangular die with dimension of 100 x50x8 mm to attain hybrid composite.

2.3. Friction stir welding of developed hybrid composite

Weldability behaviour of hybrid composite was studied with the help of Friction stir welding. CNC milling machine was used for Friction stir welding process. FSW tool was made up of D2 tool steel material that consist of two major parts namely pin and shoulder; the diameter of pin is 6 mm. Tool rotation and welding speed are the major influencing parameter for FSW process. Hence these two parameter are selected as input control factor. Taguchi method was selected to study the influence of input parameter over output response. Herein L9 orthogonal array was selected with varying input parameters viz. reinforcement weight %, tool rotation speed and welding speed. Impact strength was selected as output response.Since toughness was consider as major phenomenon to infer the property of welding joint; larger is better criteria is selected. The adopted control parameter was depicted.

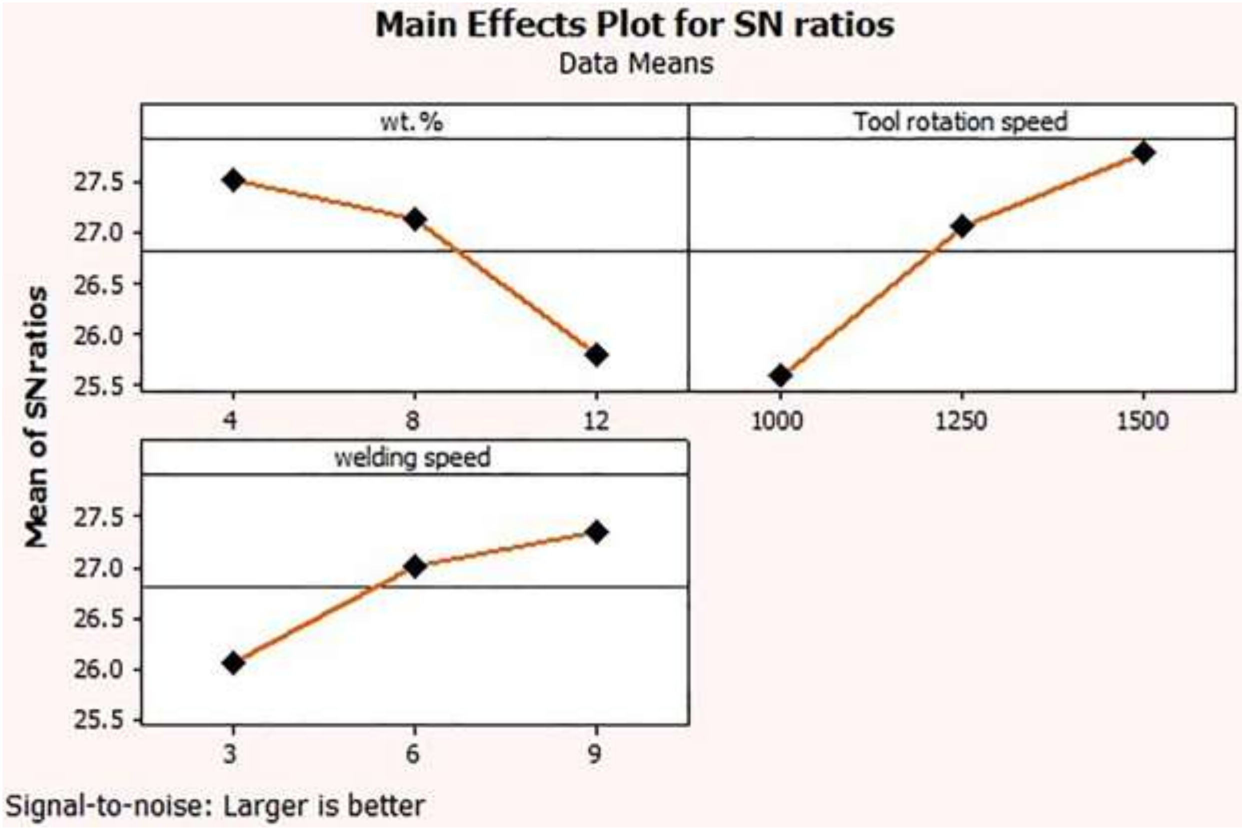

Fig. 1. Main effect plot for Impact strength.

output response and signal to noise ratio values are depictedFig. 1 depicts the influence of input parameter over toughness of the weld joints. It can be notified that increase in reinforcement decreases the toughness of the welding joints. This fact might be the brittle nature of reinforcement particles; increase in reinforcement percentage results in clustering effect near the weld zone this result in formation of void and porosities that reduces the impact strength. Addition of hard ceramic particles reduces ductility near welded zones and reduces the energy absorbing efficiency near weld joint that reduces the fracture toughness of composite joints. In FSW process tool rotation speed was consider as important factor since the heat generation near weld zone are control by tool rotation speed. From Fig. 1 it can be observed that increment in tool speed increase the impact strength of weld joint. In general phenomenon, increase in tool rotation speed increase the heat generation near weld zone that increases the turbulent flow of material that result in coarse grain formation. Conversely in the case of composite material presence of hard reinforcement reduce the chance of coarse grain formation and form fine grain structure near the weld joint thus increase the impact strength. From Fig. 1 it can notify that

Increase in welding speed increase the impact strength of welded joint. Increase in welding speed increase the contact surface between tool and weld material that results in lower heat input near stir zone this fact increase the coarse grain structure formation near weld zone however in case of composite material presence of hard reinforcements particles reduce the coarse grain formation and maintain the proper heat distribution near the stir zone thus improves the impact strength [10,11]. it can be observed that tool rotation speed act as the major parameter in controlling the impact strength of thewelded joint. Reinforcement weight percentage act as second influencing factor and welding speed have low influence on tensile strength of weld joints of composite material. Optimal parameter can be obtain for main effect plot herein lower reinforcement percentage with higher tool rotational speed and welding speed is the optimal parameter for better impact strength. Herein P value less that 0.05 was considered as the significant parameters. From table 4 it can be depicted that all the input parameter have significant over output response. It is also observed that tool rotation speed have major contribution of 48.5% on impact strength, followed by reinforcement percentage with 32.1% of contribution and welding speed have least contribution percentage of 19.2%. These results are well augmented with mean response table which depicts that welding speed have low influence over output response [29,30].

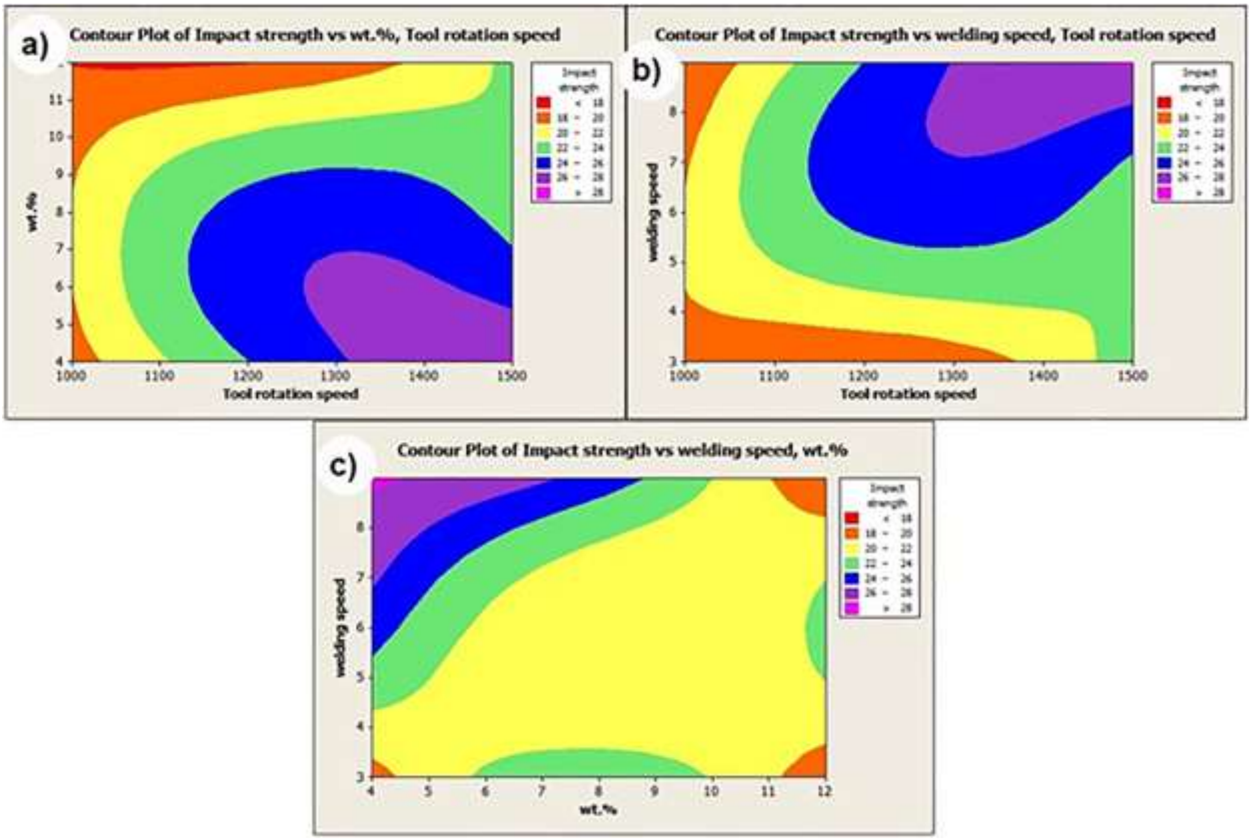

Fig. 2. Contour plot of impact strength with respect to: a) wt. % & tool rotation speed b) Tool rotation speed & welding speed c) wt. % & welding speed.

2.4. Combinational effect of input parameter over impact strength

Fig. 2a depict the influence of reinforcement weight percentage and tool speed over the output response, pink region indicates the maximum impact strength region; green depicts the optimal region and red region implies lower impact strength. It can be found that optimal region lies in middle region that implies the medium tool rotation speed and reinforcement percentage giveoptimal impact strength [33–36]. Fig. 2b display the combined effect of tool rotational speed and welding speed over impact strength of the composite joints. Contour plot depict that lower tooling speed with welding speed of 6 mm/min is the optimal parameter for output response. From Fig. 2 c in can be notified that higher welding speed ad reinforcement percentage give optimal tensile strength for welded nugget.

3. Conclusion

The hybrid aluminum composite was subjected to the friction stir welding process, and the following findings are reported:

1. The impact strength is lessened when the percentage of reinforcement is increased.

2. The main factor influencing output response is the tool's rotational speed.

3. The impact strength of welding is less affected by welding speed.

4. The ideal parameter for the output parameter is 3 weight percent of reinforcement with 1500 rom of tool rotation speed and 9 mm/min of welding speed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] K. Soorya, Prakash, R. Sathiya, Moorthy, P.M. Gopal, V. Kavimani, Effect of reinforcement, compact pressure and hard ceramic coating on aluminium rock dust composite performance, Int. J. Refract Met. Hard Mater. 54 (2016) 223–229, https://doi.org/10.1016/j.ijrmhm.2015.07.037.

[2] K.S. Prakash, P.M. Gopal, M. Purusothaman, M. Sasikumar, Fabrication andcharacterization of metal-high entropy alloy composites, Int. J. Met. (2019) 1–9.

[3] P. Senthil Kumar, V. Kavimani, K. Soorya Prakash, V. Murali Krishna, G.Shanthos Kumar, Effect of TiB2 on the Corrosion Resistance Behavior of In SituAl Composites, Int. J. Met. 14 (2020) 84–91, https://doi.org/10.1007/s40962-

[4] S.P. Kumarasamy, K. Vijayananth, T. Thankachan, G. Pudhupalayam Muthukutti, Investigations on mechanical and machinability behavior of aluminum/flyash cenosphere/Gr hybrid composites processed throughcompocasting, J. Appl. Res. Technol. 15 (2017) 430–441, https://doi.org/ 10.1016/j.jart.2017.05.005.

[5] V. Kavimani, K. Soorya Prakash, T. Thankachan, R. Udayakumar, Synergistic improvement of epoxy derived polymer composites reinforced with Graphene Oxide (GO) plus Titanium di

oxide(TiO2), Compos. Part B Eng. 107911 (2020), https://doi.org/10.1016/j.compositesb.2020.107911.

[6] V. Kavimani, K. Soorya Prakash, M. Arun Pandian, Influence of r-GO addition on enhancement of corrosion and wear behavior of AZ31 MMC, Appl. Phys. A Mater. Sci. Process 123 (2017) 514, https://doi.org/10.1007/s00339-017-1118-8.

[7] V. Kavimani, K.S. Prakash, M.S. Starvin, B. Kalidas, V. Viswamithran, S.R. Arun,Tribo-Surface Characteristics and Wear Behaviour of SiC@r-GO/Mg Composite Worn under Varying Control Factor, Silicon 12 (2020) 29–39, https://doi.org/10.1007/s12633-019-0095-2.

[8] V. Kavimani, K. Soorya Prakash, T. Thankachan, Surface characterization andspecific wear rate prediction of r-GO/AZ31 composite under dry sliding wearcondition, Surf. Interfaces 6 (2017) 143–153, https://doi.org/10.1016/j.surfin.2017.01.004.

[9] V. Kavimani, K. Soorya Prakash, T. Thankachan, Investigation of graphenereinforced magnesium metal matrix composites processed through a solventbased powder metallurgy route, Bull. Mater. Sci. 42 (2019) 39, https://doi.org/ 10.1007/s12034-018-1720-1.

[10] K. Soorya Prakash, P.M. Gopal, V. Kavimani, Effect of rock dust, cenosphere and E-waste glass addition on mechanical, wear and machinability behaviour of Al 6061 hybrid composites, Indian J. Eng. Mater. Sci. 24 (2017) 270–282.

[11] S. Karthik, K.S. Prakash, P.M. Gopal, S. Jothi, Influence of materials and machining parameters on WEDM of Al/AlCoCrFeNiMo0. 5 MMC, Mater. Manuf. Process. 34 (2019) 759 768.

[12] P.M. Gopal, K.S. Prakash, S. Nagaraja, K. Aravinth, Effect of weight fraction and particle size of CRT glass on the tribological behaviour of Mg-CRT-BN hybrid composites, Tribol. Int. 116 (2017) 338–350, https://doi.org/10.1016/j. triboint.2017.07.025.

[13] P.M. Gopal, K. Soorya Prakash and SJ. WEDM of Mg/CRT/BN Composites: Effect of Materials and Machining Parameters. Mater Manuf Process 2017. https://doi.org/10.1080/10426914.2017.1279316.

[14] P.M. Gopal, Wire Electric Discharge Machining of Silica Rich E-waste CRT and BN Reinforced Hybrid Magnesium MMC, Silicon (2018) 1–12.

[15] K. Hamsavathi, K.S. Prakash, V. Kavimani, Green high strength concrete containing recycled Cathode Ray Tube Panel Plastics (E-waste) as coarse aggregate in concrete beams for structural applications, J. Build. Eng. 30 (2020), https://doi.org/10.1016/j.jobe.2020.101192 101192.

[16] Samson Jerold Chelladurai, Samuel,, Ramesh Arthanari, Nisaanthakumar Nithyanandam, Karthikeyan Rajendran, and Kesavaprasad KothandapaniRadhakrishnan. Investigation of mechanical properties and dry sliding wear behaviour of squeeze cast LM6 aluminium alloy reinforced with copper coated short steel fibers, Trans. Indian Inst. Met. 71 (4) (2018) 813–822.

[17] Chelladurai, Samson Jerold Samuel, Ramesh Arthanari, ArunprasadNarippalayam Thangaraj, and Harishankar Sekar. Dry sliding wear characterization of squeeze cast LM13/FeCu composite using response surface methodology. China Foundry 2017; 14 (6): 525-3.

[18] Chelladurai, Samson Jerold Samuel, Ramesh Arthanari, Kirubaharan Krishnamoorthy, Kamal Shankar Selvaraj, and Prabu Govindan. Effect of copper coating and reinforcement orientation on mechanical properties of LM6 aluminium alloy composites reinforced with steel mesh by squeezecasting. Trans Indian Inst Met 2018; 71(5): 1041-8.

[19] Chelladurai, Samson Jerold Samuel, and Ramesh Arthanari. Investigation on mechanical and wear properties of zinc-coated steel wires reinforced LM6 aluminium alloy composites by squeeze casting. Surf Rev Lett 2019; 26 (01): 1850125.

[20] Chelladurai, Samson Jerold Samuel, and Ramesh Arthanari. Effect of stir cast process parameters on wear behaviour of copper coated short steel fibers reinforced LM13 aluminium alloy composites. Mater Res Express 2018; 5(6): 066550.

[21] Chelladurai, Samson Jerold Samuel, Ramesh Arthanari, Rohith Selvarajan,Sujeevan Athanarsamy, Satheshkumar Arumugam, and Gajendhiran Veerakumar. Investigation on mechanical properties and wear behaviour of squeeze cast LM13 aluminium alloy reinforced with copper coated steel wires. Zeitschrift für Physikalische Chemie 2018; 232 (12): 1787-6.

[22] Chelladurai, Samson Jerold Samuel, Ramesh Arthanari, Rohith Selvarajan, Ramakrishnan Kanagaraj, and Palanisamy Angappan. Investigation on microstructure and tensile behaviour of stir cast LM13 aluminium alloy reinforced with copper coated short steel fibers using response surface methodology. Trans Indian Inst Met 2018; 71 (9): 2221-0.

[23] Selvaraj, Kamal Shankar, and Prabu Govindan. Investigation of the mechanical properties of a squeeze-cast LM6 aluminium alloy reinforced with a zinccoated steel-wire mesh. Materiali in tehnologije 2018; 52, (2): 125-1.

[24] Chelladurai, Samson Jerold Samuel, Ramesh Arthanari, Rohith Selvarajan, Thirumal Prasanna Ravichandran, Saravana Kumar Ravi, and Siva Rama Chandran Petchimuthu. Optimisation of dry sliding wear parameters of squeeze cast AA336 aluminium alloy: copper-coated steel wire-reinforced composites by response surface methodology. Int J Metalcast 2019; 13(2): 354-6.

[25] S.J.S. Chelladurai, T. Murugesan, T. Rajamani, S. Anand, S.J.P. Asok, S. Kumaravel, Investigation on mechanical properties and tribological behaviour of stir cast LM13 aluminium alloy based particulate hybrid composites, Materialwiss Werkstofftech 50 (7) (2019) 864–874.

[26] S.J.S. Chelladurai, R. Arthanari, Prediction of hardness of stir cast LM13 aluminum alloy-copper coated short steel fiber reinforced composites usingresponse surface methodology, Materialwiss Werkstofftech 51 (2) (2020) 221–229.

[27] C. Saravanan, S. Dinesh, P. Sakthivel, V. Vijayan, B.S. Kumar, Assessment of mechanical properties of Silicon Carbide and Graphene reinforced aluminium composite, Mater. Today Proc. 21 (2020) 744–747.

[28] Sathish T, Chandramohan D, Vijayan V, Sebastian PJ. Investigation on Microstructural and Mechanical Properties of Cu Reinforced with Sic Composites Prepared by Microwave Sintering Process Investigation on Microstructural and Mechanical Properties of Cu Reinforced with Sic Composites Prepared by Microwave Sintering Process.

[29] V. Kavimani, K. Soorya Prakash, T. Thankachan, Multi-objective optimization in WEDM process of graphene – SiC-magnesium composite through hybrid techniques, Meas J. Int. Meas. Confed. 145 (2019) 335–349.

[30] V. Kavimani, K.S. Prakash, T. Thankachan, Influence of machining parameters on wire electrical discharge machining performance of reduced grapheneoxide/magnesium composite and its surface integrity characteristics, Compos. Part B Eng. 167 (2019) 621–630.

[31] V. Kavimani, K.S. Prakash, Doping Effect of SiC over Graphene on Dry Sliding Wear Behaviour of Mg/SiC@r-GO MMCs and its Surface Characterization, Silicon 10 (2018) 2829–2843, https://doi.org/10.1007/s12633-018-9823-2.

[32] A. Baradeswaran, A.E. Perumal, Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites, Compos. Part B Eng. 56 (2014) 464– 471.

[33] A.D. Das, Effect of GTAW Welding Parameters on Mechanical Properties of Aluminium Six-Series Welded Samples, J. Adv. Res. Dyn. Control Syst. 11 (2019) 1112–1118, https://doi.org/10.5373/JARDCS/V11SP12/20193317.

[34] R. Karuppasamy, A. Daniel Das, Investigations on Mechanical Properties of Squeeze Casted Al MMC Reinforced with TIC and BN, J. Adv. Res. Dyn Control Syst. 11 (2019) 1086–1092, https://doi.org/10.5373/JARDCS/V11SP12/ 20193313.

[35] A.D. Das, Effect of TIG welding parameters on mechanical properties of Al6063 welded samples, J. Adv. Res. Dyn. Control Syst. (2019;11.), https://doi.org/

10.5373/JARDCS/V11SP12/20193318.

[36] A. Daniel Das, K. Thirunavukkarasu, Multi Criteria Decision Making Investigation on Friction Welded Samples of Boiler Grade Materials using Topsis Method, Test Eng. Manag. 83 (2020) 15293–15299.