Multi Response Optimization of Setting Input Variables for Getting Better Product Quality in Machining of Magnesium AM60 by Grey Relation Analysis and ANOVA

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Abstract

This study presents the optimization of Machining parameters on AM60 Mg alloy manufactured by Gravity Die Casting and with responses supported orthogonal array with Grey relation analysis. Focuses on the optimization of Machining input parameters using the technique to get minimum surface roughness, Minimum Tool Wear, Cutting Time, Power Requirement, Torque and Maximum MRR. A number of Machining trails were conducted based on the L9 orthogonal array on CNC machine. The experiments were performed on AM60 alloy using cutting tool of an ISO 460.1-1140-034A0-XM GC3 of 12,16 and 25 mm diameter with cutting point 140 degrees, throughout the experimental work under different cutting conditions. Grey relation analysis & ANOVA were used to work out the fore most important parameters Cutting speed, feed rate, Depth of Cut and Tool Diameter which affects the Response. The expected response and measured response are fairly close. The given model could be used to select the level of Machining parameters.

Keywords

Mg Alloy, Different Cutting conditions, Grey Relation Analysis and ANOVA

1 Introduction

An incredible trouble in evolutionary computation is the correlation of calculations. For the most part, the calculations are run a few times to acquire different benchmarks. At that point, the outcomes are broke down by methods for measurable speculation tests [1-9]. The measurable tests can recognize if there are contrasts between the exhibitions of the calculations. The problem is if there are contrasts, which calculation is the best one? To utilize measurable tests in this progression, it is necessary to make pairwise examinations between the calculations. Clearly, the quantity of tests required increases incredibly with the quantity of calculations being broke down. This is risky, first on the grounds that the tire some work of looking at each match of calculations; also and more essential, the likelihood of committing an error increments. Finding an option with the most financially savvy or most astounding achievable execution under the given requirements, by boosting wanted factors and limiting undesired ones is known as process streamlining. Taguchi technique is an orderly and effectiveness way to deal with locates the ideal optimal of information parameters. This strategy uses the orthogonal exhibit of tests to decrease the quantity of analyses in any machining procedure. Utilizing the orthogonal exhibit nine trials has been directed. L9 orthogonal exhibit can't be utilized for this examination as 4 input parameters have been utilized, rather Grey connection investigation is utilized for the optimization. Magnesium combinations have been connected in different fields, for example, in car [1, 2], aviation [3], and convenient microelectronics [4, 5]. This is for the most part credited to the gentility of magnesium—33% lighter than aluminum, three-fourths than zinc, and four-fifths than steel [6]. Magnesium composites likewise have preferred machinability over other normally utilized metals [7]. The issue of chips making flashes amid get done with Machining has pulled in inquire about interests. Despite the fact that coolants can be utilized to avoid starts in Machining procedure of magnesium amalgams, dry machining is alluring as it encourages taking care of and recovery of chips. It can offer cost diminishment and an air without contamination [8]. Usually, in the shearing zone and in addition the device chip contact zone, the expansion

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in temperature on cutting apparatus and work piece significantly impacts instrument wear and the cutting procedure itself [9, 10]. A change in natural mindfulness and expanding cost weights on modern ventures have prompted a basic thought of customary cooling ointments utilized as a part of most machining forms. Contingent upon the workpiece, the generation structure, and the creation area the costs identified with the utilization of cooling ointments run from 7-17% of the aggregate expenses of the fabricated work piece [12-15]. By forsaking customary cooling greases and utilizing the advances of dry machining or least amount oil (MQL), this cost part can be decreased essentially. Other than a change in the proficiency of the creation procedure, such an innovation change makes a commitment to the assurance of work [16-18] and the earth [19, 20]. The decrease of considerable introduction to cooling ointments at the work put lessens the perils and enhances the work result in the meantime. Moreover, a venture can utilize eco-accommodating generation forms, which prompts a superior picture in the market [17-28]. Investigating and understanding the cutting procedure components is a key issue in building up a sparing and safe dry machining process. Past the reception of this new machining innovation, the development of machine apparatuses and their fringe hardware should likewise be considered [21]. Mechanical specialists may will to acknowledge dry machining innovation when far reaching arrangements exist. Subsequently, comes about for an extensive assortment of work piece materials and regular generation strategies are fundamental to demonstrate the prevalence of this creative machining innovation [15-24]. The execution of dry machining can't be proficient by just killing the cooling oil supply. Truth be told, the cooling ointment plays out a few essential capacities, which, in its nonattendance, must be assumed control by different segments in the machining procedure. Cooling oils diminish the rubbing, and along these lines the age of warmth, and disperse the produced warm. What's more, cooling oils are in charge of an assortment of optional capacities, similar to the vehicle of chips and in addition the cleaning of devices, work pieces and installations. They accommodate a failure free, robotized operation of the generation framework. Also, cooling oils help to give a uniform temperature field inside the workpiece and machine apparatus and help to meet determined resistances [21-30]. In the present Study, exploratory points of interest utilizing the Grey relation analysis of parameter configuration have been utilized for improving numerous execution attributes which incorporate least surface roughness (Ra), Min Tool Wear, Cutting Time, Power Requirement and Torque and Maximum MRR for Machining of Mg Alloy. To put it plainly, there is an abundant extent of applying the proposed technique of Grey relation analysis 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 utilized all through the trial work for the advantages of industries.

2 Experimental Methods and Measurements

The material utilized as a part of this investigation is AM60 magnesium cast combination and Experimental Setup, as appeared in Fig. 1, AM60 magnesium composite was processed by CNC HURCO machine (VM20). The rake angle for Sandvik Coromant carbide indexable face Machining is 45o and range of tidy up is 75 mm. The width of cut is 25mm, which is equivalent to the width of workpiece. The BHN for both the materials is in the range of 45-60. For surface roughness measurement Taylor Hobson – Talysurf Surface roughness testing machines are used, Material Removal Rate (MRR) is measured by measuring the work-piece before and after the machining procedure with the assistance of computerized measuring machine, taking note of the machining time with the assistance of a stopwatch and finally dividing the weight removed during machining by machining time. Tool Wear (TW) was measured by image processing techniques in Tool Presetter manufactured by ZOLLER Germany. Cutting Time (CT) was measured by CNC Machine Timer in CPU, Power utilization was measured by utilizing two watt meter strategy. Two aligned wattmeter were utilized and their readings were included in the wake of increasing them with appropriate duplicating variable to get Power Consumption (PC) in Kilo watt. Torque sensor essentially comprises of a thin-walled chamber, and a piezo-resistive MEMS strain gage reinforced on the surface of the detecting component where the shear strains is Maximum. The strain gage incorporates eight piezo resistances and four are associated in a full Wheatstone circuit connect, which is utilized to quantify the connected torque constrain amid machining strategies.
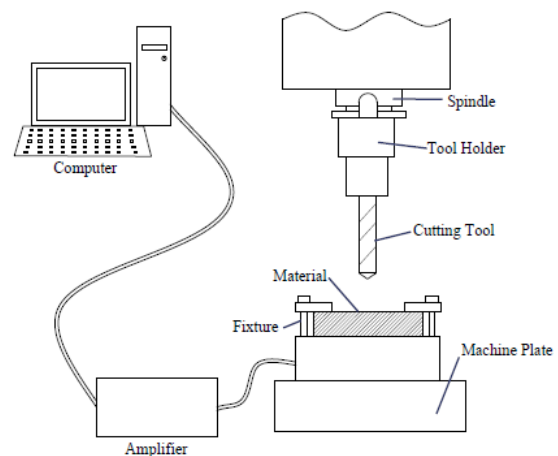

Fig. 1 Schematic Diagram for Experimental Setup

2.1 Study of Chemical composition of element

The chemical composition of AM60 material has been analyzed as per ASTM A751 – 11 standards by a spectro Machine Make Ametek, with a measuring range of 5 ppm, software used is Spectro spark analyzer pro MAXx for analytical operation

and calibration is to ensure the chemical composition at different stages (Receiving of incoming alloy, melting metal and holding alloys). The observed composition of AM60 was tabulated in Table 1.

Table 1 Chemical composition of AM60.

Alloy	Zn	Mischmetal	Si	Cu	Mn	Fe	Zr	Mg
AM60	4.16	4.15	0.12	0.03	0.12	.003	0.85	Balance

2.1.1 Step 1: Grey relation generation

The first step of Grey relation analysis is carried out by pre-processing of the output response data. It is performed for normalizing the data, which is shown in Table 2. In the case Maximum Thinning, higher the better performance characteristic is considered, and hence, it is normalized in the range between 0 to 1 using the formula (4) to avoid the effect of different units and to reduce the variability. The normalized output parameter for Maximum Thinning corresponding to the larger the better criterion is expressed as

$$X_i^*(k) = \frac{X_i^{(0)}(k) - \min X_i^{(0)}(k)}{\max X_i^{(0)}(k) - \min X_i^{(0)}(k)} \tag{1}$$

Similarly, the normalized output parameter for Maximum Thinning corresponding to the Higher the better criterion is expressed as.

$$X_i^*(k) = \frac{\max X_i^{(0)}(k) - X_i^{(0)}(k)}{\max X_i^{(0)}(k) - \min X_i^{(0)}(k)} \tag{2}$$

Where, $X_i^*(k)$ is the normalized value, is the maximum value of the sequence, is the desired sequence and is the minimum value of the sequence. $X_i^{(0)}(k)$ is the minimum value of the sequence.

2.1.2 Step 2: Grey relational coefficients

In the second step, the Grey relation coefficient is calculated to express the correlation between the best and actual experimental results for the both the responses. The Table 2, shows the Grey relation coefficient. It is expressed as.

$$\gamma x_0(k), x_i^* = \frac{\Delta_{\min} - C\Delta_{\max}}{\Delta_{oi}(k) + C\Delta_{\max}} \tag{3}$$

$$\Delta_{oi}(k) = \|X_0(k) - X_i^*(k)\|$$
$$\Delta_{\min} = \text{Smallest value of } \Delta_{oi}(k) \tag{4}$$
$$\Delta_{\max} = \text{largest value of } \Delta_{oi}(k)$$

$\Delta_{oi}(k)$: Different values for $X_0(k)$, $X_0(k)$ denotes the sequences and $X_i^*(k)$ denotesthe comparability sequences. γ is distinguishing or identified coefficient. If all the process parameters have equal weightage, then it is set to be 0.5.

2.1.3 Step 3: Grey relational Grade

The third step of Grey relation grade is to determine the average Grey relational coefficient corresponding to each performance characteristics. The evaluation of the multi objective characteristic is based on the Grey relation grade, which is shown in Table 2. If the Grey relational grade has greater value, it indicates that concerned parameters combination is the optimum value. The Grey relational grade is expressed as follows,

$$\tau_i = \frac{1}{n} \sum_{i=1}^{n} \left(\gamma(x_o(k), x_i^*(k)) \right) \tag{5}$$

Where, τ_i the Grey relational grade, where n is the number of process responses. The higher Grey relation grade represents that the corresponding experimental results are considered to be closer to the ideal normalized value.

Table 2 Factors and Levels

Parameters	Unit	Levels		
		1	2	3
Cutting speed (V)	m/min	188	207	226
Feed (F)	mm/rev	.06	.08	0.1
Depth Of Cut (DOC)	mm	0.5	1	1.5
Tool Diameter (TD)	mm	12	16	25

3 Experimentation Factors and Levels

In the present Scenario, Machining of AM60 with minimum surface roughness, Tool Wear, Cutting Time, Power Requirement and Torque and Maximum MRR is a Challenge to manufacturing industries. In the present work Cutting speed (V), Feed (mm/rev), Depth of Cut (DOC) and Tool Diameter (mm) are taken as Process parameter and are individually controllable.

4 Result and discussion

The Chemical Composition and optimization parameter for getting the final response for the industrial benefits and mechanical product quality by Grey Relation Analysis Method were determined by the above said procedure. The observations were tabulated for discussion.

4.1 Chemical Composition

From Table 1, Zinc is utilized as a part of mix with magnesium to create change in room-temperature quality; be that as it may, it increments hot shortness when included sums more noteworthy than 1 wt% to magnesium compounds. Zinc is additionally utilized as a part of blend with zirconium, rare earths, or thorium to create precipitation hardenable magnesium amalgams having great quality. Zinc likewise defeats the unsafe destructive impact of iron and nickel pollutions that may be available in the magnesium combination. Uncommon earth metals are added to magnesium combinations either as Mischmetal or as didymium. Mischmetal is a characteristic

Table 3 L9 Orthogonal array with factors and responses

SI. No	V mm/min	F mm/rev	DOC mm	TD mm	Ra μm	TW μ	MRR cm3/min	CT Sec	PR kw	T Nm
1	188	0.06	0.5	12	0.8525	0.0800	0.6074	121	1.0093	1.9336
2	188	0.08	1	16	0.9270	0.0740	3.2363	113	4.0371	10.3128
3	188	0.1	1.5	25	0.9700	0.0690	9.1020	106	7.2668	29.0046
4	207	0.06	0.5	12	0.8725	0.0610	0.6688	94	1.2236	2.1291
5	207	0.08	1	16	0.9470	0.0560	3.5633	87	4.8944	11.3550
6	207	0.1	1.5	25	0.9900	0.0490	10.0219	77	8.8098	31.9359
7	226	0.06	0.5	12	0.9525	0.0470	0.7302	79	1.4585	2.3245
8	226	0.08	1	16	0.9700	0.0420	3.8904	71	5.8341	12.3972
9	226	0.1	1.5	25	0.9900	0.0360	10.9418	62	10.5013	34.8672

Table 4 Normalized values, Grey relation coefficient and Grey grades of responses

Trail No	Normalized S/N ratio						Grey relation co efficient						Grey relation	
	Ra μm	TW μ	MRR cm3/ min	CT Sec	PR kw	T Nm	Ra μm	TW μ	MRR cm3/ min	CT Sec	PR kw	T Nm	GRADE	RANK
1	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	0.3333	1.0000	0.3333	1.0000	0.3333	0.3333	0.5556	7.0000
2	0.5604	0.9024	0.5787	0.8977	0.5918	0.5788	0.5322	0.8367	0.5427	0.8302	0.5506	0.5428	0.6392	4.0000
3	0.8630	0.8147	0.9363	0.8020	0.8428	0.9363	0.7849	0.7296	0.8870	0.7163	0.7608	0.8871	0.7943	1.0000
4	0.1547	0.6605	0.0333	0.6224	0.0822	0.0333	0.3717	0.5956	0.3409	0.5697	0.3527	0.3409	0.4286	9.0000
5	0.7028	0.5533	0.6120	0.5065	0.6741	0.6121	0.6272	0.5282	0.5630	0.5033	0.6054	0.5631	0.5650	5.0000
6	1.0000	0.3861	0.9696	0.3240	0.9250	0.9697	1.0000	0.4489	0.9427	0.4252	0.8696	0.9428	0.7715	3.0000
7	0.7413	0.3339	0.0637	0.3624	0.1572	0.0637	0.6591	0.4288	0.3481	0.4395	0.3724	0.3481	0.4327	8.0000
8	0.8630	0.1931	0.6423	0.2027	0.7490	0.6425	0.7849	0.3826	0.5830	0.3854	0.6658	0.5831	0.5641	6.0000
9	1.0000	0.0000	1.0000	0.0000	1.0000	1.0000	1.0000	0.3333	1.0000	0.3333	1.0000	1.0000	0.7778	2.0000

blend of uncommon earths containing around 50 wt% cerium, the rest of principally lanthanum and neodymium; didymium is a characteristic blend of roughly 85% neodymium and 15% praseodymium. Augmentations of uncommon earths increment the quality of magnesium combinations at raised temperatures. They additionally diminish weld breaking and porosity in throwing in light of the fact that they limit the solidifying scope of the amalgams. Zirconium has an intense grain refining impact on magnesium combinations. It is added to compounds containing zinc, uncommon earths, blend of these components, where it fills in as a grain refiner.

From Table 5, Feed per Tooth and Cutting Speed are found to be the most significant factors affecting the surface finish. Depth of cut and tool diameter contribute equally.

From Table 6, it can be inferred that cutting speed shows the maximum contribution in affecting the tool wear followed by feed per tooth. Depth of cut and tool diameter show Negligible contributions.

Table 7 indicates that Feed per Tooth has the greatest influence on Material Removal Rate. Cutting Speed, Depth of Cut and Cutting Tool Diameter have a very minimal influence.

Table 5 Results of ANOVA on Surface finish

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	0.0045	2	0.0023	11.33	4.2	23.39
FPT	0.0126	2	0.0063	31.45	4.2	64.94
DOC	0.0011	2	0.0006	2.83	4.2	5.84
CTD	0.0011	2	0.0006	2.83	4.2	5.84
Error	0.002	9	0.0002			
Total	0.0194	17				___

Table 6 Results of ANOVA on Tool Wear

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	0.0016	2	0.0008	4.04	4.2	89.28
FPT	0.0002	2	0.0001	0.48	4.2	10.66
DOC	0.0000	2	0.0000	0.00	4.2	0.01
CTD	0.0000	2	0.0000	0.00	4.2	0.05
Error	0.0020	9	0.0002			
Total	0.0018	17				___

Table 7 Results of ANOVA on Material Removal Rate

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	1.1412	2	0.5706	2852.92	4.2	0.82
FPT	137.5719	2	68.7860	343929.85	4.2	98.63
DOC	0.3863	2	0.1932	965.86	4.2	0.28
CTD	0.3863	2	0.1932	965.86	4.2	0.28
Error	0.002	9	0.000200			
Total	139.4858	17				___

Table 8, indicates that Cutting Speed has the greatest influence on Cutting Time followed by Feed per Tooth, Depth of Cut and Cutting Tool Diameter.

Table 8 Results of ANOVA on Cutting Time

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	2802.6667	2	1401.333	7006666.67	4.2	87.42
FPT	400.6667	2	200.3333	1001666.67	4.2	12.50
DOC	2.0000	2	1.0000	5000.00	4.2	0.06
CTD	0.6667	2	0.3333	1666.67	4.2	0.02
Error	0.002	9	0.000200			
Total	3206.0000	17				___

From Table 9, Feed per Tooth is found to be the most significant factor followed by Cutting Speed affecting the Power Requirement. Depth of Cut and Cutting Tool Diameter contribute equally.

Table 9 Results of ANOVA on Power Requirement

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	5.0099	2	2.5050	12524.82	4.2	5.31
FPT	87.3297	2	43.6649	218324.30	4.2	92.63
DOC	0.9707	2	0.4854	2426.87	4.2	1.03
CTD	0.9707	2	0.4854	2426.87	4.2	1.03
Error	0.002	9	0.000200			
Total	94.2811	17				___

The purpose of the Table 5-10, is to investigate which of the process parameters significantly affect the performance characteristics. This analysis provides the relative contribution of machining parameters in controlling the response of machining performance criteria i.e. Grey relation analysis during Machining. 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 table indicates that, Feed and Cutting speed are significant for all the responses (F calculated value is more than the table value at 95% confidence level).

Table 10 Results of ANOVA on Torque

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	11.5870	2	5.7935	28967.39	4.2	0.82
FPT	1397.1422	2	698.5711	3492855.57	4.2	98.63
DOC	3.9236	2	1.9618	9809.03	4.2	0.28
CTD	3.9236	2	1.9618	9809.03	4.2	0.28
Error	0.002	9	0.000200			
Total	1416.5764	17				___

Table 11 Results of ANOVA on GREY Grade

Source of variation	Sum of Squares	Degree of Freedom	Mean Square	F	F table	% contribution
CS	0.0107	2	0.0053	26.73	4.2	6.67
FPT	0.1459	2	0.0730	364.86	4.2	91.02
DOC	0.0016	2	0.0008	4.11	4.2	1.02
CTD	0.0021	2	0.0010	5.17	4.2	1.29
Error	0.002	9	0.000200			
Total	0.1603	17				___

From Fig. 2, it can be inferred that, Cutting Speed of 226 mm/min, feed rate of 0.1 mm/ rev, depth of cut of 0.5 mm and cutting Diameter 12 mm are most optimum conditions for obtaining minimum torque.

From Fig. 3, it can be inferred that, Cutting Speed of 226 mm/min, feed rate of 0.1 mm/ rev, depth of cut of 0.5 mm and cutting Diameter 12mm are most optimum conditions for obtaining minimum Power Required.

Fig. 4, indicates that, Cutting Speed of 188 mm/min, feed rate of 0.06 mm/ rev, depth of cut of 1.5 mm and cutting Diameter 25 mm are most optimum conditions for obtaining minimum tool wear.

Fig. 5, indicates that, Cutting Speed of 188 mm/min, feed rate of 0.06 mm/ rev, depth of cut of 1.5 mm and cutting Diameter 25 mm are most optimum conditions for obtaining minimum cutting time.

From Fig. 6, it can be inferred that, Cutting Speed of 226 mm/min, feed rate of 0.1 mm/ rev, depth of cut of 0.5 mm and cutting Diameter 12mm are most optimum conditions for obtaining maximum MRR.

From Fig. 7, it can be inferred that, Cutting Speed of 226 mm/min, feed rate of 0.1 mm/ rev, depth of cut of 1.5 mm and cutting Diameter 16mm are most optimum conditions for obtaining maximum surface finish.

Fig. 8, indicates that, Cutting Speed of 188 mm/min, feed rate of 0.1 mm/ rev, depth of cut of 0.5 mm and cutting Diameter 12mm are most optimum conditions according to the Grey Grade Values.

5 Confirmation trails

The affirmation analyse is led at the ideal settings to confirm the quality attributes for AM60Mg alloy by Machining process
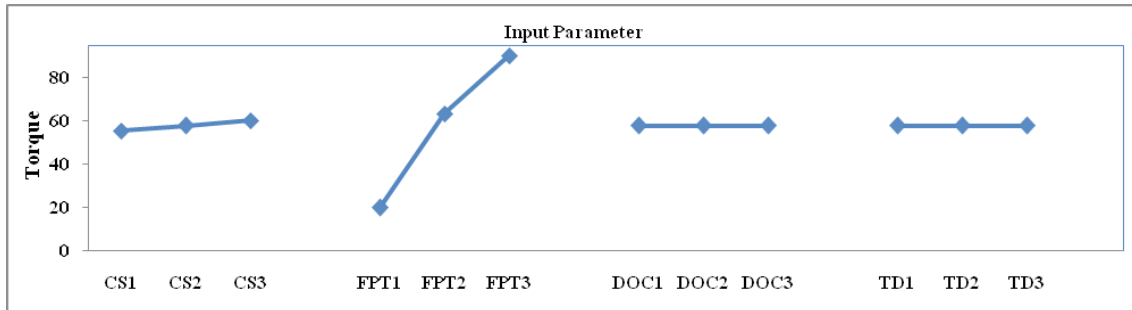
Fig. 2 Factor effects on Torque
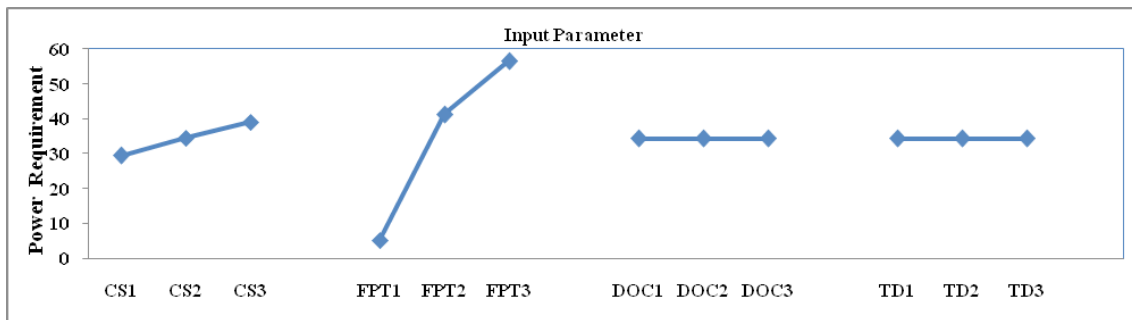
Fig. 3 Factor effects on Power Requirement
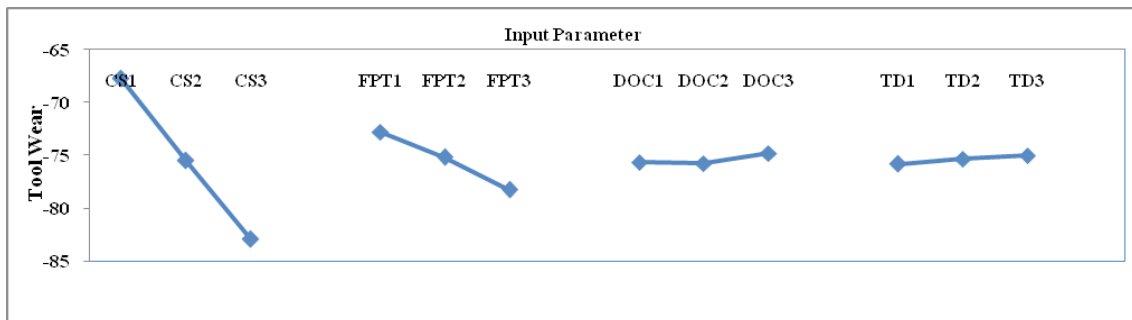
Fig. 4 Factor effects on Tool Wear
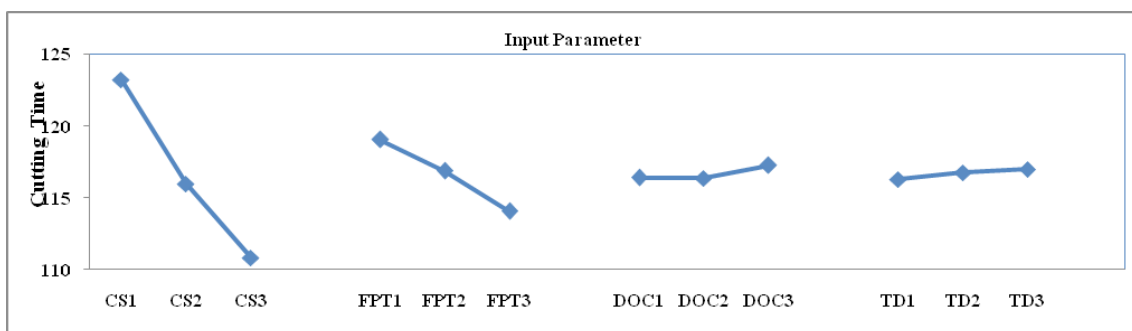
Fig. 5 Factor effects on Cutting Time
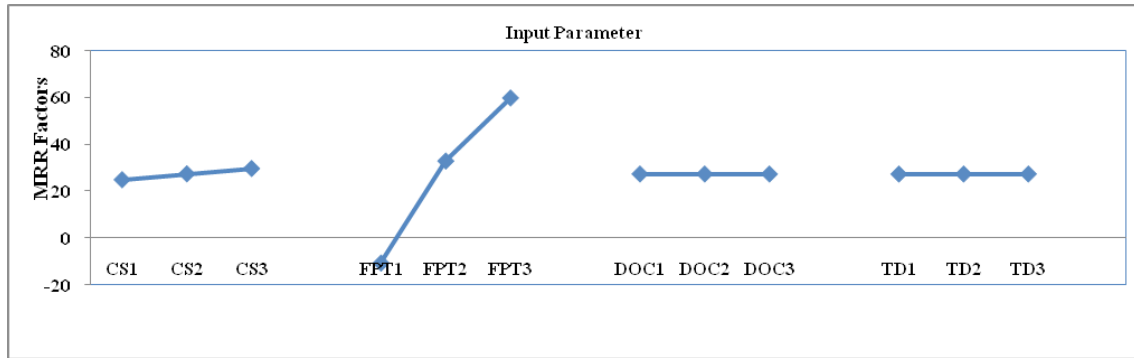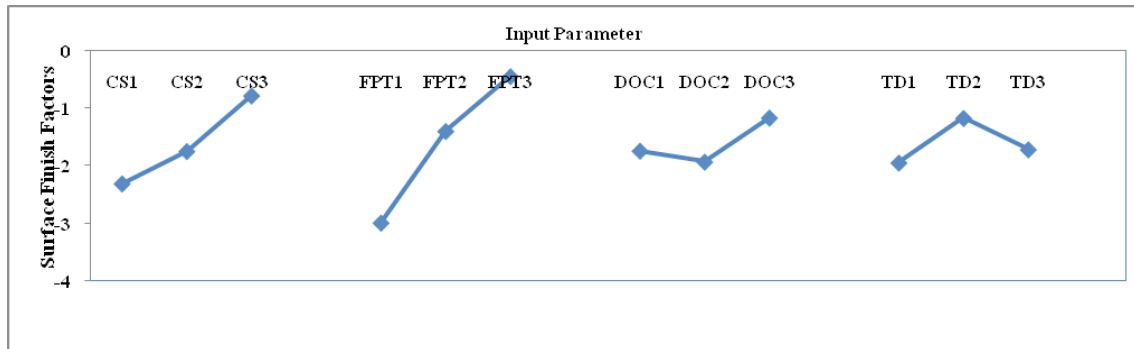
Fig. 6 Factor effects on MRR

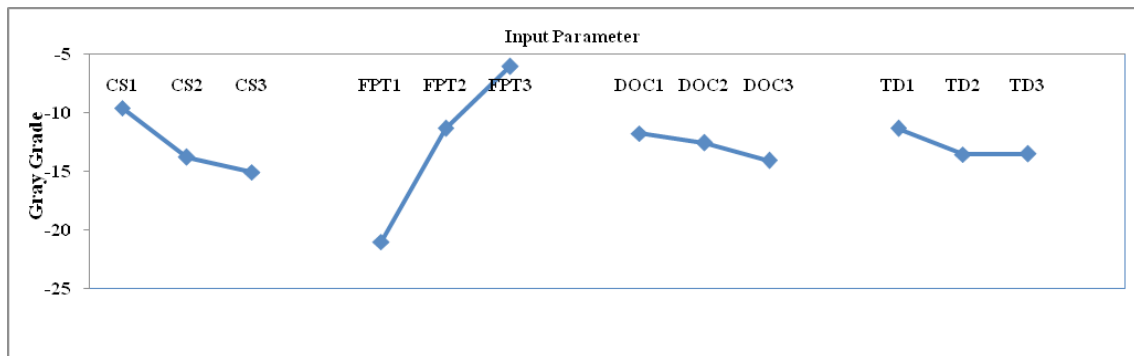**Fig. 7** Factor effects on Surface Finish

Fig. 8 Factor effects on grade values

prescribed by the examination. The reaction esteems by the affirmation try trial at the ideal settings are Cutting Speed of 207 mm/min, feed rate of 0.06 mm/rev, depth of cut of 0.5 mm and cutting Diameter 12 mm. The Grey relation investigation review an incentive according to above dialog is observed to be 0.418. Henceforth the Grey relation analysis for the advancement of the multi response issues is an extremely valuable tool for foreseeing the Output reactions.

6 Conclusion

The goal of this investigation was to discover the optimized combination of Cutting speed (V), Feed (F), Depth Of Cut (DOC) and Cutting Tool Diameters with the goal that the surface roughness (Ra), Tool Wear, Cutting Time, Power Requirement and Torque can be limited and MRR Maximized utilizing Grey relational examination and ANOVA, while Machining AM60 Mg alloy. Grey Relational analysis for the advancement of the multi reaction issues is an exceptionally valuable tool for positioning the base surface roughness (Ra), Tool Wear, Cutting Time, Power Requirement and Torque and Maximum MRR in the Machining of AM60. It does not include convoluted numerical hypothesis or calculation and consequently can be utilized by the architects without a solid statistical foundation. From this examination, it is uncovered that Cutting Speed and Feed are prominent factors which influence the Machining of AM60. The best execution qualities were gotten with AM60 when Machining the ideal parameters with the Cutting Speed of 207 mm/min, feed rate of 0.06 mm/rev and depth of cut of 0.5 mm and cutting Diameter 12 mm for Environment Benefits. Confirmation test comes about demonstrated that the decided ideal mix of machining parameters fulfils the genuine prerequisites of Machining operation of AM60.

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