Wire-Edm Statistical Optimization During Hybrid Mmc Processing

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ABSTRACT

Harder materials respond horribly to traditional machining's high tool wear rates and long cycle times, and it is extremely challenging to manufacture complex forms with such machines. For hard materials and complicated geometries, Wire Electric Discharge Machining (WEDM) is a popular non-conventional machining technique. In this work, an effort is made to look into the performance of the hybrid MMC A359/Al2O3/B4C during the wire-EDM process under various operating conditions, as well as the surface integrity of the machine surface. To assess the machined surface, SEM examination has been done. The surface roughness and MRR are used to gauge the output responsiveness. The L27 Taguchi's array was used for the analysis under the randomly planned experiment trials. In order to compare the performance efficacy of the suggested method, a grey relation analysis has been done at the conclusion of the results.

KEYWORDS: Hybrid Metal Matrix Composite, Electromagnetic Stir Casting, Wire EDM, Residual Stresses &

INTRODUCTION

Using two or more materials to create composites provides performance benefits and allows for numerous capabilities that are not possible with standard materials [1]. One of them is metal matrix composites (MMCs). These are the most suited advanced materials due to their increased qualities, which include a high strength to weight ratio, improved mechanical properties, and low weight, among others [2]. By melting the matrix material, reinforcing elements must be included into a metallic matrix when employing MMCs [3]. These composites are superior to other materials in terms of wear resistance, tensile and compressive strengths, structural effectiveness, thermophysical characteristics, and mechanical properties, which makes them ideal for many crucial engineering tasks [4]. To create hybrid MMCs, two or more reinforced materials must be added to the matrix metal in the required quantity [5]. However, due to their low machinability, MMCs are not frequently used in the industries [6]. Because of the high tool wear in composite materials like MMCs, machinability is a particularly challenging procedure. That happens because there are hard abrasive particles (reinforcements) present, which raises the cost of machining. When compared to conventional processes, non-traditional machining techniques like wire electric discharge machining (wire-EDM) offer better machining characteristics [7]. In this procedure, a work sample that is submerged in a tank filled with dielectric fluid, such as demineralized water, is fed a thin wire made of molybdenum or brass.. The major advantage of this process is that it cuts plates with up to 350 mm thickness and gives better accuracy in making of tools, dies, and punches.

The primary objective of the wire-EDM machining is to improve the performance of the output in terms of material removal rate, surface roughness, surface integrity, and dimension accuracy. However, optimum machining parameters and cost-effective machining are still the core area for the researchers along with that of reliability and reproducibility of the machining process. Other non-conventional machining processes such as abrasive waterjet also applicable to hard materials. However, the dimensional accuracy is one of the major drawback **[8, 9]**. F Muller and J Monaghan**[10]**has optimized the parametric combinations in wire-EDM. The non-dominated point concept was introduced in selecting the best combination of parameters. Mahapatra SS and Patnaik A **[11]** have optimized the wire-EDM process parameters using the Taguchi method. In this method, at the end of the analysis, a genetic algorithm is used to get the multi-objective parametric optimization of the machining process. Machining of DC-53 steel by wire-EDM and analysis of the surface roughness has been reported by Kanlayasiri K and Boonmung S **[12]**. Boujelbene M et al **[13]** have reported the analysis of surface integrity in electrical discharge machining on 50CrV4 and X200Cr15 steel. Their work has analyzed the thickness of the white layer, electrode wear ratio (EWR), metal removal rate (MRR) and the microhardness. An abrasive mixed electrical discharge machining and multi-level optimization of its machining parameters by orthogonal array and grey relational analysis have been done by Kumar Anil et al **[14]**. Kumar K and Agarwal S **[15]** have presented their work on multi-objective optimization of the wire-EDM machining parameters. Jabbaripour B. et al **[16]** investigating the results of EDM machining of Ti–6Al–4V and its parameters on surface properties, TWR and MRR. The chemical elements and compounds over the surface of the workpiece after machining was examined by EDS and XRD analyses. Sudhakara Det al
[17] have made an experimental study of EDM machining of Inconel-718. Garg HK et al **[18]** have discussed the machining of hybrid MMC of aluminum (Al/SiC/Gr and Al/Si10Mg/Fly ash/Gr). The Multi-objective optimization using non-dominating sorting genetic algorithm-II of machining parameters of EDM has been reported by Baraskar S. S. et al **[19]**. Srivastava AK et al **[2]** has studied the process parameters of wire EDM during machining of the Al2024/SiC composite. In his study, the effect of input parameters on machining outcomes such as MRR and surface roughness was evaluated. Srivastava AK et al **[5]** has reviewed the effect of conventional and non-conventional machining processes on hard materials like MMCs. They also discuss the limitations and merits of different machining processes in the processing of MMCs. Srivastava AK et al **[20]** has studied the wire EDM process parameters on turning of hybrid MMC. In his study, a fixture is used for turning motion and the rotational speed of workpiece sample was taken into

study. Srivastava AK **[21]** has compared the elements of surface integrity in procession via two non-conventional machining processes namely abrasive waterjet and wire EDM.

In this work, the analysis was carried out utilising the L27 Taguchi's array in trials for an experiment that were randomly created. In order to compare the performance efficacy of the suggested method, a grey relation analysis has been done at the conclusion of the results.

EXPERIMENTAL PROCEDURE

The experimental work started with a selection of materials. In this work, A359 aluminum alloy is used as a base metal. A359 has good casting and wettability properties. B_4C and $Al_2O_3$are used as the reinforcement material. The composition, thermal and physical properties of used materials was reported in our other published work **[22]**. A mechanical stirring process was applied to produce the hybrid MMCs. Maxicut 4 axis CNC WEDM machine of Electronica Corporation is used for machining of fabricated MMCs, as shown in figure 1(a). This machine has the flexibility to choose machining parameters as per the requirement of the selected materials. Molybdenum wire of diameter

0.18 mm and demineralized water as a working fluid was used in the experiment as fixed parameters. The photographic view of machine zone is shown in figure 1(b). The main input variable parameters of the machine were peak current (A), pulse on-time (T_{on}) (B), pulse off-time (T_{off}) (C) and wire feed (D), which were selected at three different levels on the basis of their range availability. The set of design levels is shown in table 1.

Figure 1(a) Wire EDM Machine and (b)

Machining ZoneTable 1: Input Parameters

and Level of Design

Factor	Peak Current	Pulse on Time	Pulse off Time	Wire Feed
Unit	Amp	µS	µS	m/min
Symbol	A	B	C	D
L1	2	15	3	8
L2	3	20	4	8.5

L3	4	25	5	9

Two output parameters, namely, surface roughness and MRR, which were analyzed after the machining of fabricated samples. Surface roughness was deliberated by surface roughness tester. Material removal rate was measured byusing equation (1).

Metal removal rate $=V_c$x b x t

(1)

Where $\mathbf{V_c}$ = cutting velocity, **b** = width of kerf (width of cut) and **t** = plate thickness.

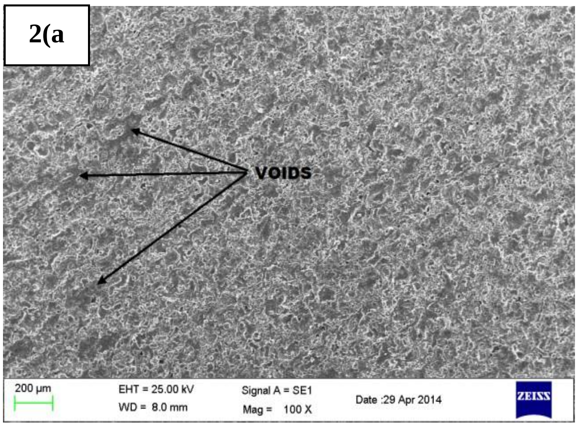
Cutting speed was calculated by measuring time to complete the cut. The kerf width was obtained by a microscope. In this work, the Taguchi technique was applied to find optimum process parameters. L_{27} array, S/N ratio and analysis of variance (ANOVA) were applied to study the performance characteristics of the machining parameters. The S/N ratio can be calculated as a logarithmic transformation of the function as shown in equations 2 and 3, below. Optimum performance characteristics for MRR are 'the larger the better', and for surface roughness, 'the smaller the better' respectively.

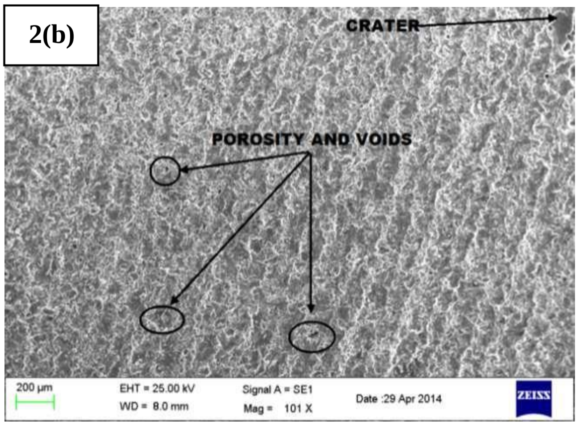
$$\frac{S}{N1} ratio for MRR = -10log_{10} \log_{n} \quad Z(_2 \,) \quad - \qquad (2)$$

$$\frac{S}{N} ratio for Ra = -10log_{10} \log_{n} \quad Z(y^2) \qquad)$$

RESULT AND DISCUSSIONS

The SEM images of machined samples were taken to analyses the micro study of the surface. The typical SEM images of the machined sample at three different places are shown in figure 2(a, b, c). The figures indicate that hard particles, which did not melt during the machining, formed the craters and voids which increased the surface roughness. Porosity is also seen on the


2(a


2(b)

surface due to the evaporation process and the explosion of gas bubbles.

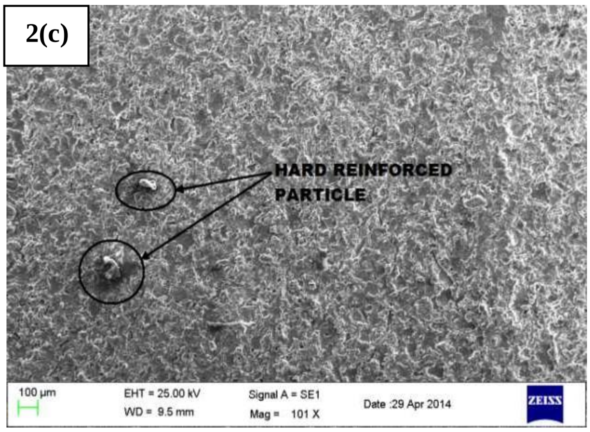


Figure 2 (a, b, c): Typical SEM Images of Machined Sample A359 +2% Al_2O_3+2% B_4C

The analysis of the experiment was done by using Minitab-17 software which is used for designing experiment applications. An L_{27} array of the Taguchi's design is shown in table 2. The output response of the experiment was transformed in S/N ratio for measuring the performance characteristic of the input machining variables. Mean signal to noise ratio graph for the two output parameters are shown in figure3 (a, b) respectively. Figure 3(a) indicates that the roughness of the surface increased with an increase of peak current. This was due to the melting of materials at high discharge energy. At high discharge energy, some of the surface particles which are not melted are removed like a brittle fracture or in the dimple nature, which creates voids at the surface. Another reason is the hard abrasive particles B_4C and Al_2O_3. These hard particles did not melt during the machining. Hence, the molten metal turned viscous resulting in a rough surface and slow removal of metals. Figure 3(b) indicates that with an increase in the peak current, metal removal rate also increased. On the other hand, the surface became rough because when the peak current increased, the discharge of heat energy increased as well. This helped in the removal of more metals. However, due to the discharge of heat energy, the molten metal at the surface started evaporating and formed gas bubbles which exploded and made the surface roughness due to the creation of voids. On the basis of parametric optimized conditions, the corresponding values of input parametersare shown in Table 3. Table 4 shows the results of the ANOVA table for surface roughness and MRR respectively. Considering the sum of square values, it was estimated that the peak current was a major factor which contributed 70.02 % to the better surface finish, however, pulse on-time (T_{on}) contributed 22.48 %.

Table 2: Experimental Design using L_{27} Orthogonal Array

		Input Parameters				**Output Response**		**S/N Ratio of Response**	
St	**Ru**	A	B	C	D	**Surface Roughness**	**MRR (mm/mi**	**S/ n**	**S/n MR**

d	**n**					**(Ra)**	**n)**	**Ra**	**R**
11	1	2	1	3	2	2.5483	1.424	-8.125	3.070
21	2	3	1	2	3	2.7846	1.4686	-8.895	3.338
9	3	1	3	3	3	2.544	1.2758	-8.110	2.116
23	4	3	2	3	2	2.898	1.5574	-9.242	3.848
15	5	2	2	1	3	2.734	1.3225	-8.736	2.428
13	6	2	2	1	1	2.722	1.3927	-8.698	2.877
18	7	2	3	2	3	2.537	1.409	-8.086	2.978
20	8	3	1	2	2	2.8193	1.4398	-9.003	3.166
26	9	3	3	1	2	3.1317	1.6476	-9.916	4.337
27	10	3	3	1	3	3.0821	1.6135	-9.777	4.155
16	11	2	3	2	1	2.559	1.452	-8.161	3.239
6	12	1	2	2	3	2.423	1.3585	-7.687	2.661
2	13	1	1	1	2	2.2637	1.212	-7.096	1.670
24	14	3	2	3	3	2.787	1.5146	-8.903	3.606
12	15	2	1	3	3	2.4997	1.395	-7.958	2.891
10	16	2	1	3	1	2.5868	1.465	-8.255	3.317
25	17	3	3	1	1	3.1146	1.6787	-9.868	4.499
14	18	2	2	1	2	2.843	1.3612	-9.076	2.678
17	19	2	3	2	2	2.576	1.426	-8.219	3.082
19	20	3	1	2	1	2.8021	1.4095	-8.950	2.981
8	21	1	3	3	2	2.586	1.2994	-8.253	2.275
22	22	3	2	3	1	2.846	1.4993	-9.085	3.518
4	23	1	2	2	1	2.408	1.3812	-7.633	2.805
5	24	1	2	2	2	2.469	1.3658	-7.850	2.708
1	25	1	1	1	1	2.2232	1.2532	-6.940	1.960
7	26	1	3	3	1	2.538	1.3186	-8.090	2.402
3	27	1	1	1	3	2.2374	1.1987	-6.995	1.574

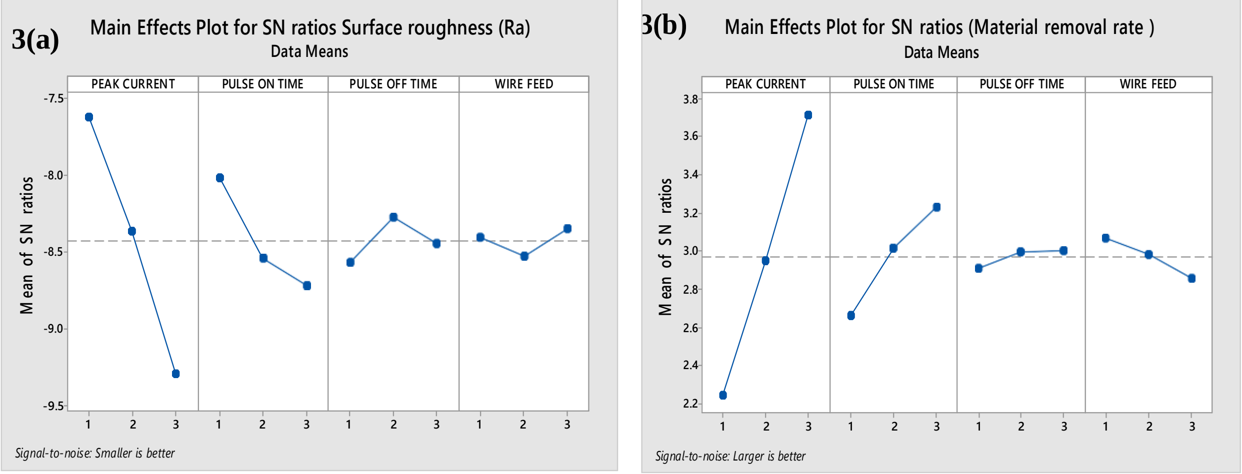


Figure 3(a, b): S/N Ratio Graph for Surface Roughness and Metal Removal Rate

Table 3: Optimized Combination Values of Input Parameters Obtained from Taguchi's Array

Output Parameters	**Variable Input Parameters**			
	A(Peak Current)	**B(T_{ON})**	**C(TOFF)**	**D(Wire feed)**
Surface Roughness	$A_1 = 2$	$B_1 = 15$	$C_2 = 4$	$D_3 = 9$
MRR	$A_3 = 4$	$B_3 = 25$	$C_3 = 5$	$D_1 = 8$

Table 4: ANOVA Table for the Output Response

Surface Roughness					
Parameter	**Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F Value**	**% Contribution**
A-Peak Current	12.05	2	6.03	724.38	70.02
B-Pulse On-time	3.87	2	1.93	232.59	22.48
C-Pulse OFF-Time	0.33	2	0.17	20.1	1.94
D-Wire Feed	0.14	2	0.07	8.06	0.79
Error	0.82	16	0.01		4.77
Total	**17.21**	**26**			**100**
Metal Removal Rate					
A-Peak Current	9.52	2	4.76	204.28	66.76
B-Pulse On-time	1.41	2	0.71	30.34	9.89
C-Pulse OFF-Time	2.32	2	1.16	49.9	16.27
D-Wire Feed	0.17	2	0.08	3.62	1.2
Error	0.84	16	0.02		5.88
Total	**14.26**	**26**			**100**

A contribution of pulse off-time (T_{off}) and wire feed was 1.94% and 0.79%, respectively which indicates that the effect of these two parameters was less significant compared to the other parameters. A 4.77 % of error was also found due to the unavoidable factors like fixed parameters. The most significant factor resulting in maximum metal removal rate was the peak current whose contribution was 66.76%. Other important parameters were pulsed off- time (T_{off}) and pulse on-time (T_{on}), contributing 16.27% and 9.89%, respectively. A contribution of wire feed was 0.43%, which indicates as less significant parameter. Total error calculated was 5.88%. The R-Squared values calculated for surface roughness and metal removal rate were 0.9923 and 0.9738 respectively which confirms the accuracy of the intended constants and fitness of the developed model. A confirmation experiment was done to verify the effect of the optimized combination of machining parameters on the output response. It also verified the reproducibility of the set of optimized input parameters. Experiments were carried out as per the set of input parameters shown in table 4. The results obtained for the optimized machining parameters are shown in table 5. It indicates that the optimized value of the surface roughness was 2.18µm and metal removal rate was 1.654 mm/min.

Grey relation analysis was also done to find the optimized combination of parameters when and where only partial information was available. According to the grey relation analysis, all the available information is white information, all the unavailable information is black information and all the partially available information is called grey information.

Table 5: Results of Confirmation Experiment for Optimized Machining Parameters

Response	Input Parameters	A Peak Current	B TON	C TOFF	D Wire feed	Output Response
Surface Roughness (µm)	Level	$A_1 = 2$	B_1= 15	C_2= 4	$D_3 = 9$	2.18
MRR (mm/min)	Level	$A_3 = 4$	B_3 =25	C_3 = 5	$D_1 = 8$	1.654

Table 6: Grey Relation Analysis

Std	Run	Input Parameters				Grey Relation Data Generation		Grey Relation Coefficient		Grey Relation Grade
		A	B	C	D	S.R	MRR	S.R	MRR	
11	1	2	1	3	2	0.672	0.469	0.427	0.516	0.449
21	2	3	1	2	3	0.4	0.562	0.556	0.471	0.4506
9	3	1	3	3	3	0.677	0.161	0.425	0.757	0.5881
23	4	3	2	3	2	0.269	0.747	0.65	0.401	0.5258
15	5	2	2	1	3	0.458	0.258	0.522	0.66	0.5512
13	6	2	2	1	1	0.472	0.404	0.514	0.553	0.5014
18	7	2	3	2	3	0.685	0.43	0.422	0.53	0.535

							8		3	6
20	8	3	1	2	2	0.36	0.502	0.581	0.499	0.4746
26	9	3	3	1	2	0	0.935	1	0.348	0.6297
27	10	3	3	1	3	0.057	0.864	0.897	0.367	0.5885
16	11	2	3	2	1	0.66	0.528	0.431	0.487	0.5374
6	12	1	2	2	3	0.816	0.333	0.38	0.6	0.542
2	13	1	1	1	2	1	0.028	0.333	0.947	0.7603
24	14	3	2	3	3	0.397	0.658	0.557	0.432	0.5496
12	15	2	1	3	3	0.728	0.409	0.407	0.55	0.4615
10	16	2	1	3	1	0.628	0.555	0.443	0.474	0.4357
25	17	3	3	1	1	0.02	1	0.962	0.333	0.6521
14	18	2	2	1	2	0.333	0.339	0.601	0.596	0.5302
17	19	2	3	2	2	0.64	0.474	0.439	0.514	0.5631
19	20	3	1	2	1	0.38	0.439	0.568	0.532	0.478
8	21	1	3	3	2	0.629	0.21	0.443	0.704	0.542
22	22	3	2	3	1	0.329	0.626	0.603	0.444	0.5194
4	23	1	2	2	1	0.834	0.38	0.375	0.568	0.4738
5	24	1	2	2	2	0.763	0.348	0.396	0.59	0.4784
1	25	1	1	1	1	1.047	0.114	0.323	0.815	0.9083
7	26	1	3	3	1	0.684	0.25	0.422	0.667	0.5484
3	27	1	1	1	3	1.03	0	0.327	1	0.7633

Similar to Taguchi’s method, here also three different approaches – ‘the larger the better’, ‘the smaller the better’, and, ‘the nominal the better’ is used as calculated by equations 5 and 6.

$$X, (k) = \frac{y_i(k) - min\,y_i(k)}{max\,y_i(k) - min\,y_i(k)}$$

$$Xi(k) = \frac{max\,y_i(k) - y_i(k)}{max\,y_i(k) - min\,y_i(k)}$$

5)

(6)

Where Xi (k) is the value after generation of grey relation, Max yi(k) and Min yi(k) are the largest and the smallest value of yi (k) for the k_{th} response, respectively. After data generation, grey relation coefficient and grey relation grade were calculated which are shown in Table 6. Response table provides the optimum parametric combination for the best machining response and performance characteristics. Table 7 shows the grey relation response of the input parameters. A maximum value of each parameter out of the three levels shows the optimum level of machining. From the table 7, optimum machining condition can be found to be A_1, B_3, C_1, $D_1$with corresponding values are peak current 2Amp, T_{on} 25 µs, %, T_{off} 3 µs, and, wire feed 8mm/min. Table 8 shows a comparative study of both the optimization techniques Taguchi's L_{27} array and grey relation analysis. Results obtained in the table show that a 3.80% improvement in the surface finish could be achieved with machining through the optimum condition of grey relation analysis. Metal removal rate was also improved by 12.02% with the grey relation parameters.

Table 7: Grey Relation Response Table

	Input Parameters			
Level	**A-Peak Current**	**B-T_{ON}**	**C-T_{OFF}**	**D-Wire Feed**
level 1	**0.623**	0.5757	**0.6539**	**0.5616**
level 2	0.507	0.519	0.5037	0.5503
level 3	0.5409	**0.5761**	0.5133	0.5589

Table 8: Comparison of Confirmation Experiment

Method of Optimization Process	**Output Response**	**Input Parameter**	**A**	**B**	**C**	**D**	**Machining Output Response**	**% Change**
Taguchi's L_{27}array	Surface Roughness	Level	A_1= 2	B_1=15	C_2= 4	D_3 = 9	**2.18**	---
	MRR	Level	A_3= 4	B_3 =25	C_3= 5	D_1 = 8	**1.654**	----
Grey relation analysis	Surface Roughness	**A_1 =2,, B_3 =25, C_1= 3, D_1 = 8**					**2.1**	**3.80%**
	MRR						**1.8**	**12.02%**

CONCLUSIONS

During the wire EDM process of the hybrid MMC and optimization of the machining parameters throughTaguchi's technique and grey relation analysis, the following conclusions could be listed:

- Peak current is the most significant factor which drastically affects surface roughness and MRR with acontribution of 70.03 % and 66.76%, respectively.
- The optimized values for surface roughness and MRR attained through Taguchi's confirmation experiment, are 2.18µmand 1.654 mm/min respectively.
- The R-Squared values calculated through Taguchi's technique for surface roughness and MRR are 0.9923and 0.9738 respectively which confirms the accuracy of the intended

constants and fitness of the developed model.

- The optimum set of machining parameters from Grey relation analysis is A_1, B_3, C_1, D_1, for performance evaluation of all the two output responses, namely, surface roughness and MRR.
- The optimized values of surface roughness and MRR attained through grey relation confirmation experiment are 2.1 µm and 1.80 mm/min respectively.
- While comparing the results of Taguchi's technique and grey relation analysis, surface roughness and MRR values discovered through grey relation analysis at 3.80% and 12.02%, respectively can be found to be much better as compared to Taguchi's experiment.

REFERENCES

1. *Srivastava, A. K., Dixit, A. R., & Tiwari, S. (2016). Investigation of micro-structural and mechanical properties of metal matrix composite A359/B$_4$C through electromagnetic stir casting,2016, 23, 171–180.*
2. *Srivastava, A.R. Dixit, S. Tiwari, Experimental Investigation of Wire EDM Process Parameteres on Aluminum Metal Matrix Composite Al2024/SiC, Int. J. Adv. Res. Innov. 2 (2014) 511–515.*
3. *Mardi KB, Dixit AR, Srivastava AK, Mallick A, J. Scucka, P. Hlavacek, S. Hloch, M. Zelenak, Effect of Water Pressure During Abrasive Waterjet Machining of Mg-Based Nanocomposite. In: Singh M., Kushvah B., Seth G., Prakash J. (eds) Applications of Fluid Dynamics. Lecture Notes in Mechanical Engineering. Springer, Singapore,*

   https://doi.org/10.1007/978-981-10-5329-0_46.
4. *Babu N. Hari, Tzamtzis S., Barekar N., Patel J. B. and Fan Z., **(2008),** Fabrication of Metal Matrix Composites under Intensive Shearing, Solid State Phenomena,141-143, 373-378.*
5. *AK Srivastava, AR Dixit, S Tiwari, A Review on intensification of metal matrix composites and its non-conventional machining, Sci. Eng. of Compos. Mater, (2016), DOI: https:// doi. Org/ 10.1515/secm-2015-0287.*
6. *A.K. Srivastava, A. Nag, A.R. Dixit, S. Tiwari, J. Scucka, M. Zelenak, S. Hloch, P. Hlavacek, Surface integrity in tangential turning of hybrid MMC A359/B 4 C/Al 2 O 3 by abrasive waterjet, J. Manuf. Process. 28 (2017) 11–20.*

7. *Garg H. K., Verma K., Manna A., Kumar R.,* ***(2012),*** *Hybrid Metal Matrix Composites and further improvement in their machinability- A Review, International Journal of Latest Research in Science and Technology, 1(1), 36-44.*
8. *Srivastava A.K., Nag A., Dixit A.R., Tiwari S., Srivastava V.S. (2019) Parametric Study During Abrasive Water Jet Turning of Hybrid Metal Matrix Composite. In: Hloch S., Klichová D., Krolczyk G., Chattopadhyaya S., Ruppenthalová L. (eds) Advances in Manufacturing Engineering and Materials. Lecture Notes in Mechanical Engineering. Springer, Cham, https://doi.org/10.1007/978-3-319-99353-9_9.*
9. *Nag A, Srivastava AK, Dixit AR, Chattopadhyaya S, Mandal A, P. Hlavacek, D. Klichova M. Zelenak, S. Hloch, Influence of Abrasive Water Jet Turning Parameters on Variation of Diameter of Hybrid Metal Matrix Composite. In: Singh M., Kushvah B., Seth G., Prakash J. (eds) Applications of Fluid Dynamics. Lecture Notes in Mechanical Engineering. Springer, Singapore https://doi.org/10.1007/978-981-10-5329-0_36*
10. *F. Muller and J. Monaghan,* ***(2000),*** *Non-conventional machining of particle reinforced metal matrix composite, International Journal of Machine Tools & Manufacture, (40), 1351–1366.*
11. *S. S. Mahapatra &Amar P.,* ***(2007),*** *Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, International Journal of Advance Manufacturing Technology, 34(9-10), 911-925.*
12. *K. Kanlayasiri, S. Boonmung,* ***(2007),*** *Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: Design of experiments and regression model, Journal of Materials Processing Technology, (192–193), 459–464.*
13. *M. Boujelbene, E. Bayraktar, W. Tebni, S. Ben Salem,* ***(2009),*** *Influence of machining parameters on the surface integrity in electrical discharge machining, Archives of Materials Science and Engineering, 37(2), 110-116.*
14. *Anil Kumar, S. Maheshwari, C. Sharma, Naveen Beri* ***(2010),*** *A Study of Multi objective Parametric Optimization of Silicon Abrasive Mixed Electrical Discharge Machining of Tool Steel, Materials and Manufacturing Processes,25(10),1041-1047.*
15. *Kapil Kumar and Sanjay Agarwal,* ***(2012),*** *Multi-objective parametric optimization on machining with wire electric discharge machining, International Journal of Advance Manufacturing Technology, (62) 617–633.*
16. *B. Jabbaripour, M. H. Sadeghi, Sh. Faridvand' M. R. Shabgard,* ***(2012),*** *Investigating the effects of EDM Parameters on Surface Integrity, MRR and TWR in machining of Ti–6Al–*

4V, Machining Science and Technology: An International Journal, 16(3), 419-444.

17. *D Sudhakara, B Venkataramana Naik, B Sreenivasulu,* **(2012),** *The experimental analysis of surface characteristics of Inconel- 718 using Electrical discharge machining, International Journal of Mechanical Engineering& Robotics Research, (1), 371- 388.*
18. *Garg H. K., Verma Ketan, Manna Alakesh and Kumar Rajesh,* **(2012),** *Hybrid Metal Matrix Composites and further improvement in their machinability- A Review, International Journal of Latest Research in Science and Technology, 1(1), 36- 44.*
19. *S. S. Baraskar, S. S. Banwait, S. C. Laroiya,* **(2013),** *Multiobjective Optimization of Electrical Discharge Machining Process Using a Hybrid Method, Materials and Manufacturing Processes, 28(4), 348-354.*
20. *A.K. Srivastava, A. Nag, A.R. Dixit, S. Hloch, S. Tiwari, J. Scucka, P. Pachauri, Surface integrity in wire-EDM tangential turning of in-situ hybrid metal matrix composite* $A359/B_4C/Al_2O_3$*, Sci. Eng. Compos. Mater. (2018), 10.1515/secm-2017-0391.*
21. *Malaquias, J. V., Celestino, S. M. C., & Xavier, M. F. F. (2018). Optimization of the roasting conditions of arabica coffee cultivated in the cerrado area of Brazil. Brazilian Journal of Food Technology, 21.*
22. *Ashish Kumar Srivastava, Akash Nag, Amit Rai Dixit, Jiri Scucka, Sergej Hloch, Dagmar Klichová, PetrHlaváček, SandeepTiwari, Hardness measurement of surfaces on hybrid metal matrix composite created by turning using an abrasive water jet and WED, Measurement,2019, 131, pp 628-639.*
23. *Nag, J. Ščučka, P. Hlavacek, D. Klichová, A.K. Srivastava, S. Hloch, A.R. Dixit, J. Foldyna, M. Zelenak, Hybrid aluminium matrix composite AWJ turning using olivine and Barton garnet, Int. J. Adv. Manuf. Technol. (2017) 1–8.*