Optimization of input parameters on WEDM of AZ61-15wt.% Zr C composites via Taguchi technique for sustainability in transportation sectors.

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Abstract Sustainability in the transportation sector in terms of materials entails many major areas aimed at reducing environmental effect and promoting sustainability over the long haul. Choosing materials that are lightweight, minimizes fuel usage and emission levels from vehicles. In this investigation, Wire Electrical Discharge Machining (WEDM) behavior of AZ61-15wt%ZrC composites was studied. The AZ61-15wt%ZrC composites were made using the stir casting technique. The specimen was created using the WEDM technique from the manufactured composite. By adjusting the input parameters of Current (I) amps, pulse-ON time (T-ON), wire feed rate (WFR), and pulse-OFF time (T-OFF) in s, at four different levels, the manufactured samples were machined via WEDM. L16 orthogonal array was employed in the Taguchi method of experiment design. Analysis of Variance [ANOVA] was utilized to find which process parameter had the greatest impact on output variables like Material Removal Rate [MRR] and Surface Roughness [SR]. WFR is found to be a substantial input parameter on MRR and T-ON on SR, contributing 32.71% and 74.98% respectively.

Keywords: Wire cut EDM, AZ61, Zirconium carbide, Machining, Casting, and Optimization.

1 Introduction

Minimizing waste formation throughout commodity creation and utilization via optimal manufacturing processes and waste management procedures is an effective strategy to improve sustainability. Due to its higher specific strength, exceptional castability, excellent machinability, and increased damping capability, light magnesium (Mg) alloys have drawn a lot of interest as weight-saving materials. The hexagonal closed-packed (HCP) structure of magnesium contributes to its low toughness and ductility. Magnesium has a density that is

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35.6% lower than that of aluminum (1.74 grams per cubic centimeter), making it the perfect material for lighter components in a variety of industrial applications. These additional uses include a variety of industrial tools and parts, such as pipelines, heat exchangers, geothermal energy components, building structural elements, solar system support structures, and ship containers. The extraordinary mechanical, chemical, and tribological characteristics of particulate reinforced magnesium matrix composites (MMCs), such as their greater strength, superior specific modulus, and improved resistance to wear, are shown [1]. Magnesium is a lightweight material; its application in metal matrix composites has expanded due to several economic and environmental factors [2]. Magnesium is one of the lightest structural metals currently available, and it can replace conventional alloys in mass-saving applications while still offering superior stiffness and strength. The addition of reinforcing elements to the metallic matrix has a substantial impact on properties when compared to conventional engineering materials. Because of their superior physical and mechanical characteristics, low density, and wide range of applications, magnesium metal matrix composites are an outstanding choice of material. [3]. One of the difficult tasks for all engineers and scientists is the development of lightweight materials. Due to its high corrosion potential and middling mechanical qualities, magnesium, a lightweight material, has a limited range of uses. The alloying component tends to improve both the mechanical & corrosion opposition of the magnesium alloy. One way to increase the usefulness of magnesium is to use particle-reinforced metal matrix composites [4].Both cast and products are made from AZ61 alloy. In general, the alloy's mechanical characteristics, corrosion opposition and oxidation resistance all rise as its aluminum percentage does, whereas castability and weldability rapidly decline [5].In order to acquire improved mechanical qualities and make load-bearing components, AZ61 reinforced with ceramic particles has been developed [6].A tough, crystalline refractory ceramic material is zirconium carbide. It is FCC cubic in structure and metallic grey in hue. High thermal and electrical conductivity characterize it [7]. In comparison to other processing techniques, stir casting offers easiness, litheness, and adaptability across an extensive range of materials, as well as an affordable and high production rate with large-scale composite production. Major limitations of the stir casting method include the agglomeration and fracturing of reinforcing particles, gas entrapment, and the creation of an impurity vortex amid mechanical distress& local solidification [8]. By applying high pressures during casting, stir casting methods develop the wettability of the particulate particles by molten metal [9]. Magnesium nanocomposites are significant because of their enhanced properties, particularly with regard to improving overall strength and refining grain structure (GR)[10]. The studies on spark eroding machine used changing input circumstances and assessed material rate responses for each parameter level. The findings of this research study demonstrated an increase in material removal rate with less wear on the tools [11]. Meignanamoorthy et al [12] explored the wire electrical discharge machining properties of AA5083-MoO_3 composites and concluded that pulse off time is the noteworthy parameter to acquire maximum MRR and least SR. Kavimani et al [13] studied the WEDM behavior of magnesium composites and reported that reinforcement wt.% and T-ON time are the majority influencing parameters for MRR and SR. Amir Mostafapo et al [14] examined the WEDM characteristics of AZ91 alloy. The experimental findings demonstrated that magnesium has a material removal rate and kerf breadth that are significantly higher than those of hard materials. Selvarasu et al [15] demonstrate the magnesium nanocomposites were stir-cast using the L16 array. COPRAS optimization revealed superior mechanical properties in the AZ61/7.5% B_4C composite. Pulse duration notably influenced MRR and SR. Quadratic models aligned with experimental values, and COPRAS identified optimal parameters: max 0.00730 g/s MRR, min 0.00127 g/s EWR, SR 3.196 µm. Nano-SiC powder with EDM oil outperformed, showing an 81% MRR, 55% EWR, and 47% SR improvement over kerosene and EDM oil.

2 Experimental Details

ZrC was used as reinforcement and AZ61 was the matrix material. The needed quantity of AZ61 and ZrC powders was measured automatically using a weigh scale. At 800 °C, AZ61 was liquefied in a crucible furnace. At 400 °C, ZrC particles were heated. Thereafter, needed percent of ZrC powder was included to the AZ61 matrix permissible to reach the liquid stage. 300 seconds of 30,000 rpm speed mixing were completed. In order to get the desired sizes, the liquid metal was finally poured into a die. The workpiece has the following measurements: 8 x 8 x 30 mm. ECOCUT WEDM was used to carry out the WEDM technique. To examine their effects on MRR and SR, the three-level process parameters TON, TOFF, and I were chosen as variables. The WEDM technique required samples that were 8 x 8 x 30 mm in size. MRR and SR were the WEDM performance benchmarks used for this inquiry. Weight differences between the workpiece before and after the WEDM process were used to compute MRR. Mitutoyo surftest SJ-210 was utilized to quantity the SR on the machined area.

3 Results and Discussions

The examination of experimental results was done using minitab-17 software. The outcomes were changed to S-N ratio of MRR & SR.

Table 1. Experimental results

Exp. No	Current I (Amps)	Pulse on Time T-ON (µs)	Wire Feed Rate WFR (m/min)	Pulse off Time T-OFF (µs)	(MRR) (mm3 /s)	Surface Roughness (Ra)
1	4	100	3	30	0.053	1.1487
2	4	110	6	40	0.184	2.2438
3	4	120	9	50	0.062	2.6914
4	4	130	12	60	0.170	2.3756
5	8	100	6	50	0.185	1.8545
6	8	110	3	60	0.088	2.8315
7	8	120	12	30	0.213	2.6155
8	8	130	9	40	0.085	2.4287
9	12	100	9	60	0.184	1.4414
10	12	110	12	50	0.224	2.8059
11	12	120	3	40	0.153	2.7642
12	12	130	6	30	0.189	2.6984
13	16	100	12	40	0.089	1.5318
14	16	110	9	30	0.171	3.4754
15	16	120	6	60	0.139	2.3159
16	16	130	3	50	0.128	2.0027

3.1 Influence of input parameters on MRR

It is obvious from figure 1 and 2 that the high spark discharge energy created causes MRR to rise with the addition of TON. Significant thrust explosions cause significant spark release energy development when the amount of evaporation and the size of the gas bubbles both rise. Initially decreasing as TOFF rises due to strong arcing and incomplete dielectric strength recovery in the gap, MRR eventually rises as TOFF rises despite of fact that dielectric power is recovered as wreckage is reddened out of the hole. However, as I, rises the MRR rises once more as a result of the extraordinary potency inclination in the spark release gap and the spark liberation energy created to facilitate the vanishing activity. Higher I, causes both the workpiece and the tool to experience greater heat loads, which raises MRR.

Table 2. Response Table for Signal to Noise Ratios for MRR

Level	I (Amps)	T-ON Time (µs)	WFR (m/min)	T-Off Time (µs)
1	-19.94	-18.97	-20.20	-17.19
2	-17.65	-16.04	-15.24	-18.36
3	-14.62	-17.76	-18.90	-17.41
4	-17.84	-17.28	-15.71	-17.09
Delta	5.32	2.93	4.95	1.27
Rank	1	3	2	4

Table 3. Response Table for Means of MRR

Level	I (Amps)	T-ON Time (µs)	WFR (m/min)	T-Off Time (µs)
1	0.1172	0.1278	0.1055	0.1565
2	0.1427	0.1668	0.1743	0.1278
3	0.1875	0.1418	0.1255	0.1497
4	0.1318	0.1430	0.1740	0.1452
Delta	0.0703	0.0390	0.0688	0.0287
Rank	1	3	2	4

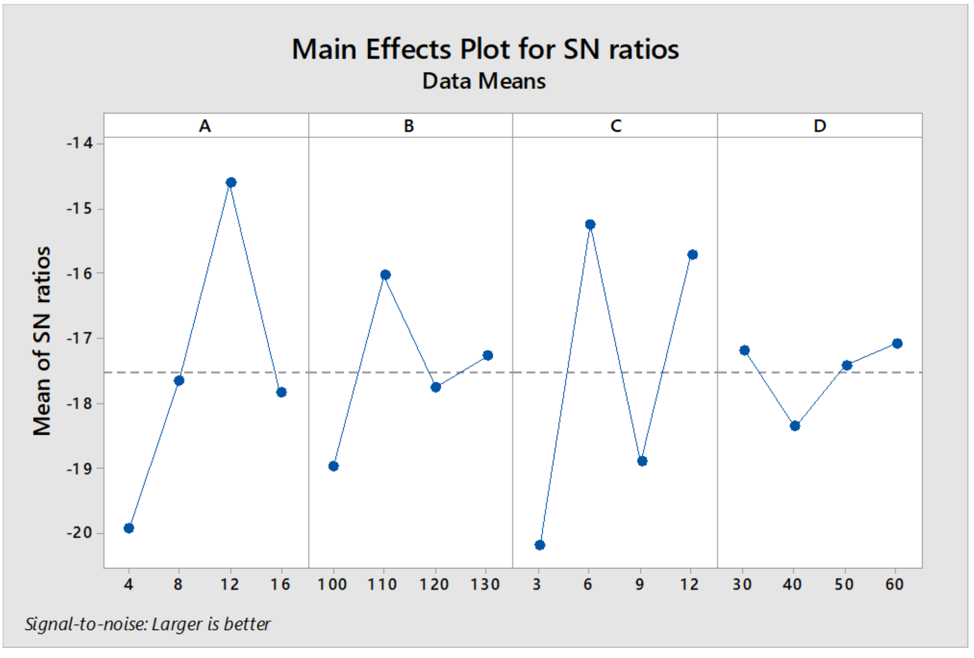

Fig. 1. SN ratio plot of MRR

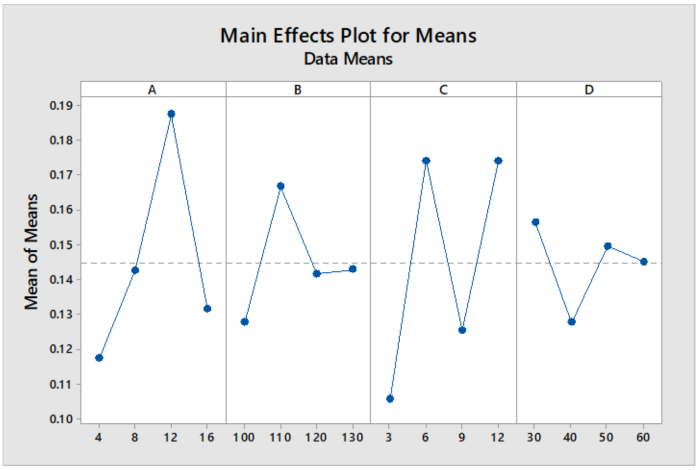

Fig 2: Mean plot of MRR

3.2 Influence of input parameters on SR

According to the S-N ratio graph shown in Figure 3, when T-ON and T-OFF grow, SR rises initially because of expansion of the stimulus energy in the discharge column and subsequently falls as T-OFF enhances due to the cessation of discharge. Figure 4 makes it evident that when T-ON and T-OFF increase, SR initially declines and then increases in the main effect plot for means. This is because the pulsation energy is being strengthened, allowing the surface layer to cool at a steady rate and improving surface finish. However, despite of particles in erosion adhering amid tool and work piece gap, as I grows, the SR initially increases and subsequently falls. As a result, it implies that SR and I are proportionate.

Table 4. Response Table for Signal to Noise Ratios

Level	I (Amps)	T-ON Time (µs)	WFR (m/min)	T-Off Time (µs)
1	-6.085	-3.362	-6.277	-7.249
2	-7.616	-8.960	-7.075	-6.816
3	-7.398	-8.269	-7.576	-7.239
4	-6.963	-7.469	-7.133	-6.756
Delta	1.531	5.598	1.299	0.493
Rank	2	1	3	4

Table 5. Response Table for Means

Level	I (Amps)	T-ON Time (µs)	WFR (m/min)	T-Off Time (µs)
1	2.115	1.494	2.187	2.485
2	2.433	2.839	2.278	2.242
3	2.427	2.597	2.509	2.339
4	2.331	2.376	2.332	2.241
Delta	0.318	1.345	0.322	0.243
Rank	3	1	2	4

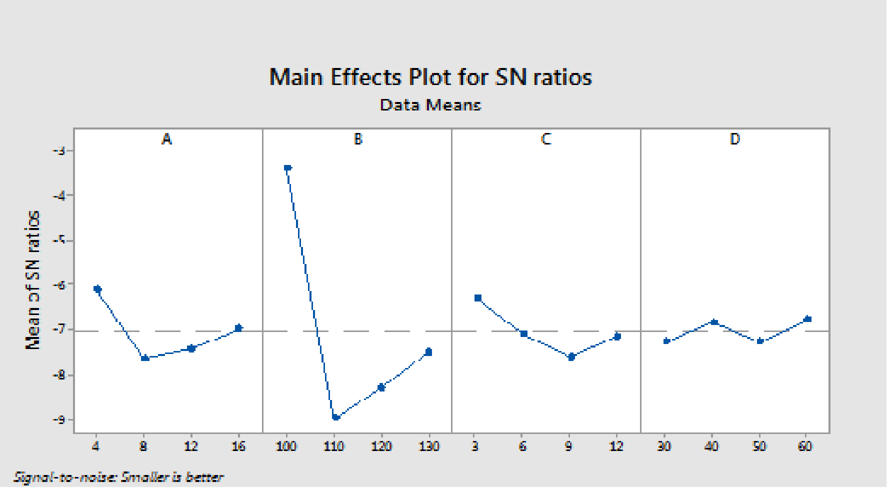

Fig. 3. SN ratio plot of SR

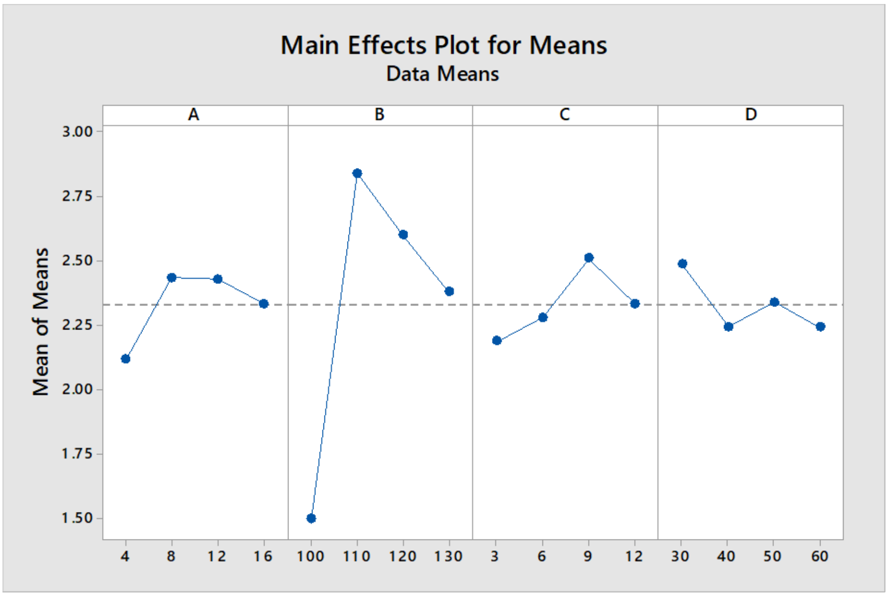

Fig. 4. Mean plot of SR

3.3 ANOVA

ANOVA was utilized to examine the influence of parameters I, T-ON, WFR, and T-OFF to obtain optimum MRR and SR. It is observed that the WFR (32.71%) has considerably effects the MRR follow by I (24.79%), T-ON (7.06%) and least significant of T-OFF(4.04%). For SR it is experimental that the T-ON(74.98%)is mainly significantly influences the SR tracked by I (4.81%), WFR (4.01%) and T-OFF (2.87%).

Table 6. ANOVAfor MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	3	0.011027	0.003676	0.79	0.574	24.79%
B	3	0.003140	0.001047	0.23	0.874	7.06%
C	3	0.014548	0.004849	1.04	0.487	32.71%
D	3	0.001809	0.000603	0.13	0.936	4.04%
Error	3	0.013946	0.004649			
Total	15	0.044470				

Table 7. ANOVAfor SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	3	0.2650	0.08834	0.36	0.787	4.81%
B	3	4.1249	1.37496	5.64	0.095	74.98%
C	3	0.2211	0.07371	0.30	0.824	4.01%
D	3	0.1581	0.05270	0.22	0.880	2.87%
Error	3	0.7319	0.24396			
Total	15	5.5010				

4 Conclusions

By adopting sustainability concepts into machining operations, companies may decrease their environmental impact, enhance productivity, and ultimately contribute to a greener industrial sector. The outcomes are discussed below

- SN ratio and ANOVA was applied to examine the WEDM characteristics of the AZ61-15wt. % ZrC composite which was produced via the stir casting route.
- The WFR is the parameter that has the maximum effect on the MRR of AZ61-15wt.%ZrC composites, tracked by I, T-ON and T-OFF as per the results of the ANOVA analysis.
- The T-ON is the parameter that has the maximum effect on the SR of AZ61-15wt.%ZrC composites, tracked by I, WFR and T-OFF as per the results of the ANOVA analysis.
- Using the SN ratio and main effect plot, the influence of WEDM factors on MRR & SR were obviously established.

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