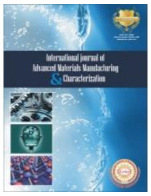

Advanced Materials
Manufacturing & Characterization

journal home page: www.ijammc-griet.com

Multi-Objective Optimization in CNC Milling Process of Al-Cu-Zn Alloy Matrix Composite by Using Taguchi-Grey Relational Analysis Technique

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ARTICLE INFO

Article history:
Received 12-12-2014
Accepted 30-01-2015

Keywords:

Stir casting process,
Cnc milling,
Taguchi method,
Grey relational analysis

ABSTRACT

In present the improved demand of lightweight materials by high strength to weight ratio in the aerospace and automotive industries has managed to the development and custom of Al-alloy-based composites. In this paper an effort has been prepared the Al6082+Cu+Zn composite material and the optimization of CNC milling process parameters for two different work materials of compositions are Al6082 96%+Cu3%+Zn1%, Al6082 89%+Cu7%+Zn4% composite material. .The characteristics of these alloys have strength as well as weight ratio makes the extensive research on Al-Cu-Zn alloy MMC is carried out universally because of it is widely used in automotive & aerospace industries. Tribological behavior of aluminum alloy matrix is fabricated by using the stir casting process was investigated. The concept of grey system stands a innovative optimizing technique for accomplishment the estimate, grey relational analysis and resolution building in various regions. In this paper, usage of grey relational analysis aimed to optimizing the machining process parameters for the work piece is surface roughness and the metal removal rate is familiarized. In directive to increase the quality and productivity by using the optimization of CNC milling process parameters like speed, feed rate, depth of cut and different coated HSS tools to afford a good surface finish as well as high material removal rate. Therefore a multi objective optimization problem has been obtained which can be solved by the hybrid Taguchi method comprising of grey relational analysis.. Finally, Taguchi method has been used to solve the optimization problem**.**

Introduction

Aluminum's weakness is its lack of strength in its pure form. Metal matrix composites (MMCs) represent a moderately new class of materials characterized by lighter weight and greater Wear resistance than conventional materials. By using this technique certain aluminum alloys can be as tough as the steel. Addition of copper to aluminum increases the strength, resistance and hardness and also makes it with heat treatable process [1]. Alternatively adding zinc causes increased tensile strength and resistance to corrosion. The presence of copper and zinc develops the strain, hardenability and enhances the material strength by the solid solution [2]. Chemical composition and heat treatment employ the important influence on the mechanical properties. A new technique of engineering cast Aluminum matrix composite has suggested increasing the wettability between alloy and reinforcement.

In this exploration the numerous surface roughness measurements of the product organized by CNC milling operation are to be studied experimentally and the results will be interpreted systematically. Quality and productivity are both of the most important criteria in any machining operation. But it can be seen that as the quality increases the productivity tends to decrease. It is therefore crucial to optimize quality and productivity concurrently. The product being machined has to have the minimum surface roughness value, and in order to attain

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- Doi: http://dx.doi.org/10.11127/ijammc.2015.03.05

high quality the processing time has to be cooperated which directly affects the productivity. [5]. Thus it is very significant to optimize both the factors simultaneously. In milling, surface finish is one of the most significant aspects. There are various roughness parameters and Ra is the most commonly used.

Yang and Chen (2001) confirmed the methodical method of consuming Taguchi parameter strategy in process control of the individual milling machines [4]. The Taguchi parameter design was agreed out in demand to recognize the optimum surface roughness recital with a particular grouping of the cutting parameters in an end-milling operation. Ghani *as* functional Taguchi optimization methodology to optimize the cutting parameters in end milling although machining hardened steel with TiN coated carbide insert tool underneath semi-finishing and finishing conditions of high speed cutting in view of the milling parameters - cutting speed, feed rate and depth of cut. Oktem focused on the advance of an effective methodology to determine the optimum cutting conditions, helping to achieve the minimum surface roughness in milling of mould surfaces by Response Surface Methodology (RSM) with an developed genetic algorithm (GA)[5].

The purpose of the current work is to familiarize the use of grey relational analysis in choosing optimum machining conditions on multi-performance characteristics, namely Surface roughness, metal removal rate (MRR). The setting of machining process parameters was proficient using the Taguchi experimental design method. In accumulation, the most effective factor and the order of importance of the controllable factors to the multi- performance appearances in the machining process were determined.

2. MATERIAL SELECTION

In the present analysis, Al-Cu-Zn alloy was selected as the base matrix subsequently its properties can be personalized through heat treatment process. For composite material selection of Matrix and reinforcement are of prime importance. For this research work we had selected material as follows.

MATRIX

Aluminium alloy 2000, 6000 and 7000 series are used for fabrication of the automotive parts. PAMC under revision consist of matrix material of aluminium alloy Al6082 has chemical composition is shown in the Table. An advantage of using aluminium as matrix material is casting technology is well recognized, and most important it is light weight material. Aluminium alloy is associated with some disadvantages such as bonding is more stimulating than steel, low strength than steel and price is 200% of that of steel. But with proper reinforcement and treatment the strength can be improved to required level.

REINFORCEMENT

Particles of Al2O3, copper and zinc are used as reinforcement.

Copper (Cu)

Copper particulates have accomplished a prime position among the various PAMC. This is due to the fact that overview of Cu to the aluminium matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. Copper with oxygen content below 10ppm is called 'oxygen-free.' 'Oxygen-free, high conductivity' (OFHC) grade copper has room temperature electrical conductivities equal to or greater than100% The resistance of Cu to acids, alkalis or molten salts up to 1083 degree Celsius makes it a good reinforcement candidate for aluminium based MMC. Moreover, Cu is easily obtainable and has good wettability with aluminium alloys. Addition of alumina particle results in good wear properties and compatibility. Addition of Cu particles results in Excellent Mechanical properties this produces a very hard and strong material.

ALUMINA

Adding of alumina particle has shown increase in tensile strength and it has good compatibility with aluminium alloy. The aluminium used is 6082. The chemical composition of Al6082 is

Table 1 Chemical composition of matrix alloy Al – 6082

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 6082	0.7-1.3	0.5	0.10	0.4 - 1.0	0.6-1.2	0.25	0.20	0.10	Remaining

ZINC

Adding of zinc particle results in low friction of composite as it is good dry lubricant hence reduces wear and abrasion and it acts as a good anti-corrosion agent.

3. COMPOSITE ALLOY PREPARATION

Procedure

Stir casting process starts with placing empty crucible in the muffle. At first heater temperature is set to 500°C and then it is progressively increased up to 1090°C. High temperature of the muffle helps to melt aluminium alloy quickly, decreases oxidation level, develop the wettability of the reinforcement particles in the matrix metal. Aluminium alloy Al-Cu-Zn is used as Matrix material. Essential quantity of aluminium alloy is cut from the raw material which is in the form of round bar. Aluminium alloy is dressed to eliminate dust particles, weighed in the crucible for melting as shown in fig 4.2. During melting nitrogen gas is used as inert gas to create the inert atmosphere around the molten matrix. Aluminium 6082, copper (Cu) and zinc are used as reinforcement.. Then it is thoroughly assorted with each other with the help of unification machine for 24 hour. This mixture is kept ready 1 day before the test has to carry out. Prior to conducting the test this mixture is kept for heating in alternative heater.

Reinforcements are heated for half hour and at temperature of 500°C. When matrix was in the fully molten condition, Stirring is started after 2 minutes. Stirrer rpm is progressively increased from 0 to 300 RPM with the help of speed controller. Temperature of the heater is set to 750°C which is underneath the melting temperature of the matrix. A uniform semisolid stage of the molten matrix was achieved by stirring it at 630°C.Pouring of preheated reinforcements at the semisolid stage of the matrix improve the wettability of the reinforcement, reduces the particle settling at the bottom of the crucible. The flow rate of reinforcements measured was 0.5 gram per second. Dispersion time was taken as 5 minutes. After stirring 5 minutes at semisolid stage slurry was reheated and hold at a temperature 900°C to make sure slurry was fully liquid. Stirrer RPM was then progressively lowered to the zero. The stir casting apparatus is physically kept side and then molten composite slurry is poured in the metallic mould as shown in fig4.5. Mould is preheated at temperature 500°C before pouring of the molten slurry in the mould. This makes sure that slurry is in molten condition during the pouring.. Then it is fast quenched with the help of air to decrease the settling time of the particles in the matrix as shown in fig 4.6

Heat Treatment

The application of the term heat treatable to aluminum alloys, together wrought and cast, is regulated to the specific operations engaged to increase strength , resistance and hardness by precipitation hardening thus the duration heat treatable serves to differentiate the heat treatable alloys from those alloys in which no major strength development can be achieved by heating and cooling.

Fig 1 Melting of alloys

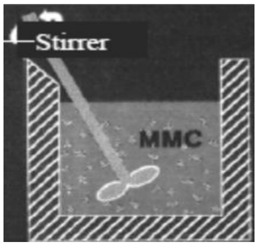

Fig 2 Stirring of metals

Fig 3 Pouring of molten metal into mould

4. EXPERIMENTAL DETAILS

Experimental works

In this the experimental setup of milling process, and measuring instruments like Talysurf meter and also experimental procedure, experimental results can be calculated.

4.1 Experimental setup

In the current work, CNC milling machine is used to machining on Al 6082 matrix alloy, the machine setup is presented in fig.4.1

Fig 4: Experimental setup (CNC Milling Machine)

4.2 Specifications of CNC Milling machine

Table 1: Specifications of CNC milling machine

Technical specifications	
Travels	
X axis	225 mm
Y axis	150 mm
Z axis	115 mm
Distance between Table top and spindle nose	70-185 mm
Table	
Table size	360mm*132 mm
Spindle	
Spindle motor capacity	0.4 kw
Programmable spindle speed	150-3000rpm
Spindle nose taper	BT 30
Accuracy	
Positioning	0.010 mm
Repeatability	+_0.005 mm
Feed Rate	
Programmable feed rate X Y Z axis	0-1.2 mm/min
CNC controller	
Control system	PC based 3 Axis continuous path
Power source	
Main supply	230V, single phase, 50 Hz

4.3 Cutting tool used

Three different tools are used in this investigation are shown in fig 12. Coated carbide tools have been initiate to execute better than uncoated carbide tools. Thus, commercially High Speed Steel (HSS), High Speed Steel+Titanium Nitrate (HSS+TiN) and High Speed Steel+Aluminium Titanium Nitrate (HSS+AlTiN) are used for conducting the experiment work.

Fig 5 Tool Types

4.4 Work piece material used

The present-day work has been carried out two different materials. They are Al6082 96%+Cu3%+Zn1%, Al6082 89%+Cu7%+Zn4% as shown in fig 11. The material properties are obtainable in the material hand book. All the specimens were in the custom of 90mm x 90mm x 12mm blocks.

4.5 TALYSURF METER

The surface roughness parameters have been dignified in this experiment using the Talysurf (Taylor Hobson, Surtronic 3+). The measured roughness parameters along with the Design matrix have been exposed in Table 8.the talysurf meter is as shown in fig 14.

Fig 6 Talysurf meter.

4.6 Design of experiment (DOE)

The Design of Experiment method permits us to carry out the modeling and analysis of the effect of process variables (design factors) on the response variables. In the extant study, depth of cut *(d* mm), spindle speed *(N* rpm) and feed rate *(f* mm/min) have been chosen as design factors while other parameters have been expected to be constant over the experimental field, for this work L_9 orthogonal array was selected.

TABLE 2. DIFFERENT LEVELS OF THE EXPERIMENT

Levels	**Process parameters**			
	Cutting speed(rpm)	**Feed rate(mm/min)**	**Depth of cut(mm)**	**Tool Type**
1	1300	30	0.3	HSS
2	1600	50	0.6	HSS+TiN
3	1800	70	0.8	HSS+AlTiN

5. PLAN OF EXPERIMENTS

The experiment was performed with three parameters: cutting speed, feed amount and depth of cut and fluctuating them for three levels. According to the rule that degree of freedom for an orthogonal array should be superior than or equal to sum of those wear parameters, a L9 Orthogonal array which has 9 rows and 3 columns was selected as exposed below:

Table 3: Orthogonal Array L9 of Taguchi

Experiments	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	Tool Type
1	1300	30	0.3	1
2	1300	50	0.6	2
3	1300	70	0.8	3
4	1600	30	0.6	3
5	1600	50	0.8	1
6	1600	70	0.3	2
7	1800	30	0.8	2
8	1800	50	0.3	3
9	1800	70	0.6	1

Material - I : (Al6082 96%+Cu3%+Zn1%)

S.no	**Cutting speed (rpm)**	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Tool type**	**Surface roughness (Ra)** (μm)	**MRR (mm^3/min)**
1	1300	30	0.3	1	0.548	1.5
2	1300	50	0.6	2	1.402	4.94117
3	1300	70	0.8	3	1.074	9.3333
4	1600	30	0.6	3	0.786	2.97872
5	1600	50	0.8	1	0.682	6.74698
6	1600	70	0.3	2	0.534	3.44262
7	1800	30	0.8	2	1.046	4.05797
8	1800	50	0.3	3	0.961	2.47058
9	1800	70	0.6	1	0.921	7.0000

Material - 2: (Al6082 89%+Cu7%+Zn4%)

S.no	**Cutting speed (rpm)**	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Tool type**	**Surface roughness (Ra)** (μm)	**MRR (mm^3/min)**
1	1300	30	0.3	1	0.624	1.50000
2	1300	50	0.6	2	7.363	5.00000
3	1300	70	0.8	3	1.520	9.33333
4	1600	30	0.6	3	2.877	3.02158
5	1600	50	0.8	1	0.657	6.43678
6	1600	70	0.3	2	1.966	3.50000
7	1800	30	0.8	2	4.361	3.94366
8	1800	50	0.3	3	0.874	2.530120
9	1800	70	0.6	1	4.970	7.00000

6. GREY RELATIONAL ANALYSIS

In our case, the problem has two performance characteristics that essential to be minimized by indicating suitable processing conditions expressed in [1]. They are: Surface roughness, Metal removal rate (MRR).

6.1 Methodology of the Present Investigation

The machining process to be examined relates to 27 different experiments. For the GRA, these 27 experiments become 27 subsystems. The impact of these subsystems on the response variable is to be analyzed using GRA technique. Hence, the machining process (system) is assessed by directing 27 experiments (subsystems) where each experiment is termed as comparability sequence (subsystem).

The response variables considered are: Surface roughness, Metal removal rate. The S/N ratio obtained for 27 experiments for all the responses were normalized [3] and the deviance sequences were determined. Additionally, grey relational coefficients for all the experiments were calculated, and the weighted grey relational grades were attained.

6.1.1 Step1: Taguchi's signal-to-noise ratio analysis on responses variables

Statistical analysis was approved obtainable on the experimental statistics attained through Taguchi experimental design using statistical software MINITAB 16.In this step, S/N ratios are calculated for responses obtained from drilling operation and the optimum mixture of input parameters are determined based on the quality requirement such as Smaller-The-Better, Larger-The-Better.

i) Smaller-The-Better

In machining process, the response features such as Surface roughness should be low for better quality, hence smaller S/N ratios are considered for these parameters. Signal-To-Noise ratio for the Smaller-The-Better

S/N = -10 *log (mean square of the response)

ii) Larger-The-Better

In machining process, the response characteristic like material removal rate should be high for better quality. Hence larger S/N ratios are considered for this kind of parameters. Signal-To-Noise ratio for the Larger-the-better. S/N = -10*log (mean square of the inverse of the response)

Table 4: S/N Values of R_a and MRR

S/N ratio values for Ra and MRR for work material 1

Experiments	Surface roughness (ra) is "smaller is better" (µm)	Mrr "larger is better" (mm^3/min)
1	5.224	3.52182
2	-2.93496	13.87659
3	-0.62008	19.40070
4	2.091549	9.480593
5	3.324312	16.582188
6	5.44917	10.73778
7	-0.39063	12.16617
8	0.34553	7.85597
9	0.71480	16.90196

Table5: S/N Values of R_a and MRR

S/N ratio values for Ra and MRR for work material 2

Experiments	Surface roughness (ra) is "smaller is better" (µm)	Mrr "larger is better" (mm^3/min)
1	4.09630	3.52182
2	-17.34109	13.9794
3	-3.63687	19.40070
4	-9.17879	9.60468
5	3.64869	16.17337
6	-5.87167	10.88136
7	-12.79172	11.91798
8	.16977	8.062822
9	-13.92712	16.90196

6.1.2 Step2: Normalization Of S/N Ratio values

If the target value of original sequence is inestimable, then it has a representative of the "higher is better". The unique order can be normalized as follows:

$$x_i^* = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)}$$

When the "lower is better" is a representative of the original sequence, then the unique sequence should be normalized as follows:

$$x_i^* = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)}$$

However, if there is a certain objective value (desired value) to be accomplished, the unique arrangement will be normalized in form:

$$x_i^* = 1 - \frac{|x_i^o(k) - x^o|}{x_i^o(k) - x^o}$$

Determination of deviation sequences $\Delta 0_i$ (k): The deviation sequence, $\Delta 0_i$ (k) is the absolute difference between the orientation arrangement x_0^* (k) and the comparability sequence x_i^*(k) after normalization.

$$\Delta 0_i(k) = |x_0^*(k) - x_i^*(k)|$$

Table 6: Normalization Values of R_a And MRR

NORMALIZATION VALUES FOR WORK MATERIAL1

Experiments	Surface roughness (ra) is "smaller is better" (µm)	Mrr "larger is better" (mm^3/min)
1	0.026856	0
2	1	0.652109
3	0.72389	1
4	0.400473	0.375264
5	0.253438	0.822499
6	0	0.454437
7	0.696530	0.544392
8	0.608726	0.272950
9	0.564682	0.842637

Table 7: Normalization Values of R_a And MRR

NORMALIZATION VALUES FOR WORK MATERIAL 2

Experiments	Surface roughness (ra) is "smaller is better" (µm)	Mrr "larger is better" (mm^3/min)
1	0	0
2	1	0.658584
3	0.36073	1
4	0.619249	0.383078
5	0.020879	0.796753
6	0.464980	0.463479
7	0.78778	0.528762
8	0.136515	0.285977
9	0.840746	0.842637

6.1.3 Step3: Calculation of grey relational coefficient (GRC)

GRC for all the sequences states the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences approve at all points, then their grey relational coefficient is 1. The grey relational coefficient ξi(k) for the *k*th performance characteristics in the *i*th experiment can be expressed.

$$\xi i(k) = \frac{\Delta\min+\zeta\Delta\max}{\Delta oi\ (k)+\zeta\Delta ma}$$

Where, Δoi is the deviance order of the reference sequence and the comparability sequence. ζ is distinguishing or identification coefficient'$s \in [0,1]$ (the value may be adjusted based on the actual system requirements). A value of ζ is the smaller and the distinguished ability is the larger. $\zeta = 0.5$ is generally used.

6.1.4 Step4: Calculation of grey relational grade (GRG)

Subsequently the grey relational coefficient is derived, it is usual to take the usual value of the grey relational coefficients as the grey interpersonal grade. The grey relational grade is defined as follows

$$\gamma_{i=1/n}\sum_{k=1}^{n}\xi i(k)$$

In the real condition of unequal weight being carried by the various factors, the grey relational grade was extended and defined the weighted grey relational grade and its order 27 comparability sequences as shown in table 7.

The grey relational grade γi signifies the level of correlation among the orientation sequence in addition to the comparability sequence. If the two sequences are identical, formerly the worth of grey interpersonal grade is identical to 1. The grey relational grade also designates the degree of impact on the comparability sequence could employ over the reference sequence.

Table 8: Values of GRC and GRG for work material 1

Experiments	**Surface roughness (ra) is "smaller is better"** (µm)	**Mrr "larger is better" (mm³/min)**	**Grey relational grade**
1	0.339410	0.333333	0.336370
2	1	0.589698	0.794849
3	0.644238	1	0.822119
4	0.454740	0.4445487	0.449644
5	0.401103	0.7380062	0.569554
6	0.333333	0.4782112	0.405772
7	0.622300	0.5232270	0.572763
8	0.560994	0.4074813	0.484237
9	0.534577	0.7606147	0.647595

Table 9: Values of GRC and GRG for work material 2

Experiments	**Surface roughness (ra) is "smaller is better"** (µm)	**Mrr "larger is better" (mm³/min)**	**Grey relational grade**
1	0.33333	0.33333	0.333331
2	1	0.5942363	0.797118
3	0.438877	1	0.719385
4	0.567697	0.4467396	0.507218
5	0.338038	0.7109877	0.524513
6	0.483082	0.482382	0.482732
7	0.70203027	0.5148068	0.6084185
8	0.3667073	0.4118538	0.3891205
9	0.7584330	0.7606147	0.7595238

6.5 Determination of optimum parameters

The weighted grey relational grade intended for each sequence is taken as a response for the additional analysis. The larger-the-better quality characteristic was used for analyzing the GRG, since a larger value indicates the better performance of the process. The number of repetitive test is one, since only one relational grade was acquired in each group for this particular calculation of S/N.

The main effects plot for S/N ratio for work material 1 as shown in below graph. The grey relation grades are now analyzed with Taguchi in Minitab software.

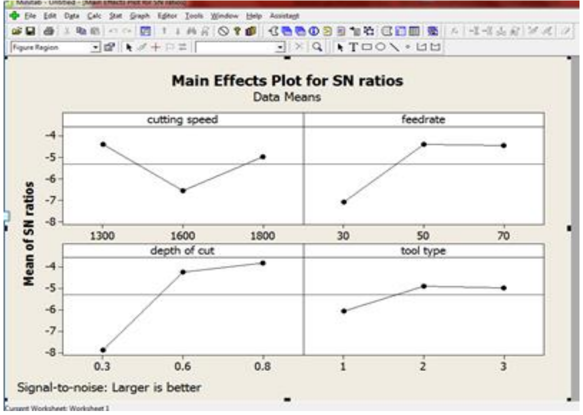

Figure 7 Optimum conditions for work material 1

Response Table for Signal to Noise Ratios

Larger is better

Level	**Cutting speed**	**Feed rate**	**Depth of cut**	**Tool type**
1	-4.386	-7.082	-7.866	-6.042
2	-6.555	-4.394	-4.237	-4.890
3	-4.971	-4.437	-3.810	-4.981
Delta	2.169	2.688	4.055	1.153
Rank	3	2	1	4

The best optimum condition is the (cs1,fd2,doc3,tt2) i.e., at a cutting speed of 1300rpm, feed rate of 50 mm/min, doc of 0.8mm and tool material HSS+TiN is the optimum condition for work material 1.

The main effects plot for S/N ratio for work material 2 as shown in below graph. The grey relation grades are now analyzed with Taguchi in Minitab software.

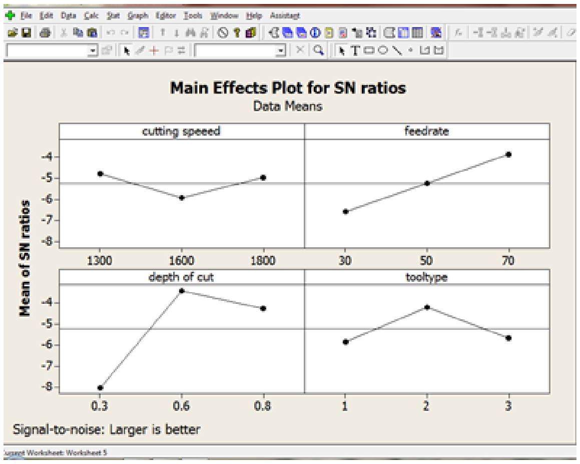

Figure 8 Optimum conditions for work material 2

Response Table for Signal to Noise Ratios

Larger is better

Level	Cutting speed	Feed rate	Depth of cut	Tool type
1	-4.791	-6.585	-8.022	-5.846
2	-5.942	-5.258	-3.418	-4.204
3	-4.968	-3.859	-4.261	-5.652
Delta	1.151	2.726	4.604	1.642
Rank	4	2	1	3

The best optimum condition is the (cs1,fd3,doc2,tt2) i.e., at a cutting speed of 1300rpm, feedrate of 70 mm/min, doc of 0.6mm and tool material HSS+TiN is the optimum condition for work material 2.

7. CONFORMATION TEST RESULTS

After determining the optimum conditions, confirmation test is to be done to check the responses obtained from the optimum conditions.

For work material 1:

Initial Machining Parameters		**Optimized Machining Parameters**
Setting Level	$A_1B_1C_1D_1$	$A_1B_2C_3D_2$
Surface roughness, Ra(µm)	0.548	0.417
MRR(mm^3/min)	1.5000	1.824

For work material 2:

Initial Machining Parameters		**Optimized Machining Parameters**
Setting Level	$A_1B_1C_1D_1$	$A_1B_3C_2D_2$
Surface roughness, Ra(µm)	0.624	0.501
MRR(mm^3/min)	1.500	1.904

Conclusion

A TGRA was suggested to study the optimization of multiple milling process parameters. Surface roughness and MRR are designated as quality objectives. Nine experimental runs based on orthogonal arrays were performed on two different composition work materials. Homogenous dispersion of Cu and Zn particles in the Al matrix shows an increasing trend in the samples prepared by stirring process, with manual stirring. The improved demand of lightweight materials with high strength to weight ratio and good mechanical properties because of this , Al6082 96%+Cu3%+Zn1% and Al6082 89%+Cu7%+Zn4% has more applications in the field of aerospace and automotive industries. The results from the research work suggest that with increase in composition of Cu and Zn an increase in hardness, tensile strength and improves corrosion resistance have been obtained.

Optimal parameter setting has been evaluated for Al6082 96%+Cu3%+Zn1% and Al6082 89%+Cu7%+Zn4%.

i) The optimal parameter setting for work material 1 for Al96%+Cu3%+Zn1% has cutting speed =1300 rpm, feedrate=0.6mm/min, depth of cut=0.8mm, tool type=HSS+TiN.

ii) The optimal parameter setting for work material 1 for Al89%+Cu7%+Zn4% has cutting speed =1300 rpm, feedrate=70mm/min, depth of cut=0.6mm, tool type=HSS+TiN.

Taguchi-grey relational analysis method has been found satisfying for evaluating the optimum parameter settings and responding on a multi-objective optimization problematic in order to increase the quality and productivity.

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