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Multi Response Optimization of Setting Process Variables in Face Milling of ZE41 Magnesium Alloy using Ranking Algorithms and ANOVA

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ABSTRACT:

This study presents the optimization of machining parameters on ZE41 Mg alloy fabricated by gravity die casting and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Focus on the optimization of machining parameters using the technique to get minimum surface roughness, cutting force, thermal stress, residual stress, chip thickness and maximum MRR. A number of machining experiments were conducted based on the L27 orthogonal array on computer numerical control vertical machining center. The experiments were performed on ZE41 using cutting tool of an ISO 460. 1-1140-034A0-XM GC3 of 20, 25 and 30mm diameter with cutting point 140 degrees, for different cutting conditions. TOPSIS and ANOVA were used to work out the fore most important parameters cutting speed, feed rate, depth of cut and tool diameter which affect the response. The expected values and measured values are fairly close. Finally, the study for optimizing machining process is surveyed and results show improvement in real experiments.

KEYWORDS:

Mg alloy; Different cutting conditions; TOPSIS; ANOVA; Machining; L27 array

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1. Introduction

Machining are run several times to obtain multiple benchmarks. Then, the results are analysed by means of statistical hypothesis tests [1-2]. The statistical tests can detect if there are differences between the performances of the algorithms. The problem is if there are differences, which algorithm is the best one? To use statistical tests in this step, it is necessary to make pair wise comparisons between the algorithms. Obviously, the required number of tests increases greatly with the number of algorithms being analysed. This is problematic, first because the tire some work of comparing each pair of algorithms; secondly, the probability of making a mistake increases. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang & Yoon [3] to evaluate the performance of alternatives through the similarity with the ideal solution. According to this technique, the best alternative would be one that is closest to the positive-ideal solution.

The positive-ideal solution is the one that maximizes the benefit criteria and minimizes the cost criteria. In summary, the positive-ideal solution is composed all best values attainable by the criteria. The interested reader shall refer to [4] for a broad survey about TOPSIS. Magnesium alloys have been applied in various fields such as in automotive [1, 2], aerospace [3], and portable microelectronics [4, 5]. This is mainly attributed to the lightness of magnesium being -one-third lighter than aluminium, three-fourths than zinc, and four-fifths than steel [6]. Magnesium alloys also have better machinability than other commonly used metals by the researcher [7]. The problem of chips creating sparks during finish machining has attracted research interests.

Though coolants can be used to prevent sparks in machining process of magnesium alloys, dry machining is desirable as it facilitates handling and reclamation of chips. It can offer cost reduction and an atmosphere without pollution was concluded by Kainer [8]. Usually, in the shearing zone and the tool chip contact zone, the increase in temperature on cutting tool and work-piece greatly influences tool wear and the cutting process itself [9, 10]. A change in environmental awareness and increasing cost pressures on industrial enterprises have led to a critical consideration of conventional cooling lubricants used in most machining processes. Depending on the work-piece, the production structure, and the production location the costs related to the use of cooling lubricants range from 7 - 17% of the total costs of the manufactured work piece [12-15]. By abandoning conventional cooling lubricants and using the technologies of dry machining or minimum quantity lubrication (MQL), this cost component can be reduced significantly. Besides an improvement in the efficiency of the production process, such a technology change makes a contribution to the protection of labour [16-18] and the environment [19, 20]. An enterprise can use eco-friendly production processes, which leads to a better image in the market [17-29].

Analysing and understanding the cutting process mechanisms is a key issue in developing an economical and safe dry machining process. Beyond the adoption of this new machining technology, the construction of machine tools and their peripheral equipment must also be considered [21]. Industrial practitioners will only be willing to accept dry machining technology when comprehensive solutions exist. Thus, results for a large variety of work piece materials and common production methods are essential to prove the superiority of this innovative machining technology [15-24]. The implementation of dry machining cannot be accomplished by simply turning off the cooling lubricant supply. In fact, the cooling lubricant performs several important functions, which, in its absence, must be taken over by other components in the machining process. Cooling lubricants reduce the friction, and thus the generation of heat, and dissipate the generated heat. In addition, cooling lubricants are responsible for a variety of secondary functions, like the transport of chips as well as the cleaning of tools, work pieces and fixtures. They provide for a failure-free and automated operation of the production system. In addition, cooling lubricants help to provide a uniform temperature field inside the work-piece and machine tool and help to meet specified tolerances was concluded by the researcher [21- 32]. In the present study, experimental details using the TOPSIS of parameter design have been employed for optimizing multiple performance characteristics which include minimum surface roughness, cutting force, thermal stress, residual stress, chip thickness and maximum MRR for machining of Mg alloy.

In short, there is an ample scope of applying the proposed methodology of TOPSIS for the optimization of machining parameters of Mg alloy and ANOVA for significant percentage contribution using the economical cutting tool of an ISO 460.1-1140-034A0-XM GC3 of different diameter with cutting point 140 degrees, which is used throughout the experimental work.

2. Experimental methods & measurements

The material used in this study is ZE41 magnesium cast alloy with the following chemical composition (in wt. %): 4.6 Zn, 1.5 rare earths, 0.85 Zr and balance Mg. To carry out the face milling of ZE41 die cast magnesium alloy, there were many experiments performed through different parametric conditions and required range of the process. They are dry face milling (by CNC milling machine, make BFW model Gaurav), cutting forces calculation (by dynamometer, make Kistler, make 9257B), residual stress calculation (by XRD and analytical method), thermal stress calculation (by infrared thermometer), chip thickness calculation (by image analysing software), surface roughness (by Talysurf) and material removal rate (by difference between initial and final by initial multiply by density). The machine used for face milling operation is a 3 axis vertical milling CNC machine with maximum axis feed of 10000 mm/min and a maximum spindle speed of 8000 RPM. The inserts used are 0.8mm nose radius carbide cutting inserts. To control the input parameters, spindle speed, feed rate, tool diameter and depth of cut were taken into consideration. Fig 1 shows the experimental setup. The chemical composition of ZE41 material has been analysed as per ASTM A751 - 11 standards by a spectro machine make Ametek, with a measuring range of 5 ppm, software used is Spectro spark analyser pro MAXx The observed composition of ZE41 was given tabulated in Table 1.

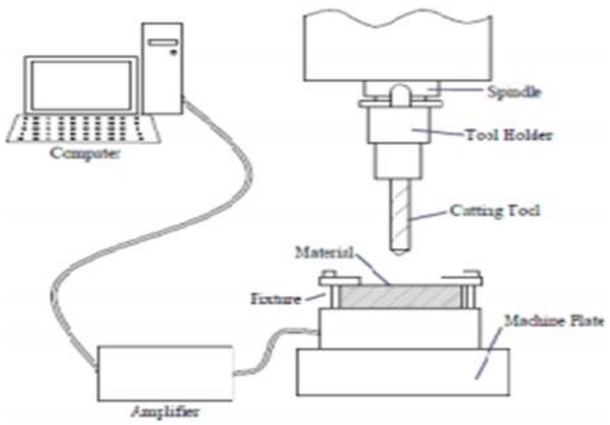

Fig. 1: Schematic diagram for experimental setup

Table 1: Chemical composition of ZE41

Alloy	Zn	Rare Earths	Zr	Mg
ZE41	4.6	1.5	0.85	Balance

The basic concept of TOPSIS method is that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the non-ideal solution. Each attribute in the decision matrix takes either monotonically increasing or decreasing utility. The steps involved for multi objective optimization are:

- **Step 1**: Determine the objective and identify the pertinent evaluation criteria.
- **Step 2**: Construct a decision matrix based on all the information available for the criteria. Each row of the decision matrix is allocated to one alternative and each column to one criterion. Therefore, an element, x_{ij} of the decision matrix shows the performance of i^{th} alternative with respect to j^{th} criterion.
- **Step 3**: Obtain the normalized decision matrix, r_{ij} using.

$$r_{ij} = x_{ij}/\sqrt{\sum_{i=1}^{m} x_{ij}^2} \tag{1}$$

- **Step 4**: Construct the weighted normalized decision matrix using,

$$GN_j = \left[\prod_{j=1}^{N} a_{ij}\right]^{1/N} \tag{2}$$

$$w_j = GN_j/\sum_{j=1}^{N} GN_J \tag{3}$$

a) Calculate the matrices, A3 and A4 such that A3 = A1 × A2 and A4 = A3/A2; $A_2 = [W_1, W_2 \dots W_N]^T$.
b) Determine the maximum Eigen value (λ_{max}) which is average of matrix A4.
c) Calculate the consistency index as CI = (λ_{max} - N)/ (N - 1). The smaller the value of CI, the smaller is the deviation from consistency.
d) Calculate the consistency ratio, CR = CI/RI, where RI is the random index value obtained by different orders of the pair-wise comparison matrices.
e) Usually, a CR of 0.1 or less is considered as acceptable, indicating the unbiased judgments made by the decision makers.

- **Step 5**: Obtain the weighted normalized matrix, V_{ij}, using,

$$V_{ij} = W_{ij} r_{ij} \quad (4)$$

- **Step 6**: Determine ideal (best) and non-ideal (worst) solutions using the following Eqn.:

$$V^+ = \{[\sum_i^{Max} V_{ij}/j \in J], [\sum_i^{Min} V_{ij}/j \in J']/1,2..N\} \quad (5)$$

$$V^- = \{[\sum_i^{Min} V_{ij}/j \in J], [\sum_i^{Max} V_{ij}/j \in J']/1,2..N\} \quad (6)$$

Where J = (j= 1, 2,...,N)/ j is associated with beneficial attributes and J^I = (j = 1,2,...,N)/ j is associated with non-beneficial attributes.

- **Step 7**: Obtain the separation measures. The separations of each alternative from the ideal and the non-ideal solutions are calculated by the corresponding Euclidean distances, as given in the following Eqn.:

$$S_i^+ = \left\{\sum_{j=1}^N \left(V_{ij} - V_j^+\right)^2\right\}^{0.5}, \qquad i = 1,2 \dots N \quad (7)$$

$$S_i^- = \left\{\sum_{j=1}^N \left(V_{ij} - V_j^-\right)^2\right\}^{0.5}, \qquad i = 1,2 \dots N \quad (8)$$

- **Step 8**: The relative closeness of a particular alternative to the ideal solution is computed as follows:

$$P_i = S_i^- / (S_I^+ + S_i^-) \quad (9)$$

- **Step 9**: A set of alternatives is arranged in the descending order, according to P_i value, indicating the most preferred and the least preferred solutions.

In the present scenario, machining of ZE41 minimum surface roughness, cutting force, thermal stress, residual stress, chip thickness and maximum MRR is a challenge to manufacturing industries for product quality and productivity improvement. In the present work spindle speed (rpm), feed per tooth (mm), depth of cut (mm) and tool diameter (mm) are taken as process parameter and are individually controllable as per Table 2.

Table 2: Factors and levels

Parameters	Unit	Levels		
		1	2	3
Spindle speed(V)	Rpm	7000	7500	8000
Feed (F)	mm	0.6125	0.634	0.645
Depth of cut (DOC)	mm	1.5	2	2.5
Tool diameter (TD)	mm	20	25	30

3. Results and discussion

The chemical composition and optimization parameter for getting the final response for the industrial benefits and mechanical product quality by TOPSIS method were determined. The observations were tabulated for discussion in Tables 3 and 4. Now the separation distance is measured from both positive ideal solution and negative ideal solution using Eqn. (6). The relative closeness index are calculated using Eqn. (7) and tabulated in Table 7. From the table, it is clearly visible that run 10 is getting the 1st rank. Hence, the corresponding input parameter i.e. V of 7500 rpm, F of 0.6125 mm, DOC of 1.5 mm and cutting diameter 20 mm is found to be the optimum combination. In course of data analysis, the normalized values are determined. The normalized values are tabulated in Table 5. Based on the impact on machining yield, the priority weight has been assigned to each response. Here, equal weight (0.167) has been assigned to each performance characteristic and weighted (normalized) decision-making matrix has been shown in Table 6.

The positive ideal solutions and negative ideal solutions are determined using Eqns. (4) – (5). As higher MRR is desirable (as it corresponds to higher-is-better criterion), maximum value among the recorded values are considered as positive ideal solution and minimum value referred as negative ideal solution. For rest of the responses like surface roughness, cutting force, thermal stress, residual stress and chip thickness lower values are desirable (as they correspond to lower-is-better, criterion). Hence, minimum value of the recorded value is regarded as positive ideal solution and maximum value represents the negative ideal solution. The positive ideal solution and negative ideal solution are determined and tabulated in Table 7 to Table 10.

Table 3: Orthogonal array with factors and responses

V (rpm)	F (mm)	DOC(mm)	TD (mm)	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
7000	0.6125	1.5	20	2.1794	38.5875	834.0791919	7994544	26596401.94	330.1
7000	0.6125	2	25	2.1476	51.45	1210.714107	9993180	34841716.89	431.04
7000	0.6125	2.5	30	3.0448	64.3125	1342.193141	12658028	-18614190.72	491.73
7000	0.634	1.5	20	2.1881	39.942	860.6629923	13990452	59934491.25	511.01
7000	0.634	2	25	2.1687	53.256	1291.877661	16655300	48182455.17	539.51
7000	0.634	2.5	30	3.1008	66.57	1410.706852	19320148	-29779123.45	572.92
7000	0.645	1.5	20	2.1905	40.635	904.3851903	21318784	41034134.64	556.97
7000	0.645	2	25	2.1798	54.18	1330.741711	24649844	42783845.17	697.94
7000	0.645	2.5	30	3.2348	67.725	1582.119221	26648480	159235647.4	760.74
7500	0.6125	1.5	20	1.4434	41.34375	927.1384742	20652572	28467766.43	796.03
7500	0.6125	2	25	2.6987	55.125	1142.513625	23317420	171067410.4	817.59
7500	0.6125	2.5	30	2.9917	68.90625	1794.256525	25316056	-180587813.7	832.83

V (rpm)	F (mm)	DOC(mm)	TD (mm)	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
7500	0.634	1.5	20	1.5587	42.795	949.0319116	27980904	133789660.6	722.8
7500	0.634	2	25	2.8298	57.06	1236.583624	30645752	50655166.37	820.48
7500	0.634	2.5	30	3.0564	71.325	1873.440283	34643024	-48944494.68	923.48
7500	0.645	1.5	20	1.7002	43.5375	1001.954631	37974084	56647503.86	779.92
7500	0.645	2	25	2.9792	58.05	1429.277654	39972720	87230583.74	786.57
7500	0.645	2.5	30	3.1769	72.5625	2075.096383	43303780	31457249.75	946.15
8000	0.6125	1.5	20	1.6616	44.1	1019.235684	29979540	95435578.5	986.03
8000	0.6125	2	25	2.2215	58.8	1557.17828	31978176	199293776.9	1118.95
8000	0.6125	2.5	30	3.9211	73.5	2132.043329	34643024	-199390229.9	1224
8000	0.634	1.5	20	1.8779	45.648	1056.07481	37974084	52408018.35	1044.16
8000	0.634	2	25	2.3761	60.864	1678.061682	40638932	185370585.3	1140.42
8000	0.634	2.5	30	4.0132	76.08	2195.305049	41971356	-151657008.7	1222.9
8000	0.645	1.5	20	1.9456	46.44	1075.769515	44636204	92319047.55	1079.2
8000	0.645	2	25	2.5007	61.92	1702.264317	46634840	187402841.8	1127.13
8000	0.645	2.5	30	4.1131	77.4	2287.73272	47967264	4371931760	1233.26

Table 4: Minimizing criteria

S. No	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
Level 1	1.9337	38.8125	-93.0593	39972720	4345335358	903.16
Level 2	1.9655	25.95	-376.635	37974084	4337090043	802.22
Level 3	1.0683	13.0875	-508.114	35309236	4390545951	741.53
Level 4	1.925	37.458	-26.5838	33976812	4311997269	722.25
Level 5	1.9444	24.144	-457.798	31311964	4323749305	693.75
Level 6	1.0123	10.83	-576.628	28647116	4401710883	660.34
Level 7	1.9226	36.765	-70.306	26648480	4330897625	676.29
Level 8	1.9333	23.22	-496.663	23317420	4329147915	535.32
Level 9	0.8783	9.675	-748.04	21318784	4212696113	472.52
Level 10	2.6697	36.05625	-93.0593	27314692	4343463994	437.23
Level 11	1.4144	22.275	-308.434	24649844	4200864350	415.67
Level 12	1.1214	8.49375	-960.177	22651208	4552519574	400.43
Level 13	2.5544	34.605	-114.953	19986360	4238142099	510.46
Level 14	1.2833	20.34	-402.504	17321512	4321276594	412.78
Level 15	1.0567	6.075	-1039.36	13324240	4420876255	309.78
Level 16	2.4129	33.8625	-167.875	9993180	4315284256	453.34
Level 17	1.1339	19.35	-595.198	7994544	4284701176	446.69
Level 18	0.9362	4.8375	-1241.02	4663484	4340474510	287.11
Level 19	2.4515	33.3	-185.156	17987724	4276496182	247.23
Level 20	2.4515	33.3	-185.156	17987724	4276496182	247.23
Level 21	1.8916	18.6	-723.099	15989088	4172637983	114.31
Level 22	0.192	3.9	-1297.96	13324240	4571321990	9.26
Level 23	2.2352	31.752	-221.996	9993180	4319523742	189.1
Level 24	1.737	16.536	-843.982	7328332	4186561175	92.84
Level 25	0.0999	1.32	-1361.23	5995908	4523588769	10.36
Level 26	2.1675	30.96	-241.69	3331060	4279612712	154.06
Level 27	0	0	-1453.65	0	0	0
Normalized	9.026311	127.7525	3608.322	1.15E+08	22089895651	2481.457

Table 5: Normalized data matrix

S. No	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
Level 1	0.214229	0.30381	0.001025	0.348437	0.196711448	0.363964
Level 2	0.217752	0.203127	-0.10438	0.331015	0.196338186	0.323286
Level 3	0.118354	0.102444	-0.14082	0.307786	0.198758112	0.298828
Level 4	0.213265	0.293208	-0.00737	0.296171	0.195202247	0.291059
Level 5	0.215415	0.18899	-0.12687	0.272942	0.195734257	0.279574
Level 6	0.11215	0.084773	-0.1598	0.249713	0.199263544	0.26611
Level 7	0.21314	0.287783	-0.01948	0.232291	0.196057858	0.272537
Level 8	0.214185	0.181758	-0.13764	0.203255	0.195978649	0.215728
Level 9	0.097304	0.075732	-0.20731	0.185833	0.190706927	0.19042
Level 10	0.295769	0.282235	-0.02579	0.238099	0.196626732	0.176199
Level 11	0.156697	0.174361	-0.08548	0.214869	0.190171308	0.16751

S. No	Surface finish (µm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (µm)
Level 12	0.124237	0.066486	-0.2661	0.197448	0.206090588	0.161369
Level 13	0.282995	0.270875	-0.03186	0.174218	0.191858856	0.20571
Level 14	0.142173	0.159214	-0.11155	0.150989	0.195622318	0.166346
Level 15	0.117069	0.047553	-0.28805	0.116146	0.200131152	0.124838
Level 16	0.267319	0.265063	-0.04652	0.087109	0.195351048	0.182691
Level 17	0.125622	0.151465	-0.16495	0.069687	0.193966565	0.180011
Level 18	0.103719	0.037866	-0.34393	0.040651	0.196491399	0.115702
Level 19	0.271595	0.26066	-0.05131	0.156797	0.193595128	0.099631
Level 20	0.271595	0.26066	-0.05131	0.156797	0.193595128	0.099631
Level 21	0.271595	0.26066	-0.05131	0.156797	0.193595128	0.099631
Level 22	0.209565	0.145594	-0.2004	0.139375	0.188893513	0.046066
Level 23	0.021271	0.030528	-0.35971	0.116146	0.206941765	0.003732
Level 24	0.247632	0.248543	-0.06152	0.087109	0.195542967	0.076205
Level 25	0.192437	0.129438	-0.2339	0.06388	0.189523809	0.037413
Level 26	0.011068	0.010332	-0.37725	0.052266	0.204780903	0.004175
Level 27	0.001025	0.001025	-0.40286	0.001025	0.001025	0.001025

Table 6: Weighted normalized decision-making matrix

S. No	Surface finish (µm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (µm)
Level 1	0.085692	0.060762	0.001025	0.034844	0.019671145	0.036396
Level 2	0.087101	0.040625	-0.01044	0.033102	0.019633819	0.032329
Level 3	0.047342	0.020489	-0.01408	0.030779	0.019875811	0.029883
Level 4	0.085306	0.058642	-0.00074	0.029617	0.019520225	0.029106
Level 5	0.086166	0.037798	-0.01269	0.027294	0.019573426	0.027957
Level 6	0.04486	0.016955	-0.01598	0.024971	0.019926354	0.026611
Level 7	0.0852	0.057557	-0.00195	0.023229	0.019605786	0.027254
Level 8	0.085674	0.036352	-0.01376	0.020325	0.019597865	0.021573
Level 9	0.038922	0.015146	-0.02073	0.018583	0.019070693	0.019042
Level 10	0.118307	0.056447	-0.00258	0.02381	0.019662673	0.01762
Level 11	0.062679	0.034872	-0.00855	0.021487	0.019017131	0.016751
Level 12	0.049695	0.013297	-0.02661	0.019745	0.020609059	0.016137
Level 13	0.113198	0.054175	-0.00319	0.017422	0.019185886	0.020571
Level 14	0.056869	0.031843	-0.01115	0.015099	0.019562232	0.016635
Level 15	0.046828	0.009511	-0.0288	0.011615	0.020013115	0.012484
Level 16	0.106927	0.053013	-0.00465	0.008711	0.019535105	0.018269
Level 17	0.050249	0.030293	-0.0165	0.006969	0.019396656	0.018001
Level 18	0.041488	0.007573	-0.03439	0.004065	0.01964914	0.01157
Level 19	0.108638	0.052132	-0.00513	0.01568	0.019359513	0.009963
Level 20	0.108638	0.052132	-0.00513	0.01568	0.019359513	0.009963
Level 21	0.108638	0.052132	-0.00513	0.01568	0.019359513	0.009963
Level 22	0.108638	0.052132	-0.00513	0.01568	0.019359513	0.009963
Level 23	0.083826	0.029119	-0.02004	0.013937	0.018889351	0.004607
Level 24	0.008508	0.006106	-0.03597	0.011615	0.020694176	0.000373
Level 25	0.099053	0.049709	-0.00615	0.008711	0.019554297	0.007621
Level 26	0.076975	0.025888	-0.02339	0.006388	0.018952381	0.003741
Level 27	0.001025	0.001025	-0.04029	0.001025	0.001025	0.001025

Table 7: Positive ideal solution and negative solution

Ideal	0.118307	0.060762	0.001025	0.034844	0.020694176	0.036396
The worst	0.000125	0.005698	-0.04029	0.001236	0.0045123	0.000014

Table 8: Ranking of the alternative

S. No	di+	di-	ci	Result - Rank	S. No	di+	di-	ci	Result - Rank
Level 1	0.0326318	0.124835	0.79277	3	Level 15	0.098375097	0.055735	0.361656	24
Level 2	0.038845697	0.112491	0.743316	11	Level 16	0.034986659	0.12769	0.784932	4
Level 3	0.083162491	0.07472	0.473263	18	Level 17	0.08336389	0.068974	0.45277	20
Level 4	0.034292436	0.11994	0.777657	9	Level 18	0.107135346	0.048475	0.311513	25
Level 5	0.04302161	0.107353	0.713904	13	Level 19	0.03552556	0.128358	0.783227	5
Level 6	0.088106778	0.067966	0.435477	21	Level 20	0.03552556	0.128358	0.783227	5
Level 7	0.036467219	0.117082	0.762505	10	Level 21	0.03552556	0.128358	0.783227	5

S. No	di+	di-	ci	Result - Rank	S. No	di+	di-	ci	Result - Rank
Level 8	0.047770197	0.10309	0.683347	14	Level 22	0.03552556	0.128358	0.783227	5
Level 9	0.096854783	0.056554	0.368649	23	Level 23	0.03552556	0.09462	0.727032	12
Level 10	0.02237489	0.140957	0.863009	1	Level 24	0.063582793	0.025322	0.284823	26
Level 11	0.066370438	0.085182	0.562063	16	Level 25	0.134812301	0.118118	0.466997	19
Level 12	0.09114355	0.062517	0.406852	22	Level 26	0.045200074	0.085802	0.654968	15
Level 13	0.025216711	0.134981	0.84259	2	Level 27	0.149260445	0.000127	0.0012365	27
Level 14	0.074276947	0.077357	0.510156	17					

Table 9: From ideal

S. No	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
Level 1	0.032616	0.001236	0.0005632	0.000123	0.001023032	0.000012
Level 2	0.031207	0.020137	0.010438	0.001742	0.001060358	0.004068
Level 3	0.070966	0.040273	0.014082	0.004065	0.000818365	0.006514
Level 4	0.033001	0.002121	0.000737	0.005227	0.001173952	0.00729
Level 5	0.032142	0.022964	0.012687	0.007549	0.001120751	0.008439
Level 6	0.073448	0.043807	0.01598	0.009872	0.000767822	0.009785
Level 7	0.033108	0.003205	0.001948	0.011615	0.001088391	0.009143
Level 8	0.032633	0.02441	0.013764	0.014518	0.001096312	0.014824
Level 9	0.079386	0.045616	0.020731	0.01626	0.001623484	0.017354
Level 10	0.000123	0.004315	0.002579	0.011034	0.001031503	0.018776
Level 11	0.055628	0.02589	0.008548	0.013357	0.001677046	0.019645
Level 12	0.068613	0.047465	0.02661	0.015099	8.51177E-05	0.020259
Level 13	0.00511	0.006587	0.003186	0.017422	0.001508291	0.015825
Level 14	0.061438	0.028919	0.011155	0.019745	0.001131945	0.019762
Level 15	0.07148	0.051251	0.028805	0.023229	0.000681061	0.023913
Level 16	0.01138	0.007749	0.004652	0.026133	0.001159072	0.018127
Level 17	0.068059	0.030469	0.016495	0.027875	0.00129752	0.018395
Level 18	0.07682	0.053189	0.034393	0.030779	0.001045037	0.024826
Level 19	0.00967	0.00863	0.005131	0.019164	0.001334664	0.026433
Level 20	0.00967	0.00863	0.005131	0.019164	0.001334664	0.026433
Level 21	0.00967	0.00863	0.005131	0.019164	0.001334664	0.026433
Level 22	0.00967	0.00863	0.005131	0.019164	0.001334664	0.026433
Level 23	0.00967	0.00863	0.005131	0.019164	0.001334664	0.026433
Level 24	0.034481	0.031643	0.02004	0.020906	0.001804825	0.03179
Level 25	0.109799	0.054656	0.035971	0.023229	0.00012365	0.036023
Level 26	0.019255	0.011053	0.006152	0.026133	0.00113988	0.028776
Level 27	0.118307	0.060762	0.040286	0.034844	0.020694176	0.036396

Table 10: From the worst

S. No.	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
Level 1	0.085692	0.060762	0.040286	0.034844	0.019671145	0.036396
Level 2	0.087101	0.040625	0.029848	0.033102	0.019633819	0.032329
Level 3	0.047342	0.020489	0.026204	0.030779	0.019875811	0.029883
Level 4	0.085306	0.058642	0.039549	0.029617	0.019520225	0.029106
Level 5	0.086166	0.037798	0.027599	0.027294	0.019573426	0.027957
Level 6	0.04486	0.016955	0.024306	0.024971	0.019926354	0.026611
Level 7	0.0852	0.057557	0.038338	0.023229	0.019605786	0.027254
Level 8	0.085674	0.036352	0.026522	0.020325	0.019597865	0.021573
Level 9	0.038922	0.015146	0.019555	0.018583	0.019070693	0.019042
Level 10	0.118307	0.056447	0.037707	0.02381	0.019662673	0.01762
Level 11	0.062679	0.034872	0.031738	0.021487	0.019017131	0.016751
Level 12	0.049695	0.013297	0.013676	0.019745	0.020609059	0.016137
Level 13	0.113198	0.054175	0.0371	0.017422	0.019185886	0.020571
Level 14	0.056869	0.031843	0.029131	0.015099	0.019562232	0.016635
Level 15	0.046828	0.009511	0.011482	0.011615	0.020013115	0.012484
Level 16	0.106927	0.053013	0.035634	0.008711	0.019535105	0.018269
Level 17	0.050249	0.030293	0.023791	0.006969	0.019396656	0.018001

S. No.	Surface finish (μm)	MRR (cm^3/min)	Cutting force (N)	Thermal stress (N/mm^2)	Residual stress (N/mm^2)	Chip thickness (μm)
Level 18	0.041488	0.007573	0.005893	0.004065	0.01964914	0.01157
Level 19	0.108638	0.052132	0.035155	0.01568	0.019359513	0.009963
Level 20	0.108638	0.052132	0.035155	0.01568	0.019359513	0.009963
Level 21	0.108638	0.052132	0.035155	0.01568	0.019359513	0.009963
Level 22	0.108638	0.052132	0.035155	0.01568	0.019359513	0.009963
Level 23	0.083826	0.029119	0.020246	0.013937	0.019359513	0.009963
Level 24	0.008508	0.006106	0.004315	0.011615	0.018889351	0.004607
Level 25	0.099053	0.049709	0.034134	0.008711	0.020694176	0.000373
Level 26	0.076975	0.025888	0.016896	0.006388	0.019554297	0.007621
Level 27	0.0001236	0.0001235	0.000741	0.000147	0.0001236	0.000452

3.1. Confirmation experiment

The confirmation experiment is conducted at the optimum settings to verify the quality characteristics for ZE41 Mg alloy by machining process recommended by the investigation. The TOPSIS grade value is found to be 0.596. Hence the TOPSIS for the optimization of the multi response problems is a very useful tool for predicting the output responses. From Table 11, F are found to be the most significant factors affecting the surface finish, and V, DOC and TD contribute equally. From Fig. 2, it can be inferred that the V of 7500 rpm, F of 0.6125 mm, DOC of 2.5 mm and cutting diameter 30 mm are most optimum conditions for obtaining minimum torque. From Table 12, except F, other input parameters such as, and V, DOC and TD are found to be the most significant factors affecting the MRR. From Fig. 3, it can be inferred that, V of 8000 rpm, F of 0.6125 mm, DOC of 2.5mm and cutting diameter 30mm are most optimum conditions for obtaining maximum material rate. From Table 13, except F, other input parameters such as, and V, DOC and TD are found to be the most significant factors affecting the minimum cutting force.

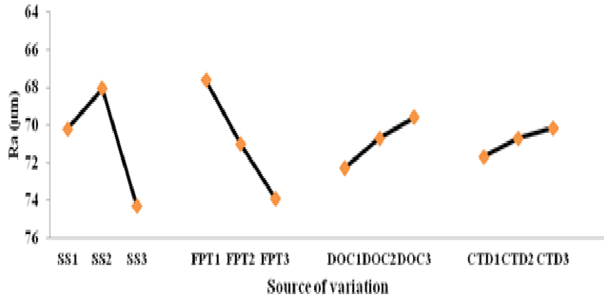

Fig. 2: Factor effects on surface finish

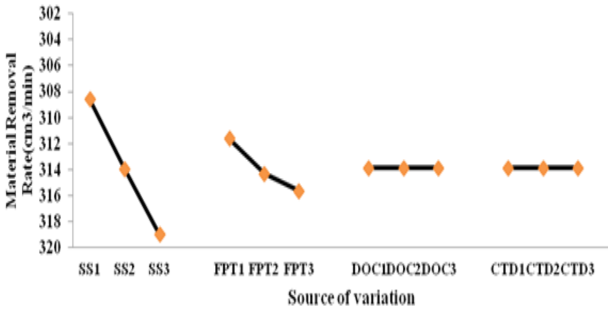

Fig. 3: Factor effects on MRR

Table 11: Results of ANOVA on surface finish

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	-1135.61	2	-567.8058809	-283902.9404	4.2	22%
F (mm)	-1672.98	2	-836.492412	-418246.206	4.2	33%
D O C(mm)	-1136.61	2	-568.3074148	-284153.7074	4.2	22%
T D(mm)	-1136.66	2	-568.3297288	-284164.8644	4.2	22%
Error	0.002	27	0.002			
SSF	-5081.870873					

Table 12: Results of ANOVA on MRR

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	228749.74	2	114374.8682	57187434.09	4.2	35%
F (mm)	-32842.26	2	-16421.13088	-8210565.439	4.2	-5%
D O C(mm)	227977.11	2	113988.5573	56994278.66	4.2	35%
TD (mm)	227977.11	2	113988.5573	56994278.66	4.2	35%
Error	0.002	27	0.002			
SSF	651861.7039					

Table 13: Results of ANOVA on cutting force

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	162102271.56	2	81051135.78	40525567891	4.2	34%
F (mm)	-105638.05	2	-52819.02274	-26409511.37	4.2	0%
DOC(mm)	159518484.95	2	79759242.47	39879621237	4.2	33%
TD (mm)	159511240.79	2	79755620.4	39877810198	4.2	33%
Error	0.002	27	0.002			
SSF	481026359.3					

From Fig. 4, it can be inferred that, V of 7000 rpm, feed per tooth of 0.6125 mm, DOC of 2mm and cutting diameter 20mm are most optimum conditions for obtaining minimum cutting force. From Table 14, except feed per tooth, other input parameters such as, and V, DOC and TD are found to be the most significant factors affecting the minimum thermal stress. From Fig. 5, it can be inferred that, V of 7000 rpm, F of 0.6125 mm, DOC of 2mm and cutting diameter 20 mm are most optimum conditions for obtaining minimum thermal stress. From Table 15, except F, other input parameters such as, and V, DOC and TD are found to be the most significant factors affecting the minimum residual stress.

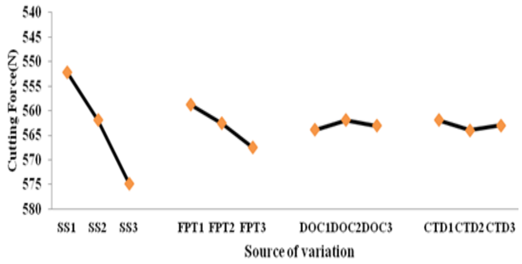

Fig. 4: Factor effects on cutting force

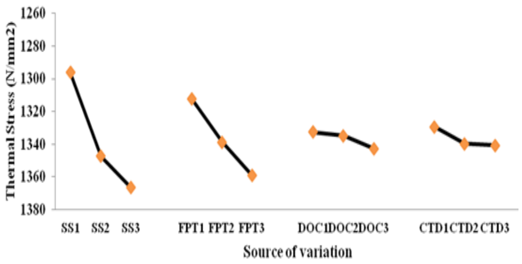

Fig. 5: Factor effects on thermal stress

From Fig. 6, it can be inferred that, V of 7000 rpm, F of 0.634 mm, DOC of 2mm and cutting diameter 25mm are most optimum conditions for obtaining minimum residual stress. From Table 16, except F, other input parameters such as, and V, DOC and TD are found to be the most significant factors affecting the minimum residual stress. From Fig. 7, it can be inferred that, spindle speed of 7000 rpm, F of 0.6125 mm, DOC of 1.5 mm and cutting diameter 20 mm are most optimum conditions for obtaining minimum residual stress. The significance of a variable on the quality characteristic can be evaluated by using F-ratio. The F-ratio is the ratio of MS to the error. Generally, when F is greater than P - value, it means that the change of experimental variables has a significant effect on the quality characteristics. The ANOVA indicates that, F and V speed are significant for all the responses (F calculated value is more than the F table value at 95% confidence level).

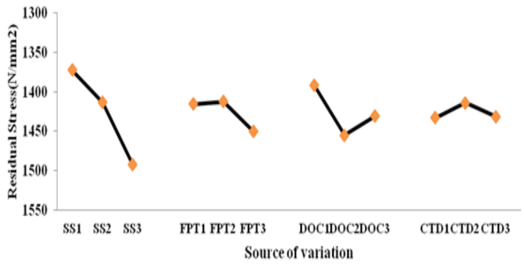

Fig. 6: Factor effects on Residual Stress

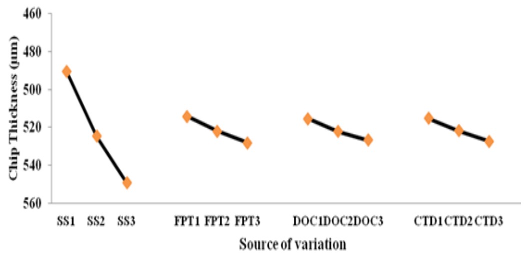

Fig. 7: Factor effects on chip thickness

Table 14: Results of ANOVA on thermal stress

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	77020909981629500	2	3.85105E+16	1.92552E+19	4.2	35%
F (mm)	-595636.69	2	-297818.3439	-148909171.9	4.2	0%
DOC(mm)	69987550344296900	2	3.49938E+16	1.74969E+19	4.2	32%
TD (mm)	69958552900272500	2	3.49793E+16	1.74896E+19	4.2	32%
Error	0.002	27	0.002			
SSF	2.16967E+17					

Table 15: Results of ANOVA on residual stress

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	7866801400683710000	2	3.9334E+18	1.9667E+21	4.2	34%
F (mm)	-677825.89	2	-338912.9431	-169456471.6	4.2	0%
DOC(mm)	7623193853621940000	2	3.8116E+18	1.9058E+21	4.2	33%
TD (mm)	7857228506237750000	2	3.92861E+18	1.96431E+21	4.2	34%
Error	0.002	27	0.002			
SSF	2.33472E+19					

Table 16: Results of ANOVA on chip thickness

Source of variation	Sum of squares	DOF	Mean square	F	F table	Contribution %
V (rpm)	60784861.28	2	30392430.64	15196215321	4.2	35%
F (mm)	-90643.14	2	-45321.57002	-22660785.01	4.2	0%
DOC(mm)	56196652.84	2	28098326.42	14049163211	4.2	32%
TD (mm)	56213303.53	2	28106651.76	14053325881	4.2	32%
Error	0.002	27	0.002			
SSF	173104174.5					

4. Conclusion

The objective of this study was to find out the optimized combination of V, F, DOC and cutting tool diameters so that the minimum surface roughness, cutting force, thermal stress, residual stress, chip thickness and maximum MRR using TOPSIS and ANOVA, while machining ZE41 Mg alloy. From this analysis, it is revealed that the V and F are prominent factors which affect the machining of ZE41. The best performance characteristics were obtained with ZE41 when machining the optimum parameters with the V of 7500 rpm, F of 0.6125 mm, DOC of 1.5 mm and cutting diameter 20 mm for environment benefits. Confirmation test results proved that the determined optimum combination of machining parameters satisfy the real requirements of machining operation of ZE41.

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