ISSN 1392–1320 *MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 25, No. 4. 2019*

Effect of Stir Casting Process Parameters on Properties of Aluminium Composites – Taguchi's Analysis

Hemalatha ARIHARAPUTHIRAN [1] *, Dhanalakshmi VENKADASAMY [2]

[1] *K.L.N. College of Engineering, Pottapalayam – 630612, Tamilnadu, India*
[2] *Thiagarajar College of Engineering, Madurai – 625015, Tamilnadu, India*

crossref http://dx.doi.org/10.5755/j01.ms.25.4.20864

Received 31 May 2018; accepted 11 October 2018

The need for lightweight materials in various industries, increased fuel price, requirement of improved mechanical, thermal properties leads to the development of aluminium metal matrix composites. Stir casting method is employed for preparing composite consisting of aluminium die casting -12 alloy and reinforcement of 10 % by weight proportion of silicon carbide. Taguchi's experimental analysis is employed for varying the process parameters of stir casting method like process temperature, stirring time and stirring speed. Tests were conducted to measure mechanical property like compressive strength, wear property such as sliding wear, micro abrasion and thermal property like coefficient of thermal expansion. An attempt has been made to study the unrelated properties like compressive strength, sliding wear resistance, micro abrasion wear and coefficient of thermal expansion of aluminium composites by Principal Component Analysis method. The experimental investigation shows that increase in processing temperature reduces sliding wear, micro abrasion wear and coefficient of thermal expansion and also increases compressive strength.

Keywords: aluminium composites, process parameters, compressive strength, sliding wear, micro abrasion, coefficient of thermal expansion, principal component analysis.

1. INTRODUCTION

Aluminium based metal matrix composites have been developed since nineteenth century and find applications in sports goods, aerospace, automotive components, medical industries and electrical housings. An important innovation in the development of composites is the possibility of introducing required mechanical, chemical and thermal properties by the proper composition of the constituent materials. Aluminium alloys are most desired base matrix material due to its better corrosion resistance, increase in strength by precipitation, good electrical and thermal conductivity. The reinforcement in the base aluminum metal determines the mechanical properties of the composites. Silicon carbide proves to be a better reinforcement [1] among various commercially available materials because of its higher strength, lower coefficient of thermal expansion, better wear resistance at higher working temperatures. Homogeneous mixture of base metal and reinforcement particles plays an important role in the development of required properties of composites. For proper dispersing of the reinforcement particles, suitable method must be chosen for producing homogeneous mixture of reinforcement and the matrix. Stir casting is a continuous stirring of the molten matrix metal and the reinforcement particles by a mechanical stirrer for producing a homogeneous mixture. Clustering of the reinforcement particles are because of lesser surface energy, segregation of particles, chemical binding. Preheating of the reinforcement for a longer period of time has increased the chemical bonding [2]. The microstructure of the composite showed that the heavier particles settle more quickly [3].

Particle clustering of A384 alloy with 10 % weight of SiC of size 64 µm is observed and noted that it occurred at a stirrer speed of 500 rpm by Karthiresan on 2006 [4].

Addition of magnesium, preheating of ceramic particles, introducing ultrasonic vibration in the stirring process when the metal is in the semisolid state will provide better wettability of Al-SiC composites [5]. Bending strength and hardness resistance of the composite found to be decreased with the increase in the particle size of SiC in which the composite was prepared by dual ceramic powder made of SiC and alumina [6]. Optimization of circularity, surface roughness, tool wear rate, metal removal rate, simultaneously was carried out by Debaprasanna Puhan on 2013 [7]. An in-situ process was developed for the preparation of multi-component reinforced composite and Taguchi method was used for optimizing the properties like density, porosity and hardness [8]. A multi-input and multi-output model by using a Neural Networks-Levenberg Marquardt Algorithm (NN-LMA) was created and predicted the mechanical properties of Al-TiB_2composites [9]. Singh and Chauhan [10] reviewed the influence of the mechanical parameters and the material factors on the wear performance of Al-composites. The material and technological aspects for the production of composite suspensions for industries was presented by Dolata on 2012 [11]. The optimum machining conditions for minimum surface roughness through Taguchi's technique and genetic algorithm was determined and verified the results with confirmation experiments [12]. The influence of turning parameters on surface roughness of aluminium, silicon carbide and fly ash composite was studied by Baburaj on 2016 [13]. Stir casting

* Corresponding author. Tel.: +91-9047382541.
E-mail address: *ahemalatharamesh@gmail.com* (A. Hemalatha)

process parameters for the preparation of Al6061 alloy with reinforcements like SiC, graphite, alumina are studied by Rajesh Kumar on 2013 [14]. The number and the angle of blades are determined and the suitable process temperature was found for good wettability. Computational as well as experimental analysis was done for Al-SiC composite for the process parameters like stirrer speed, processing period, reinforcement size for two different viscosity levels to produce uniform distributions [15]. Effect of stirrer blade angle, stirring speed, direction of stirring and baffles are investigated and optimized by water model [16]. Tensile and density properties were studied for the same composite by neural network modeling [17]. The effect of speed and time of the stirrer on tribology of the prepared composite material was investigated by Bala Sivanandhaprabu on 2006 [18]. Wear resistance properties of aluminium alloy 7075 metal matrix composites studied by response surface methodology and Taguchi's analysis [19]. Variations of process temperature and stirring time caused changes in mechanical properties of the produced composite [20]. Thakur and Nandedkar [21] analyzed using Taguchi method the influence of process parameters on mechanical strength of austenitic stainless steel AISI 304 prepared by resistance spot welding. Thakur et al., [22] investigated the tensile strength for galvanized steel by Taguchi's method. Experiments were conducted using L9 orthogonal array of Taguchi method by varying die squeezing pressure, mould temperature and duration of pressure application and tensile strength and hardness of the alloy is analyzed using GA [23]. Hemalatha and Dhanalakshmi [24] studied the influence of stir casting process parameters on compressive strength and wear resistance of aluminium composites. Taguchi's method along with Principal component analysis method is used to determine the optimal process conditions.

Numerous research works have been carried out in the preparation of aluminium metal matrix composites reinforced with different materials at different proportions by stir casting process. From the above studies, it is observed that poor distribution of the reinforcement particles can be avoided by adopting proper process parameters of the stir casting process. Still there is a need for research to study the influence of stir casting process parameters on the properties like compressive strength, sliding wear resistance, micro abrasion wear and coefficient of thermal expansion. There is rarity of articles addressing the determination of optimal process parameters affecting the above properties.

The objective of this research work is to prepare aluminium composite with reinforcement of 10% weight of SiC by stir casting process by varying the process parameters like stirring speed, stirring temperature and stirring time and study the properties like compressive strength, sliding wear resistance, micro abrasion wear and coefficient of thermal expansion. And also it aims at the determination of the optimum process parameters by Taguchi's method and Principal Component analysis.

2. EXPERIMENTAL DETAILS

The aluminium alloy ADC-12 is chosen as the base metal matrix in this research work. The chemical composition of ADC-12 is tested in laboratory of Indusrite metals, Chennai and it is shown in Table 1.

Table 1. Chemical composition of ADC-12

Element	Si	Fe	Cu	Mn	Mg	Zn	Ni	Sn	Al
Weight %	12	1.3	3.5	0.5	0.3	1	0.5	0.2	80.7

Addition of SiC as reinforcement material to the base matrix increases the modulus, abrasive wear resistance strength, and thermal stability of the composite [1], [10]. The properties of silicon carbide were tested in the Laboratory report from Madras metallurgical services pvt ltd., and were shown in Table 2.

Table 2. Properties of silicon carbide

Density	3.22 g/cm³
Melting point	2973 ºC
Coefficient of thermal expansion	4 μm/mºC
Thermal conductivity	126 W/mK
Young's modulus	410 GPa

Balasivanandhaprabu [18] analyzed the process parameters such as stirring speed and stirring time for improvement of mechanical properties of the composites. Sozhamannan [20] considered processing temperature and stirring time for the study of mechanical properties. An attempt has been made in this research work to correlate mechanical and thermal properties by considering the following process parameters for the experimental analysis: stirring speed, stirring time, process temperature.

Taguchi's method is used for determining the experimental conditions which reduces the number of iterative experiments, experimental cost and testing time for the required design.

Three levels for each factor are taken into account.

Nine Specimens are prepared using Taguchi's OA9 orthogonal array design consisting of 9 combinations of process parameters. According to the Taguchi's design methodology, three factors without interaction are considered in three levels.

Table 3 shows the experimental conditions for the preparation of composites.

Table 3. Experimental design of composite preparation

Experimental factors	Level 1	Level 2	Level 3
Stirring speed, Rpm	400	500	600
Stirring time, min	5	10	15
Processing temperature, °C	700	750	800

Composite specimens as shown in Fig. 1 were prepared using Stir casting apparatus. The electrical induction furnace of the Stir casting apparatus is heated to 500 ºC. A kg of aluminium ADC-12 is taken in the crucible which is placed in the electrical induction furnace. Reinforcement (SiC) in the form of powder is preheated to 800 ºC separately in the muffle furnace. The furnace temperature is raised to the experimental temperature slowly. Flux of 5 gm is added to remove the impurities and degasser of 5 gm is added to remove the dissolved gases in molten metal. The stirrer is placed at 1/3rd of its total height from the top of the crucible as shown in Fig. 2 and the stirring speed is raised to the required value.

Fig. 1. Specimen S1 prepared by stir casting

Fig. 2. Stir casting apparatus with stirrer at 1/3rd height

Fig. 3. Die of Ø50 × 250 mm

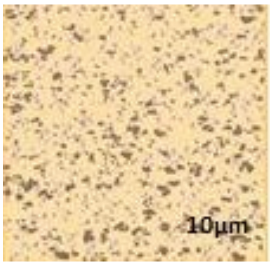

Fig. 4. Microstructure at ×50

Fig. 5. Specimen after compression

Distribution of preheated SiC into the molten aluminium alloy is carried out. The alloy and SiC powder are mixed together for the designed time period.

The stirrer is brought to ideal condition and the metal in the molten state is poured into the die of dimension 50 mm diameter and 250 mm length as shown in Fig 3 and compressed at pressure of 127 MPa. The microstructure of the specimen 1 is shown in Fig 4.

3. TESTING OF PROPERTIES

The test results are shown in Table 4. The wear tests are conducted as per ASTM G99. The specimen dimensions are of diameter 10 mm and length of 25 mm. The wear rate is measured with the help of pin on disc wear testing machine (Model: Wear and Friction Monitor TR20, DUCOM) as dry test at 400 rpm, 20 N for 475 seconds [19].

The compression strength is measured using compression testing machine (PCTE UTM 4131). The machine has data acquisition system auto instrument series 2005 to acquire data from the load cell and the displacement measuring device. The compressive strength tests are conducted on these samples according to the ASTM – E9-95. The specimen dimensions are of diameter 15 mm and length 20 mm. The compressed sample specimen is shown in Fig 5.

Micro-abrasion wear volume is measured with a micro-abrasion tester (Wear and Friction Tech Ltd., Chennai) as dry test for 300 seconds, 6 N and 200 rpm. The specimens are prepared for 24 mm diameter and 12 mm thickness. The testing ball is made of high carbon high chromium steel of 25 mm diameter.

Coefficient of thermal expansion of the prepared specimen is measured by hytherm computerized dilatometer between the temperature range of 27 °C to 500 °C. The dimensions of the specimen are 10mm Diameter and 45 mm length.

4. DISCUSSION

Principal Component Analysis (PCA) method is applicable to solve a multi response optimization problem with uncorrelated quality attributes. The response correlations that exist between the responses are eliminated by PCA to evaluate uncorrelated quality indices called principal components. The data is reduced to minimum number of dimensions without any information loss. Chintan Kayastha and Jaivesh Gandhi [25] optimized the turning process parameters of copper by using PCA and Taguchi's method. Narinder [26] employed a combination of Taguchi-GRA-PCA for optimization of wear behavior of Aluminium composites. Mihir Patel [27] utilized PCA with Taguchi's analysis for optimization of CNC TC parameters. Hemalatha et al [24] followed the Principal Component Analysis method for optimizing the stir casting process parameters such as stirring speed, stirring temperature and stirring time for increased compressive strength and reduced wear.

The procedure followed in Principal Component Analysis is:

Step 1: Data Collection. Experimental test results are collected by measuring the properties of the composite specimens and shown in Table 4.

Step 2: Data Normalization. Experimental data are normalized and shown in Table 5.

Higher the better is chosen for compression strength:

$$Xi*(k) = \frac{Xi(k)}{maxXi(k)}. \quad (1)$$

Lower the better is chosen for Sliding wear resistance, Micro abrasion wear volume, coefficient of thermal expansion:

$$Xi*(k) = \frac{minXi(k)}{Xi(k)}, \quad (2)$$

where i = 1, 2, … m; j = 1, 2, … n; m is the number of experimental runs in Taguchi's OA design; n is the number of quality characteristics; $Xi(k)$ is the normalized data of the k^{th} element in the i sequence.

Step 3: Determination of correlation coefficient array
Step 4: Calculation of Eigen vectors and Eigen values
Step 5: Evaluation of principal components (PC).

In order to eliminate response correlations, Principal component analysis has been applied to derive two independent quality indices called principal components. The independent quality indices are denoted as PC1, PC2, PC3 and PC4. Table 5 shows the values of these independent principal components for 9 experimental runs.

Signal to Noise ratio is used for obtaining the maximum value of Multi Performance Index (MPI). "Larger the better" is selected as the quality characteristics. The process parameters of Stir casting process having greater influence in the performance characteristics are determined by Analysis of Variance (ANOVA).

Table 4. Measured properties for nine specimens

Specimen No.	Operating condition			Sliding wear resistance, microns	Compression strength, MPa	Wear volume, mm³	Coefficient of thermal expansion, µm/K
	Stirring speed, rpm	Stirring time, min	Process temperature, °C				
S1	400	5	700	0.000113	292	0.024129	2.30E-05
S2	400	10	750	0.000299	312	0.01144	2.04E-05
S3	400	15	800	0.000382	294	0.003262	2.37E-05
S4	500	5	750	0.000376	292	0.022382	2.19E-05
S5	500	10	800	0.000226	277	0.006904	2.08E-05
S6	500	15	700	0.000238	206	0.009521	2.26E-05
S7	600	5	800	0.000151	297	0.001476	2.30E-05
S8	600	10	700	0.000459	250	0.009268	2.15E-05
S9	600	15	750	0.000254	224	0.020731	1.94E-05

Table 5. Calculation of normalized data, principal components, MPI and S/N ratio

Specimen No.	Normalized data				Principal component				MPI	S/N ratio
	Sliding wear resistance, microns	Compression strength, MPa	Wear volume, mm³	Coefficient of thermal expansion, µm/K	PC 1	PC 2	PC 3	PC 4		
1	1	0.935897	0.061171	0.843478	0.214	0.039	– 0.527	– 0.733	– 0.25175	– 12.479
2	0.377926	1	0.129021	0.95098	0.379	0.009	0.083	– 0.156	0.07875	– 12.428
3	0.295812	0.942308	0.452483	0.818565	0.318	– 0.551	0.401	– 0.195	– 0.00675	– 9.996
4	0.300532	0.935897	0.065946	0.885845	0.378	0.562	0.094	– 0.152	0.2205	– 12.456
5	0.5	0.887821	0.213789	0.932692	0.383	– 0.435	– 0.012	– 0.023	– 0.02175	– 10.848
6	0.47479	0.660256	0.155026	0.858407	0.371	– 0.061	– 0.127	0.316	0.12475	– 11.599
7	0.748344	0.951923	1	0.843478	0.079	0.159	0.704	– 0.334	0.1125	– 5.489
8	0.246187	0.801282	0.159258	0.902326	0.372	0.401	0.161	0.168	0.2755	– 13.638
9	0.444882	0.717949	0.071198	1	0.371	0.009	– 0.091	0.371	0.165	– 15.775

In this study, Minitab Software Version 18 is used for developing general linear model ANOVA "Larger the better" is chosen for determining the influence and optimum conditions of process parameters.

The MPI and S/N ratio values are calculated and tabulated in Table 5. General linear model ANOVA identifies the optimum process parameters for the given experimental responses. The results obtained using Minitab 18 software is shown in Table 6.

Table 6. Analysis of variance for principal component

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Stirring speed	2	12.082	12.082	6.041	0.19	0.540
Stirring time	2	3.884	3.884	1.942	0.06	0.642
Processing temperature	2	176.793	176.793	88.397	2.79	0.025
Error	2	63.426	63.426	31.713		
Total	8	256.186				
S = 0.0976 R-Sq = 98.56% R-Sq (adj) = 97.23%						

Table 7. Response table for means

Level	Speed	Time	Temp
1	0.6506	0.7144	0.5915
2	0.5726	0.5918	0.5733
3	0.6572	0.5743	0.7156
Delta	0.0847	0.1401	0.1423
Rank	3	2	1

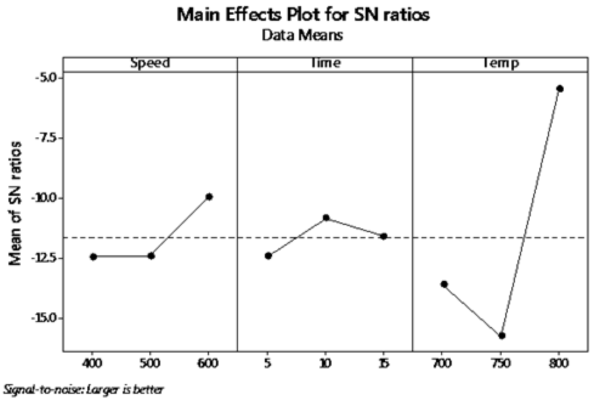

Fig. 6. Speed, time, temperature plot for S/N ratio

From the Response table and ANOVA for principal components shows that at significant level of 5 %, the process parameter namely Process temperature is significant parameter on compressive strength, sliding wear resistence, micro abrasive wear resistance and Coefficient of Thermal expansion. The other process parameters such as stirrer speed and stirring time are found to be insignificant from ANOVA for the above mentioned four properties.

From speed, time, temperature plot for S/N ratio, it is observed that the optimal process parameters for the stir casting process in the preparation of ADC-12 alloy with 10 % SiC composite are stirring speed 600 rpm, stirring time 10min and processing temperature 800 ºC. After applying the optimal setting of process parameters, confirmation test was carried out to validate the analysis. The improvement of the compressive strength from the initial condition to the multi optimal condition is about 10% and reduced sliding wear, micro abrasive wear approximately 9 % and coefficient of thermal expansion approximately 7 % from individual optimal condition.

5. CONCLUSION

Aluminium Composite Specimens of Aluminium Die Casting-12 reinforced with 10 % by weight of ceramic Silicon Carbide is prepared by stir casting process under various experimental conditions and the Sliding wear resistance, compressive strength, micro abrasive wear resistance test and dilatometric tests are conducted for the prepared specimens. The results are analyzed using Taguchi's method along with Principal Component Analysis. From the analysis of test results, it is evident that Process temperature is the most influencing parameter in the improvement of mechanical and thermal properties of the prepared composites. From the Mean effects plot for SN ratio, the optimum conditions for the chosen composite is found as stirring speed 600 rpm, stirring time 10min and processing temperature 800 ºC. And also it is shown that Sliding wear, micro abrasive wear and coefficient of thermal expansion decrease and Compressive strength increases with increasing processing temperature and stirring speed. Other process parameters like preheat temperature of the mould, preheat temperature of the reinforcement particles, powder feed rate can be further considered for research.

Acknowledgments

We acknowledge Department of Mechanical Engineering, Government College of Engineering, Coimbatore, India for providing their kind support in the preparation of the composite specimen.

REFERENCES

1. **Khedera, A.R.I., Marahleh, G.S., Al-Jamea, D.M.K.** Strenghthening of Aluminium by SiC, Al_2O_3 and MgO *Jordan Journal of Mechanical and Industrial Engineering* 5 (6) 2011: pp. 533 – 541.
2. **Dashwood, R.J, Youssef, Y.M, Lee, P.D.** Effect of Clustering on Particle Pushing and Solidification Behaviour in TiB Reinforced Aluminium PMMCs *Composites A* 36 2005: pp. 747 – 63. https://doi.org/10.1016/j.compositesa.2004.10.027
3. **Lin, C.B., Ma, C.L., Chung, Y.W.** Microstructure of A380-SiCp Composites for Die Casting *Journal of Materials Processing Technology* 84 1998: pp. 236 – 246. https://doi.org/10.1016/S0924-0136(98)00226-X
4. **Kathiresan, S., Prabu, S., Karunamoorthy, L., Mohan, B.,** Influence of Stirring Speed And Stirring Time on Distribution of Particles in Cast Metal Matrix Composite *Journal of Materials Processing Technology* 171 2006: pp. 268 – 273. https://doi.org/10.1016/j.jmatprotec.2005.06.071
5. **Hashim, J., Looney, L., Hashim, M.S.J.** Particle Distribution in Cast Metal Matrix Composite *Journal of Materials Processing Technology* 123 2002: pp. 258 – 263. http://dx.doi.org/10.1016/S0924-0136(02)00098-5
6. **Altinkok, N., Koker, R.** Neural Network Approach to Prediction of Bending Strength and Hardening Behaviour of Particulate Reinforced (Al–Si–Mg)-Aluminium Matrix Composites *Materials and Design* 25 2004: pp. 595 – 602. http://dx.doi.org/10.1016/j.matdes.2004.02.014
7. **Puhan, D., Patra JambeswarSahu, S.S., Das, L.** A Hybrid Approach for Multi Response Optimization of Non-Conventional Machining on AlSiCp MMC *Measurement* 46 2013: pp. 3581 – 3592. http://dx.doi.org/10.1016%2Fj.measurement.2013.06.007
8. **Ghosh, S., Partha Saha, K.B.** Development of an In-Situ Multi-Component Reinforced Al Based Metal Matrix Composite by Direct Metal Laser Sintering Technique-Optimization of Process Parameter *Journal of Materials Processing Technology* 186 2014: pp. 82 – 86. https://doi.org/10.1016/j.matchar.2014.03.021
9. **Akbari, M.K., Shirvanimoghaddam, K., Hai, Z., Zhuiykov, S., Khayyam, H.** Al-TiB2 Micro/Nanocomposites: Particle Capture Investigations, Strengthening Mechanisms and Mathematical Modelling of Mechanical Properties *Material Science and Engineering A* 682 2017: pp. 98 – 106. https://doi.org/10.1016/j.msea.2016.11.034
10. **Singh, J., Chauhan, A.** Overview of Wear Performance of Aluminium Matrix Composites Reinforced With Ceramic Materials under the Influence of Controllable Variables *Ceramics International* 42 2016: pp. 56 – 81. http://dx.doi.org/10.1016%2Fj.ceramint.2015.08.150
11. **Dolata, A.J., Dyzia, M.** Aspects of Fabrication Aluminium Matrix Heterophase Composites by Suspension Method *IOP Conference Series Material Science and Engineering* 35 2012: pp. 1 – 7. https://doi.org //10.1088/1757-899X/35/1/012020
12. **Selvam, M.D., Senthil, P., Sivaram, N.M.** Parametric Optimisation for Surface Roughness of AISI 4340 Steel during Turning under Near Dry Machining Condition *International Journal of Machining and Machinability of Materials* 19 (6) 2017: pp. 554 – 569. https://doi.org/10.1504/IJMMM.2017.088896
13. **Baburaj, E., Sundaram, K.M., Senthil, P.** Effect of High Speed Turning Operation on Surface Roughness of Hybrid Metal Matrix (Al-SiCp-fly ash) Composite *Journal of Mechanical Science and Technology* 30 (1) 2016: pp. 89 – 95. https://doi.org //10.1007/s12206-015-1210-y
14. **Bhandare,R.G., Parshuram, M.** Sonawane. Preparation of Aluminium Matrix Composite by Using Stir Casting Method *International Journal of Engineering and Advanced Technology* 3 (2) 2013: pp. 61 – 65. http://inpressco.com/category/ijcet
15. **Naher, S., Brabazon, D., Looney, L.** Computational and Experimental Analysis of Particulate Distribution during Al–Sic MMC Fabrication *Composites: Part A* 38 2007: pp. 719 – 729. http://dx.doi.org/10.1016/j.compositesa.2006.09.009
16. **Ravi, K.R., Sreekumar, V.M., Pillai, R.M., Mahato, C., Amaranathan, K.R., Arul, K., Pai, B.C.** Optimization of Mixing Parameters through A Water Model for Metal Matrix Composites Synthesis *Materials and Design* 28 2007: pp. 871 – 881. http://dx.doi.org/10.1016/j.matdes.2005.10.007
17. **Altinkok, N., Koker, R.** Modelling of the Prediction Of Tensile And Density Properties in Particle ReinforcedoMetal Matrix Composites by using Neural Networks *Materials and Design* 27 2006: pp. 625 – 631. https://doi.org //10.1016/j.matdes.2005.01.005

18. **Balasivanandhaprabu, S., Karunamoorthy, L., Kathiresan, S., Mohan, B.** Influence of Stirring Speed Stirring Time on Distribution of Particles in Cast Metal Matrix Composite *Journal of Materials Processing Technology* 171 2006: pp. 268 – 273. https://doi.org //10.1016/j.jmatprotec.2005.06.071

19. **Baradeswaran, A., Elayapermal, A., Franklin Issac, R.** A Statistical Analysis of Optimization of Wear Behavior of Al-Al_2O_3 Composites Using Taguchi Technique *Procedia Engineering* 64 2013: pp. 973 – 982. https://doi.org //10.1016/j.proeng.2013.09.174

20. **Sozhamannan, G.G., Balasivanandhaprabu, S. Venkatagalapathy, V.S.K.** Effect of Process Parameters on Metal Matrix Composites: Stir Casting *Journal of Surface Engineered Materials and Advanced Technology* 2 2012: pp. 11 – 15. https://doi.org //10.4236/jsemat.2012.21002

21. **Thakur, A.G. Nandedkar, V.M.** Application of Taguchi Method to Determine Resistance Spot Welding Conditions of Austenitic Stainless Steel *Journal of Scientific and Industrial Research* 69 2012: pp. 680 – 683.

22. **Thakur, A.G., Rao, T.E., Mukhedkar, M.S., Nandedkar, V. M.** Application of Taguchi Method for Resistance Spot Welding of Galvanized Steel *ARPN Journal of Engineering and Applied Sciences* 5 2010: pp. 690 – 693.

23. **Vijian, P., Arunachalam, V.P.** Modelling And Multi Objective Optimization of LM24 Aluminium Alloy Squeeze Cast Process Parameters using Genetic Algorithm *Material Characterization* 93 2007: pp. 68 – 78. https://doi.org //10.1016/j.protcy.2014.08.021

24. **Hemalatha, A., Dhanalakshmi, V.** Influence of Stir Casting Process Parameters on Properties of Aluminium Composites *International Journal of ChemTech Research* 10 (14) 2017: pp. 151 – 162.

25. **Kayastha, C., Gandhi, J.** Optimization of Process Parameter in Turning of Copper by Combination of Taguchi and Principal Component Analysis *International Journal of Scientific & Engineering Research* 4 (6) 2013: pp. 1568.

26. **Krishna Madhavi, S., Sreeramulu, D., Venkatesh, M.** Evaluation of Optimum Turning Process of Process Parameters Using DOE and PCA Taguchi Method *Materials Today Proceedings Part A* 4 (2) 2017: pp. 1937 – 1946. http://dx.doi.org/10.1016/j.matpr.2017.02.039

27. **Kaushik, N., Singhal, S.** Hybrid Combination of Taguchi-GRA-PCA for Optimization of Wear Behavior in AA6063/SiC_p Matrix Composite *Production & Manufacturing Research* 6 (1) 2018: pp. 171 – 189. https://doi.org/10.1080/21693277.2018.1479666

28. **Patel, M., Ingle, P.** Optimization of CNC TC Process Parameters Using PCA- based Taguchi Method *International Journal of Innovative Research in Science, Engineering and Technology* 5 (4) 2016: pp. 4722 – 4731. https://doi.org//10.15680/IJIRSET.2016.0504016