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OPTIMUM COMBINATION OF PROCESS PARAMETERS TO OPTIMIZE SURFACE ROUGHNESS AND CHIP THICKNESS DURING END MILLING OF ALUMINIUM 6351-T6 ALLOY USING TAGUCHI GREY RELATIONAL ANALYSIS

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ABSTRACT

In any machining operations, quality is the important conflicting objective. In order to give assurance for high productivity, some extent of quality has to be compromised. Similarly productivity will be decreased while the efforts are channelized to enhance quality. In this study, the experiments were carried out on a CNC vertical machining center (KENT and INDIA Co. Ltd, Taiwan make) to perform 10mm slots on Al 6351-T6 alloy work piece by K10 carbide, four flute end milling cutter as per taguchi design of experiments plan by L9 orthogonal array was choosen to determine experimental trials. Furthermore the spindle speed (rpm), the feed rate (mm/min) and depth of cut (mm) are regulated in these experiments. Surface roughness and chip thickness was measured by a surface analyser of Surf Test-211 series (Mitutoyo) and Digital Micrometer (Mitutoyo) with least count 0.001 mm respectively. Grey relational analysis was employed to minimize surface roughness and chip thickness by setting of optimum combination of machining parameters. Minimum surface roughness and chip thickness obtained with 1000 rpm of spindle speed, 50 mm/min feed rate and 0.7 mm depth of cut respectively. Confirmation experiments showed that Grey relational analysis precisely optimized the drilling parameters in drilling of Al 6351-T6 alloy.

Keywords: Al 6351-T6 alloy, Surface roughness, Chip thickness, Grey relational analysis

1. INTRODUCTION

Milling is the most extensively used machining process which may be employed in at least one stage of fabrication in manufacturing industries. In the present days CNC milling machines are commonly used as they possesses versatility, flexibility and allows manufacture of products in shorter time at reasonable cost and good surface finish.

End milling is one of the important milling operations, which is commonly used in manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. In end milling process, surface finish and material removal rate are two important aspects, which require attention both from industry personnel as well as in Research and Development, because these two factors greatly influence machining performance. CNC machines are most suitable to achieve high quality products in shorter time and to produce products at minimum cost.

The thickness of the chips on milling operation changes continuously and they have a complex shape which depends from many different factors. In order to simplify the matter it’s better to talk about the average thickness of the chips: this is a parameter which give an idea about the cutting force and how much the milling cutter and the milling machine are stressed.

It is common knowledge that a chip produced through a milling process is not of uniform thickness. Assuming climb milling, the chip is thicker towards its beginning than its end. Every chip has a maximum thickness at a single point and gets gradually thinner from there. Given a constant spindle speed and feedrate, the thickness of a chip is a function of its length; the longer the chip, the thicker the chip.

The ideal average chip thickness for a particular insert depends on the insert’s edge preparation. Compared to the sharp angle formed by the rake and flank faces of a typical turning insert, a milling insert’s cutting edge generally has a small chamfer to protect against the shock of repeated material entry.

Chips should be at least as thick as this edge protection (typically in the form of a T-land or hone) to properly dissipate heat. Chips that are too thin indicate that

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the cutting action and the heat it generates is constrained to a relatively small portion of the insert edge. This can lead to premature cratering, thermal cracking or flank wear. Chips that are too thick indicate high cutting forces that could overwhelm and break the insert.

1.1. Background literature

Sreenivasulu and Rao (2012) applied Taguchi method and GRA to optimize drilling parameters for surface roughness and roundness error simultaneously. Joshi and Kothiyal (2013) investigated the SR response on CNC milling by Taguchi technique. Surface finish is analyzed, which shows the percentage contribution of each influencing factor.

Nair and Govindan (2013) conduct the study on application of Principal Component analysis (PCA) coupled with Taguchi method to solve correlated multi-attribute optimization of CNC end milling operation.PCA has been proposed to eliminate correlation between the responses and to estimate uncorrelated quality indices called principal components.

Ahmad, Sharma and Mittal (2014) studied the machining parameters like depth of cut, cutting speed, feed rate and tool diameter are optimized with multiple performance characteristics, and concluded that the S/N ratio with Taguchi"s parameter design is a simple, systematic, reliable and more efficient tool for optimizing multiple performance characteristics of CNC milling process parameters.

Kumar and Thirumurugan (2012) had studied The end milling of titanium alloys, for the investigation of the optimum parameters that could produce significant good surface roughness whereby reducing tooling cost and concluded that The significant factors for the surface roughness in milling CP Ti Grade 2 were the spindle speed and the tool grade, with contribution of 30.347 and 29.933 respectively.

Sreenivasulu (2014) had conducted the study to deals with optimization of surface roughness and delamination damage on GFRP material during end milling using grey- based taguchi method. From the results of ANOVA, it was concluded that cutting speed and DOC are the most significant factors. PR.

Periyanan, Natarajan and Yang (2011) had carried out experiment to focus the taguchi technique for the optimization in microend milling operation to achieve

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maximum metal removal rate & result shows that the optimal combination as medium cutting speed, high feed rate and high depth of cut.

Pandey et al. (2013) conducted experiments to perform the parametric optimization of CNC end milling machine tool in varying condition. Results showed that cutting speed and feed are the powerful control parameters for the material removal rate and depth of cut as powerful factors for controlling the surface finish of Mild Steel.

Barman and Sahoo (2009) had conducted an experimental study of fractal dimension characteristics of surface profile produced in CNC milling and optimization of machining parameters based on Taguchi method. It is also observed with increase in spindle speed the fractal dimension increases.

Chawale et al. (2013) had conducted to study experimentally the influence of depth of cut, cutting speed, and feed and work piece material type on cutter temperature during milling process. It was concluded that, the cutting speed is most contributory factor, work material is second important factor and Feed rate is third important factor.

Abhishek et al. (2008) had conducted study for the multiple response optimization of end milling parameter using grey based taguchi method. The feed rate was identified as the most influential process parameter on surface roughness.

2. EXPERIMENTATION

In any experimental work, it is difficult to consider all these factors that affect the quality and productivity. From the literature it is observed that the parameters such as depth of cut, spindle speed and feed rate are the three predominant cutting parameters influencing on quality and productivity in any machining operation. These three cutting parameters are considered to investigate their affect on surface roughness.

The design of experiments technique permits us to carry out the modeling and analysis of the influence of process variables (design factors) on the response variables. In the present experiment spindle speed (A, rpm), feed rate (B, mm/min) and depth of cut (C, mm) have been selected as design factors (their levels are selected by considering the specifications of machine and from previous literature) while other parameters have been assumed to be constant over the experimental domain. The dimensions of the work piece are 300mm X 50mm X 25mm.

In this study, the experiments were carried out on a CNC vertical machining center (KENT and ND Co. Ltd, Taiwan make) to perform 10mm s lots on Al 6351-T6 alloy work piece by K10 carbide, four flute end milling cutter as shown in Figure 1. Furthermore the cutting speed (rpm), the feed rate (mm/min) and depth of cut (mm) are regulated in this experiment.

Each experiment was conducted three times and the chips are collected and measured the chip thickness (mm) with Digital Micrometer (Least Count 0.001mm, Mitutoyo make) which are shown in Figure2, finally surface roughness is measured at five places on each slot then average of them in µm is considered by a surface analyser of Surf Test-211 series (Mitutoyo) shown in Figure 1. The experimentation has been conducted through the following step by step procedure.

Step 1: The work piece is clamped in milling-vice on the working table of CNC milling machine using T-clamps, bolts, jigs and fixture.

Step 2: Select the suitable CNC end milling cutter and their axis is selected. The selected cutter is fixed in the main spindle using different collets.

Step 3: Performing milling operation on specimens in involving various combinations of input parameters such as cutting speed, feed and depth of cut. A manual part programming is developed for CNC end milling.

Step 4: Measured the surface roughness with the help of a Surf Test-211 series at five places on each slot then average of them in µm was tabulated.

Step 5: Measured the chip thickness 3 times for different chips randomly collected during the machining operation as per L9 orthogonal array with the help of Digital micrometer (Least Count 0.001 mm, Mitutoyo make) and average reading depicted in the table.2.

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Figure 1: Experimental setup, Measurement of surface roughness using Surf Test-211 series

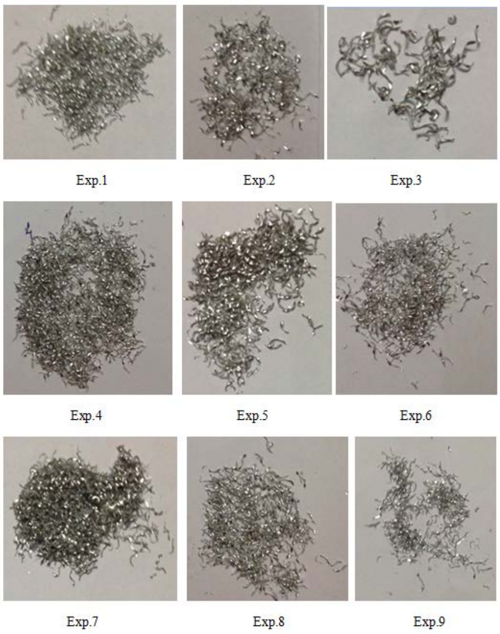

Figure 2: Camera images of collected chips with different machining conditions

Table 2: Machining parameters and their levels

Symbol	**Factors**	**Units**	**Level 1**	**Level 2**	**Level 3**
A	Spindle Speed	rpm	600	800	1000
B	Feed Rate	mm/min	50	100	150
C	Depth of Cut	mm	0.3	0.5	0.7

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Table 3: Experimental plan as per Taguchi L9 orthogonal array and measured responses

Exp.No.	Machining Parameters			Surface Roughness (Ra) µm	Chip Thickness mm
	Spindle Speed (A)	Feed Rate (B)	Depth of Cut (C)		
1	1	1	1	0.166	0.125
2	1	2	2	0.216	0.140
3	1	3	3	0.233	0.230
4	2	1	2	0.145	0.180
5	2	2	3	0.165	0.190
6	2	3	1	0.170	0.210
7	3	1	3	0.190	0.100
8	3	2	1	0.240	0.130
9	3	3	2	0.225	0.220

3. GREY RELATIONAL ANALYSIS

The validity of traditional statistical analysis techniques is based on assumptions such as the distribution of population and variances of samples. Nevertheless sample size will also affect the reliability and precision of the results produced by traditional statistical analysis techniques. J. Deng argued that many decision situations in real life do not conform to those assumptions, and may not be financially or pragmatically justified for the required sample size.

Making decisions under uncertainty and with insufficient or limited data available for analysis is actually a norm for managers in either public or private sectors. To address this problem, J. Deng developed the grey system theory, which has been widely adopted for data analysis in various fields.

The grey relational analysis introduced in the following is a method in grey system theory for analyzing discrete data series. A procedure for the grey relational analysis consists of the following steps.

1. Generate reference data series X_0.

   $X_0 = (d_{01}, d_{02}, ..., d_{0m})$

   In general, the X_0 reference data Series consists of m values representing the most favored responses.

2. Generate comparison data series X_i.

   $X_i = (d_{i1}, d_{i2}, ..., d_{im})$

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Where i = 1,2,..., k. k is the number of scale items. So there will be k comparison data series and each comparison data series contains m values.

3. Compute the difference data series Δ_i.

   $\Delta_i = (|d_{01} - d_{i1}| , |d_{02} - d_{i2}| , ..., |d_{0m} - d_{im}|)$

4. Find the global maximum value Δmax and minimum value Δmin in the difference data series.

   $\Delta max = \forall_i^{max} (max\ \Delta_i)$

   $\Delta min = \forall_i^{min} (min\ \Delta_i)$

5. Transform each data point in each difference data series to grey relational coefficient. Let $\gamma_i(j)$ represents the grey relational coefficient of the j_{th} data point in the i_{th} difference data series, then

$$\gamma_i(j) = \frac{\Delta min + \varsigma \Delta max}{\Delta i\,(j) + \varsigma \Delta max} \qquad \text{Eq .1}$$

   Where $\Delta_i(j)$ is the j_{th} value in Δ_i difference data series. ς is a value between 0 and 1. The coefficient ς is used to compensate the effect of Δmax should Δmax be an extreme value in the data series. In general the value of ς can be set to 0.5.

6. Compute grey relational grade for each difference data series. Let Γ_i represent the grey relational grade for the i_{th} scale item and assume that data points in the series are of the same weights 1, then

$$\Gamma_i = \frac{1}{m} \sum_{n=1}^{m} Y_i(n) \qquad \text{Eq .2}$$

   The magnitude of Γ_i reflects the overall degree of standardized deviance of the i_{th} original data series from the reference data series. In general, a scale item with a high value of Γ indicates that the respondents, as a whole, have a high degree of favored consensus on the particular item.

7. Sort Γ values into either descending or ascending order to facilitate the managerial interpretation of the results. This is brief procedure for the grey relational analysis. Now discuss in detailed the Grey theory and method as follows:

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Table3: Grey Relational Analysis calculations as per eqs.1&2

Experiment No.	**Comparability sequence**		**Grey Relational Coefficient**		**Grey Relational Grade**
	Ra	Ct	Ra	Ct	
1	0.7789	0.8076	0.6934	0.7221	0.7077
2	0.2526	0.6923	0.4008	0.6190	0.5099
3	0.0736	0.0000	0.3505	0.3333	0.3419
4	1.0000	0.3846	1.0000	0.4482	0.7241
5	0.7894	0.3076	0.7036	0.4193	0.5614
6	0.7368	0.1538	0.6551	0.3714	0.5132
7	0.5263	1.0000	0.5135	1.0000	**0.7567**
8	0.0000	0.7692	0.0000	0.6842	0.5087
9	0.1578	0.0769	0.3725	0.3513	0.3619

Table.4: Average grey relational grade for factors and levels of the experiment

Factor/Level	**1**	**2**	**3**
A	0.5198	**0.5995**	0.5424
B	**0.5968**	0.5266	0.4056
C	**0.5996**	0.5319	0.5533

4. RESULTS&DISCUSSIONS

According to the performed experiment design it is clearly observed from Table 3 and Figure 3 that the milling process parameters setting of experiment no. 7 has the highest grey relational grade. Thus the experiment no7 gives the best multi-performance characteristics among the 9 experiments.

The response table of Taguchi method was employed here to calculate the average grey relational grade for each factor level. The procedure was to group the relational grades firstly by factor level for each column in the orthogonal array and then to average them.

Since the grey relational grades represented the level of correlation between the reference and comparability sequences, the larger grey relational grade means the comparability sequence exhibits a stronger correlation with reference sequence. Therefore, the comparability sequence has a larger value of grey relational grade for average surface roughness and chip thickness.

Based on this premise the study selects the level that provides the largest average response. In Table 4, A3 B1 C3 shows the largest value of grey relational grade for factors A, B and C respectively. Therefore A3 B1 C3 is the condition for the optimal parameter combination of the milling to minimize average surface roughness and chip thickness.

The influence of each cutting parameter can be more clearly presented by means of the grey relational grade graph. It shows the change in the response, when

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the factors go for their level 1 to level 3. The response graph for the milling parameters are drawn from data of Table 4 and depicted in Figure 4, in this figure, the greater values average grey relational grades give the low surface roughness and chip thickness.

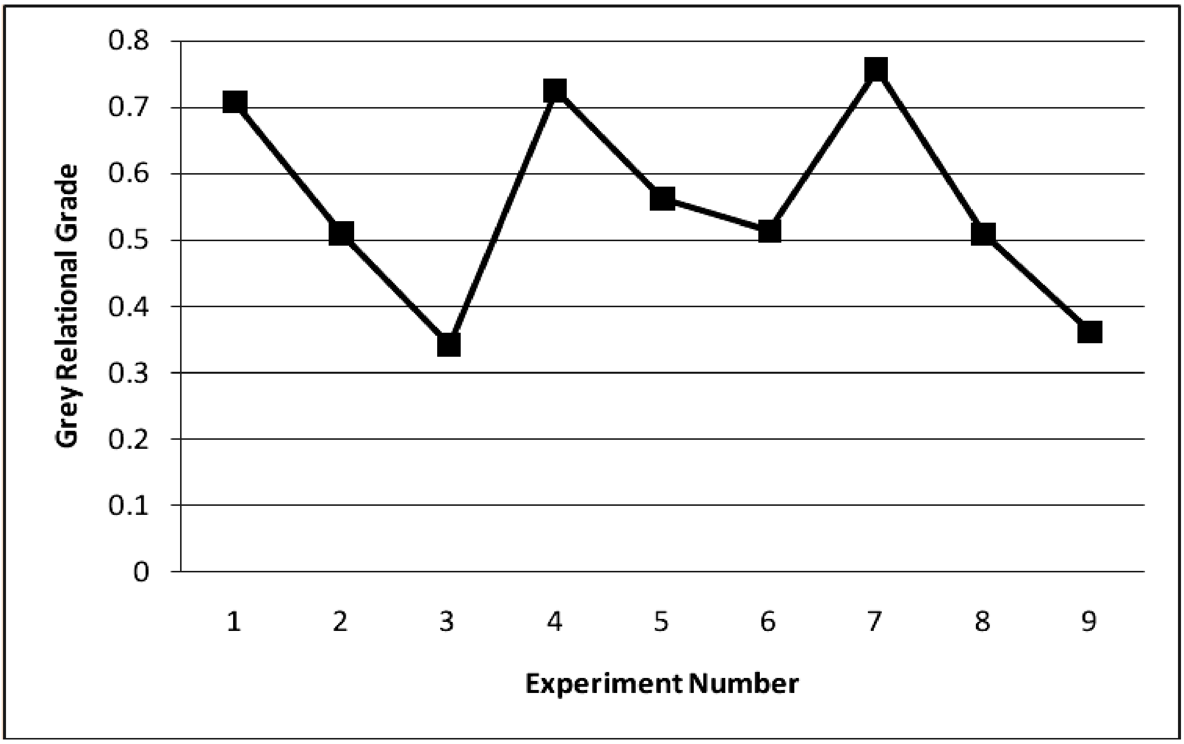

Figure 3: Graph for grey relational grade

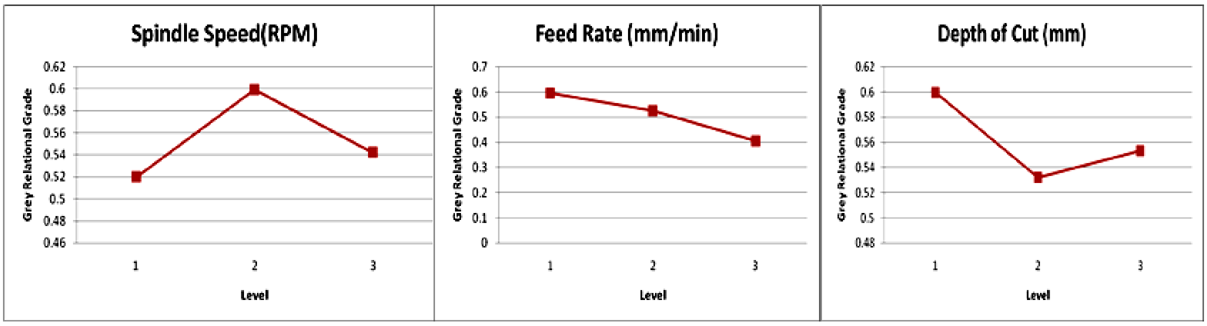

Figure 4: Grey relational grade graphs for milling parameters

5. CONCLUSIONS

The Grey relational analysis based on an orthogonal array of the Taguchi methods was a way of optimizing the process parameters in milling for Al6351 alloy. The analytical results summarized as follows:

1. From the response table of the average grey relational grade, it is found that the largest value of the GRA for the spindle speed of 1000 rpm, the feed rate of 50 mm/min and depth of cut 0.7 mm. It is the recommended levels of the controllable

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parameters for the process of milling as the minimization of average surface roughness and chip thickness.

2. The order of the importance of influential factors based on the Taguchi response table in sequence is chip thickness, spindle speed and feed rate.

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