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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Abstract :

In present the increased demand of lightweight materials with high strength to weight ratio in the aerospace and automotive industries has led to the development and use of Al-alloy-based composites. In this paper an attempt has been made to prepare Al6082+Cu+Zn composite material and the optimization of CNC milling process parameters for three different work materials of compositions are Al6082 96%+Cu3%+Zn1%, Al6082 92%+Cu5%+Zn3% and 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 Metal matrix composite (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 theory of grey systems is a new optimizing technique for performing the prediction, grey relational analysis and decision making in many areas. In this paper, the use of grey relational analysis for to optimizing the machining process parameters for the work piece is surface roughness and the metal removal rate is introduced. In order to improve the quality and productivity the present study highlights the optimization of CNC milling process parameters like speed, feed rate, depth of cut and different coated HSS tools to provide a good surface finish as well as high material removal rate. Hence 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.

Key**words- Optimization, Composite materials, CNC milling, Taguchi.**

I. INTRODUCTION:

In the present era of globalization manufacturers are facing the challenges of higher Quality and productivity are two important but conflicting criteria in any machining operations. In order to ensure high productivity, extent of quality is to be compromised. It is, therefore, essential to optimize quality and productivity simultaneously. Productivity can be interpreted in terms of material removal rate in the machining operation and quality represents satisfactory yield in terms of product characteristics as desired by the customers. Dimensional accuracy, form stability, surface smoothness, fulfillment of functional requirements in prescribed area of application etc. are important quality attributes of the product. Increase in productivity results in reduction in machining time which may result in quality loss. On the contrary, an improvement in quality results in increasing machining time thereby, reducing productivity. Therefore, there is a need to optimize quality as well as productivity. Optimizing a single response may yield positively in some aspects but it may affect adversely in other aspects. The problem can be overcome if multiple objectives are optimized simultaneously. It is, therefore, required to maximize material removal rate (MRR), and to improve product quality simultaneously by selecting an appropriate (optimal) process environment. To this end, the present work deals with multi-objective optimization philosophy based on Taguchi-Grey relational analysis method applied in CNC end milling operation.

II. LITERATURE SURVEY:

G.Vijaya Kumar and P.Venkataramaiah is focused on selection of optimal parameters in drilling of Aluminium Metal Matrix Composites (AMMC) using “Grey Relational Analysis”. AMMC samples are prepared based on selected material parameters and drilling experiments are conducted on these samples as per Taguchi OA L27 which is designed based on material and drilling parameters. The experimental results: power consumption, temperature, surface roughness, and burr height are measured for each experimental run. These results are analysed using Grey Relational Analysis and optimal parameters combination is identified. This identified combination of influential factors is tested through confirmation experiment and is satisfactory.

A. RiazAhamed, ParavasuAsokan , SivanandamAravindan and M. K. Prakash performed drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix composites with HSS drills is possible with lower speed and feed combination. The cutting conditions for minimized tool wear and improved surface roughness are identified. Characterization of tool wear and surface integrity are also carried out. The experimental results shown that the tools wear of HSS tools increased with increasing cutting speeds. Cutting speed is the key factor, which has greater influence on surface roughness. Irrespective of feed rates, lower speed results in smoother surface roughness. It has been concluded that drilling of Al-5%SiC-5% B4C composites with HSS tool has to be carried with lower speed and feed combination.

Reddy Sreenivasulu and Ch. SrinivasaRao attempting the Machining processes are widely used in the aerospace, aircraft and automotive industries although that non-traditional machining method have improved in the manufacturing industries in response to new and unusual machining requirement that could not be satisfied by conventional methods. Non-traditional machining including ultrasonic machining, abrasive water jet cutting, electrochemical machining (ECM), and chemical machining (CHM) are some of the examples. In machining processes, cutting fluids are used to lubricate the process and reducing the temperature that contributes of wear and tear to the cutting tool. Aluminum alloys widely used for automotive and aerospace industries which durability, strength, and light weight are desired and these materials subjected to machining operations where the criterion of minimization of lubricant or coolant use is becoming more topicality. Manufacturer have desired to work without any lubricant because of reasons such as the cost of using it, supply and maintenance of the lubricant, hazard arising from the lubricant and the disposal of used lubricant, therefore an alternative methods of machining is a dry machining. A statistical technique, fractional factorial experiments and analysis of variance (ANOVA), has been employed to investigate the influence of cutting parameters. This paper presents a literature review on optimization of various machining processes using design of experiments based grey relational analysis.

The present work concentrates on optimizing the multi responses of CNC milling process by using the Taguchi-grey relational analysis in AL-CU-ZN alloy matrix. In order to find the best optimum condition for the Al-Cu-Zn alloy using milling process.

III. METHODOLOGY:

Grey Relational Analysis:

In our case, the problem has two performance characteristics that need to be minimized by choosing appropriate processing conditions. They are: Metal Removal Rate and surface roughness. In such cases, the problem is converted into a single objective problem using Grey relational analysis. The grey relational analysis deals with the ranks and not with the real value of the grey relational grade.

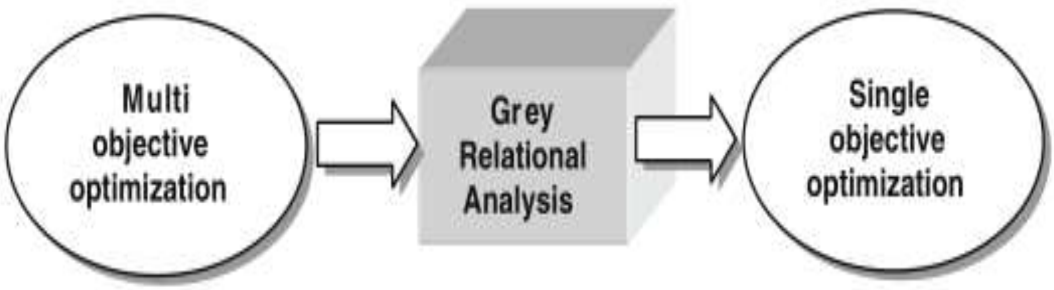

Figure: Conversion of Grey relational analysis

Approach of the present investigation:

The milling process to be investigated corresponds to 9 different experiments on each three different composition metal alloys. For the GRA, these 9 experiments become 9 subsystems. The influence of these subsystems on the response variable is to be analyzed using GRA technique. Hence, the milling process (system) is assessed by conducting 9 experiments (subsystems) where each experiment is termed as comparability sequence (subsystem).

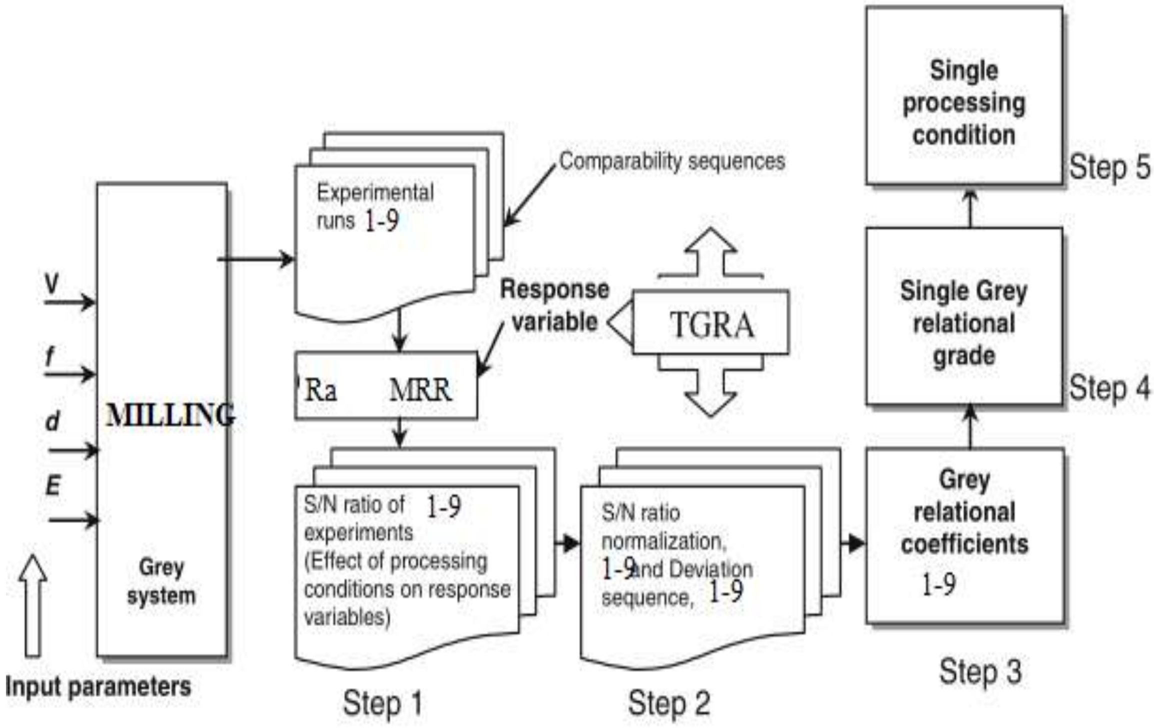

Figure: Experimental procedure of grey relational analysis

Design of Experiment (DOE):

Design of Experiment (DOE) is a structured, organized method for determining the relationship between factors affecting a process and the output of that process. Conducting and analyzing controlled tests to evaluate the factors that control the value of a parameter or group of parameters. "Design of Experiments" (DOE) refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables.

Design of experiment techniques as follows:

- Factorial design
- Response surface methodology
- Mixture design
- Taguchi design

Among those we had selected Taguchi Design for optimizing process parameters in drilling Operation.

Taguchi method:

Competitive crisis in manufacturing during the 1970's and 1980's that gave rise to the modern quality movement, leading to the introduction of Taguchi methods to the U.S. in the 1980's. Taguchi's method is a system of design engineering to increase quality. Taguchi Methods refers to a collection of principles which make up the framework of a continually evolving approach to quality. Taguchi Methods of Quality Engineering design is built around three integral elements like the loss function, signal-to-noise ratio and orthogonal arrays, which are each closely related to the definition of quality.

Taguchi approach for parameter design:

The objective of the robust design is to find the controllable process parameter settings for which noise or variation has a minimal effect on the product's or process's functional characteristics. It is to be noted that the aim is not to find the parameter settings for the uncontrollable noise variables but the controllable design variables. To attain this objective, the control parameters, also known as inner array variables are systematically varied as stipulated by the inner orthogonal array. For each experiment of the inner array, a series of new experiments are conducted by varying the level settings of the uncontrollable noise variables. The level combinations of noise variables are done using the outer orthogonal array. The influence of noise on the performance characteristics can be found using the ratio. Where S is the standard deviation of the performance parameters for each inner array experiment and N is the total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise. Using this result, it is possible to predict which control parameter settings will make the process insensitive to noise.

Taguchi method focuses on Robust Design through use of

- Orthogonal arrays.
- Signal-To-Noise ratio.

3Orthogonal array:

In order to reduce the total number of experiments "Sir Ronald Fisher" developed solution:" orthogonal arrays". The orthogonal array can be thought of as a distillation mechanism through which the engineers experiment passes (Ealey, 1998).

The array allows the engineer to vary multiple variables at one time and obtain the effects that set of variables has an average and the dispersion.

Taguchi employs design experiments using specially constructed table known as "Orthogonal Arrays (OA)" to treat the design process, such that the quality is built into the product during the product design stage. Orthogonal Arrays (OA) are a special set of Latin squares, constructed by Taguchi to lay out the product design experiments. An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. Orthogonal arrays are employed to study the effect of several control factors. Orthogonal arrays are used to investigate quality. Orthogonal arrays are not unique to Taguchi. They were discovered considerably earlier (Bendell, 1998). However Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects (ASI, 1989; Taguchi and Kenishi, 1987).

Table : A typical L9 orthogonal array matrix

S.no	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	Tool type
1	1300	30	0.3	HSS
2	1300	50	0.6	HSS+TiN
3	1300	70	0.8	HSS+Al+TiN
4	1600	30	0.6	HSS+Al+TiN
5	1600	50	0.8	HSS
6	1600	70	0.3	HSS+TiN
7	1800	30	0.8	HSS+TiN
8	1800	50	0.3	HSS+Al+TiN
9	1800	70	0.6	HSS

In this array the columns are mutually orthogonal. That is for any pair of columns all combination of factors occurs and they occur an equal number of times. Here there are 4 parameters, A, B, C and D each at three levels. This is called an 'L9' design; with the 9 indication the 9 rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus L9means that 9 experiments are to be carried out to study four variables with three levels. There are greater savings in testing for larger arrays.

IV. EXPERIMENTAL SETUP:

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

Figure: Experimental setup (CNC Milling Machine)

Specifications of CNC Milling machine:

Table: 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

Tools used:

i) High Speed Steel (HSS)

ii) TitaniumNitrade(TiN)

iii) Titanium Aluminum Nitride (TiAlN) coating

Work material preparation:

The work material is cut as required sizes of 90x90x12 mm from Al6082-Cu-Zn alloy matrix raw stock to perform milling operation on them. The chemical compositions of three alloy matrix work material are shown in Tables.

Table: Chemical compositions of three different alloy matrix

ALLOY	WORK MATERIAL 1	WORK MATERIAL 2	WORK MATERIAL 3
Al+Cu+Znalloy (%)	96%+3%+1%	92%+5%+3%	89%+7%+4%

These work materials are prepared by using the stir casting process. The experimental procedure followed in our work as represented in the flow chart:

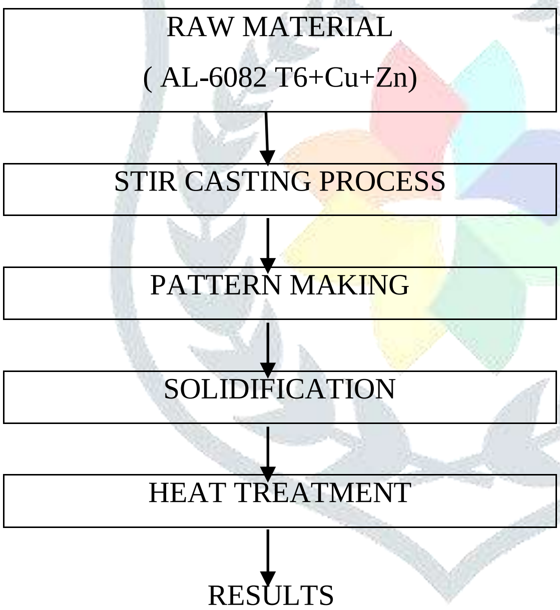

Figure: flowchart of experimental procedure

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 gradually increased up to 1090°C. High temperature of the muffle helps to melt aluminium alloy quickly, reduces oxidation level, enhance the wetability of the reinforcement particles in the matrix metal. Aluminium alloy Al-Cu-Zn is used as Matrix material. Required quantity of aluminium alloy is cut from the raw material which is in the form of round bar. Aluminium alloy is cleaned to remove 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.. At a time total 900 gram of molten composite was processed in the crucible. Required quantities of reinforcement powder are weighed on the weighing machine. Then it is thoroughly mixed with each other with the help of blending 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 another 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 gradually increased from 0 to 300 RPM with the help of speed controller. Temperature of the heater is set to 630°C which is below 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 enhance the wettability of the reinforcement, reduces the particle settling at the bottom of the crucible. Reinforcements are poured manually with the help of conical hopper. 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 gradually lowered to the zero. The stir casting apparatus is manually 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 throughout the pouring. While pouring the slurry in the mould the flow of the slurry is kept uniform to avoid trapping of gas. Then it is quick quenched with the help of air to reduce the settling time of the particles in the matrix as shown in fig.

Figure: Melting of alloys

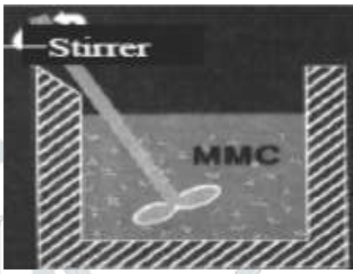

Figure: Stirring of metals

Figure: Pouring of molten metal into mould

Figure: Pattern making for test specimen

The required work materials are prepared by using the stir casting process with three different compositions of aluminum-copper-zinc alloy matrix. After completion of these process the specimens or work materials are as follow

Figure: Composite work material

Surface finish measurement:

Talysurf meter:

Talysurf meter instrument is widely used to measure the shape or form of components. A profile measurement device is usually based on a tactile measurement principle. The surface is measured by moving a stylus across the surface. As the stylus moves up and down along the surface, a transducer converts these movements into a signal which is then transformed into a roughness number and usually a visually displayed profile. Multiple profiles can often be combined to form a surface representation. Talysurf meter is shown in fig 5.0

Figure: Talysurf meter

Experimental procedure:

i. The Input parameters of the milling process and their levels(each input parameter has three levels) are listed based on previous works (Table 4.3).

ii. Milling operation is performed on Al 6082-Cu-Zn alloy work material according to full factorial design using CNC milling machine.

iii. The surface roughness values are measured using Talysurf meter (Table 4.4).

iv. The Metal removal rate is calculated by means of formula is given by,

MRR= Tool diameter(mm)*material length machining(mm)*depth of cut(mm) / Machining time(in min)

Table: Process parameters and their levels

Levels	Process parameters			
	Cutting speed(rpm)	**Feed rate(mm\min)**	**Depth of cut (mm)**	**Tool type**
1	1300	30	0.3	Uncoated Hss
2	1600	50	0.6	Hss+TiN
3	1800	70	0.8	Hss+TiAlN

Orthogonal array table creation:

This orthogonal array table is generated by using minitab16 software. The procedure for L9 array table as follows-

Step 1: Open Minitab → go to stat → DOE → Taguchi → Create Taguchi design.

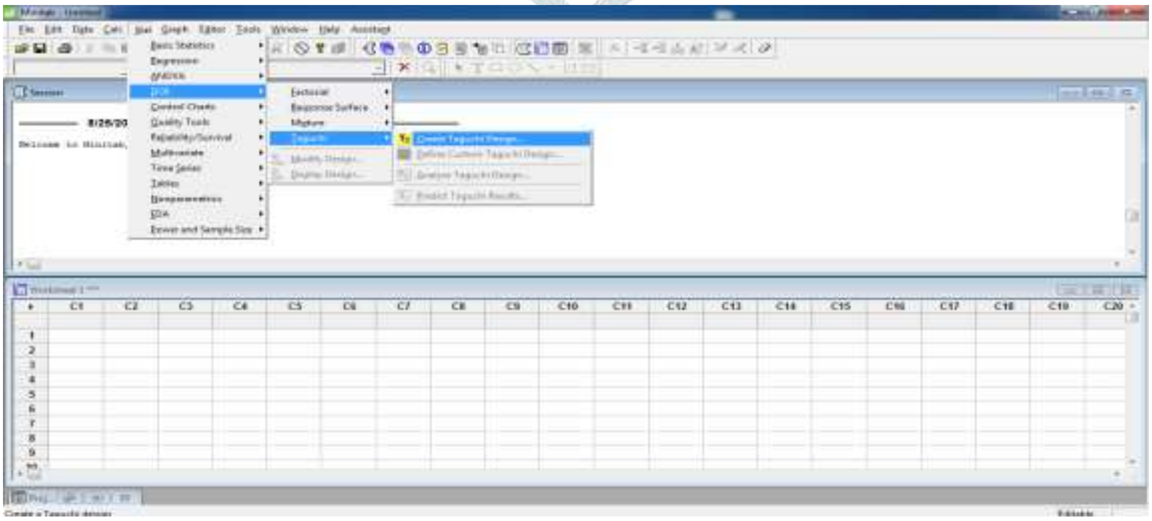

Figure: procedure for creating a Taguchi design

Step 2: After creation of taguchi design it opens a dialogue box. By entering the number of levels and number of factors it shows the L9 design table.

Number of levels is 3

Number of factors is 4

DOE = (L-1)*F+1

Where,

L= number of levels and

F= number of factors.

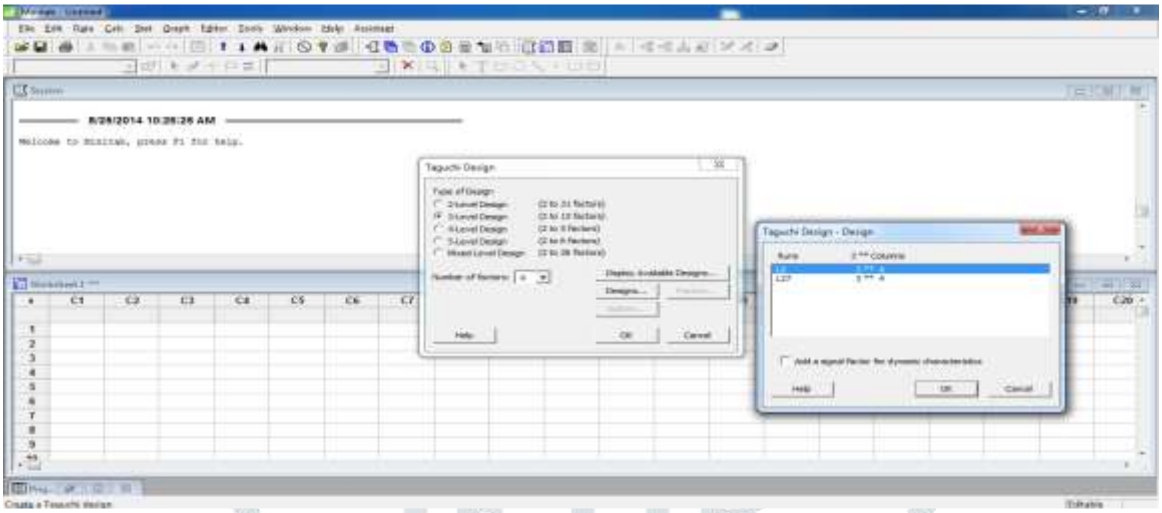

Figure: Procedure for creating a orthogonal array

Table: Experimental design using L_9 orthogonal array matrix

S.no	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

Experimental Data for Three Different Composition Work Materials (Al-Cu-Zn alloy):

ALLOY	WORK MATERIAL 1	WORK MATERIAL 2	WORK MATERIAL 3
Al+Cu+Zn alloy (%)	96%+3%+1%	92%+5%+3%	89%+7%+4%

For work material 1:

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

For work material 2:

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	0.663	1.5
2	1300	50	0.6	2	0.872	4.94117
3	1300	70	0.8	3	1.139	9.18032
4	1600	30	0.6	3	0.704	3.0000
5	1600	50	0.8	1	0.707	6.51162
6	1600	70	0.3	2	0.632	3.55932
7	1800	30	0.8	2	1.251	3.97163
8	1800	50	0.3	3	0.694	2.41379
9	1800	70	0.6	1	0.920	6.363636

For work material 3:

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

V. RESULTS AND DISCUSSION :

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

Response table for signal to noise ratio for material 1

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, feedrate of 50 mm/min, depth of cut of 0.8mm and tool material HSS+TiN is the optimum condition for work material 1.

Response table for signal to noise ratio for material 2

Level	Cutting speed	Feed rate	Depth of cut	Tool type
1	-5.225	-6.488	-8.451	-6.231
2	-6.888	-6.283	-5.754	-5.154
3	-4.950	-4.292	-2.858	-5.678
Delta	1.937	2.195	5.593	1.078
Rank	3	2	1	4

Response table for signal to noise ratio for material 3

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, depth of cut of 0.6mm and tool material HSS+TiN is the optimum condition for work material 3.

Optimum conditions of work material 1 is given below surface roughness – 0.548 for machining parameters, initial surface roughness – 1.5000 for initial machining parameter, when an optimized machining parameters are 0.417 and 1.824

VI. CONCLUSION:

A Taguchi Grey relational analysis was proposed to study the optimization of CNC milling process parameters. The Input parameters for milling process are cutting speed, feed rate, depth of cut and tool type and responses for process are Surface roughness and Material removal rate are selected as the quality targets. The three different compositions of work materials(Al608296%+Cu3%+Zn1%, Al608292%+Cu5%+Zn3% andAl6082 89%+Cu7%+Zn4%) are fabricated by using the stir casting process. The Nine experimental runs on each material is done based on orthogonal arrays were performed on three different composition work materials by using Taguchi and grey relational analysis. The results are evaluated and conformation test is completed on three composition work materials. The conclusions based on the Taguchi Grey relational analysis are summarized as follows:

The recommended optimum parameter setting levels of milling parameters for Al6082 96%+Cu3%+Zn1%, Al6082 92%+Cu5%+Zn3% and Al6082 89%+Cu7%+Zn4% of Surface roughness, material removal rate are simultaneously considered are :

- The optimal parameter setting for work material 1 for Al96%+Cu3%+Zn1% has cutting speed =1300 rpm, feed rate=0.6mm/min, depth of cut=0.8mm,tool type=HSS+TiN with an response of surface roughness = 0.417 and MRR =1.824
- The optimal parameter setting for work material 2 for Al92%+Cu5%+Zn3% has cutting speed =1800 rpm, feedrate=70 mm/min, depth of cut=0.8mm, tool type=HSS+TiN with an response of surface roughness = 0.593 and MRR =1.621
- The optimal parameter setting for work material 3 for Al89%+Cu7%+Zn4% has cutting speed =1300 rpm, feedrate=70 mm/min, depth of cut=0.6mm, tool type=HSS+TiN with an response of surface roughness = 0.501 and MRR =1.904

Taguchi-grey relational analysis method has been found rewarding for evaluating the optimum parameter settings and solving such a multi-objective optimization problem in order to improve the quality and productivity.

VII. FUTURE WORK:

The Grey relational analysis is a robust process for optimization of the single response as well as multiple responses. In present work, optimization of two responses is considered are surface roughness and Metal Removal Rate. Due to time constraints, optimized only two responses, although for strength of parts compression test, fatigue test, wear test, hardness test, may be carried out in future.

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