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MULTI PARAMETER OPTIMISATION USING GREY RELATIONAL TECHNIQUE IN TURNING OF EN24 STEEL WITH MINIMUM QUANTITY LUBRICATION (MQL)

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ABSTRACT

Since many years ago, multi-objective optimization technique has been used in a variety of diverse fields. The selection of optimum machining parameters plays a significant role to ensure quality of a product, reduce the manufacturing cost and increase productivity in computer control manufacturing process. Turning is an inherent complex process in competitive engineering problem. This study investigates multi response optimization of turning process for an optimal parametric combination to yield the minimum surface roughness and tool wear using a GRA (grey relational analysis). Confirmation test is conducted for the optimal machining parameters to validate the test result. Various input parameters, such as cutting fluid quantity, distance of nozzle block from the cutting point, cutting speed, feed and depth of cut are considered as input. This indicates the application feasibility of the grey-based Taguchi technique for a continuous improvement in product quality of manufacturing industry.

Keywords: *Surface Roughness, Tool Wear, Grey Relational Analysis (GRA).*

1.Introduction

Turning is a machining process which shapes material into various profiles. In majority of the turning operations, turning is followed by finishing processes. Grinding being one of the finishing processes carried out in industrial practices requires change of machine tool and is associated with more set up time. Finish hard turning is an alternative process which allows machining the parts in single set up giving greater accuracy. Using a single point cutting tool and work holding device, one can produce different parts of various forms and sizes, Machinability of material is questioned by many industries. Many researchers are finding the optimum level of parameters to address the stated problem. In 1950, Boulger and in 1989, Smith had encompassed criterias related to machinability pointing towards the properties of a work material which produces satisfactory products by chip removal methods. Performance of ceramic cutting tools over plain cutting tools is studied with increase in layers as they carry the strength and toughness [1].

Deng developed the Grey System Theory used in various fields of engineering industry, stock exchange, processing industry, electronic industry problems [2, 3]. Gray based Taguchi analysis is used with eight independent variables to minimize surface roughness, dimensional deviation and to maximise accuracy in turning tool steel [4].

Some of the researchers applied GRA to various conventional machining processes like drilling, milling, etc. [5, 6, 7] and some have used for non conventional machining process such as EDM, chemical polishing [8, 9]. Multiple performances like tool life, cutting force, surface roughness are analysed using grey relational analysis [10]. In turning of Al/SiCp metal matrix composite, Taguchi grey relational analysis is also applied to analyse surface roughness and tool wear. In some of multipoint processes like drilling, milling, Taguchi and grey relational analysis are used to determine the best combination for optimal control parameters to investigate effect on burr height, material removal rate and surface roughness [11, 7]. This shows effectiveness of GRA in solving interrelationships among multiple operational and process characteristics [12]. Also Optimum parameters of cutting speed, feed and depth of cut are found effective in reducing surface roughness and tool wear [21].

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The literature studied shows that many experiments are performed with surface roughness and tool flank wear as output parameter individually under dry, wet and MQL lubrication condition. In much of the literature the cutting conditions are considered as the input parameters. To the best of the knowledge of the authors, no significant study is reported involving various MQL parameters. This suggest that the MQL specific parameters can be worked out to check their effectiveness on the response parameters. Recently, some have worked on MQL specific parameters with variation in pressure of cutting fluid coming out of nozzle, cutting fluid quantity with machining parameters. However, they have considered two levels of all parameters. The set up developed here is capable of changing the quantity of mixture of cutting fluid and air coming out of nozzle and the distance between nozzle block exit point and cutting point.

Hence, in the present experiment a study is conducted using MQL specific parameters viz quantity of mixture of cutting fluid and air, distance of nozzle block from the cutting point along with machining parameters on surface roughness and tool flank wear. As the two output parameters are required to study simultaneously, the grey relational approach is used in present work to analyse the surface roughness and tool flank wear. Also the sequence of importance of input to output parameters was determined. Further the paper is structured in following manner: 2nd Section deals with experimental method, section 3 discusses methodology used in Grey relational analysis and results-conclusion in section 4 and 5.

2. Experimental Details

2.1 Component and Tool Material

AISI 4340 alloy steel components with diameter 38 mm with length 160 mm are used in machining. The diameter and length of the workpiece is so selected that turret will have easy sliding movement during machining. The present work deals with grey relational technique used to optimise the conditions namely surface roughness and tool flank wear in MQL cutting environment. The workpiece material composition is given in Table 1 [20]. The carbide inserts CNMG 12 04 08 with DCLNR 25 25 M 12 tool holder was used throughout the study.

Table 1. AISI 4340 Material Composition

C	Si	Mn	Cr	Ni	Mo
0.35 – 0.45	0.1 – 0.35	0.4 – 0.7	0.9 – 1.3	1.25 – 1.75	0.2 – 0.35

2.2 Experimental Design

The cutting test are carried out on CNC lathe machine PILATUS 25T with 11 kW motor power having FANUC controller. Five levels of each input parameters are considered. The values of cutting speed, feed and depth of cut were selected based on the recommendations of manufacturers catalogue and discussions with some of the industry experts. The levels of distance between cutting point to exit of nozzle block and quantity of mixture of cutting fluid and air are so selected such that the mixture will be directed and sprayed directly into the cutting zone. The cutting fluid mixture rate is selected within the MQL range reported in the literature. Maximum flow rate is chosen to be 500 ml/hr and minimum is selected near to dry condition (i.e. 100 ml/hr). Table 2 shows the input levels of parameters used in the experimental design. As outlined in section, there are five input parameters selected for experimentation with five levels each. L25 orthogonal array [18, 19] is used with 25 experimental runs is shown in Table 3.

Table 2. Experiment Factors with Levels

Factors Levels	1	2	3	4	5
Discharge (ml/hr)	100	200	300	400	500
Distance of nozzle (D) (cm)	2.5	3.5	4.5	5.5	6.5
Cutting speed (V) (m/min)	100	110	120	130	140
Feed (f) (mm/rev)	0.1	0.15	0.2	0.25	0.3
Depth of cut (d) (mm)	0.1	0.2	0.3	0.4	0.5

3.Methodology used in grey relational analysis

Taguchi analysis focuses on optimisation of single characteristics which shows its limitation in optimising the multiple performance characteristic. Such cases can be solved using Grey Relational Analysis. A grey theory carries data between black and white. The analysis is effective in analysing data with less information and can optimise the multiple outcomes. For this, GRA is chosen in this experiment. The following procedure was adopted to optimise:

1. Normalization of parameters (lower is best)
2. Determine Grey relational coefficient
3. Evaluate Grey relational grade

Pre-processing of data is required to transfer original data into comparable sequence. So the first step, normalisation, was conducted using the below equation (1) according to "the lower-the-better" approach. Initially data pre-processing is normally required as the range and units used in data may differ from each others. It is also required when the range is very large direction of target in the data is different. Linear normalisation of the recorded data in a range between zero to one is used in this experiment to study surface roughness and tool flank wear. In MQL turning process, the main objective is to achieve the minimum surface roughness also to have a lower tool flank wear. Hence normalised data preprocessing for both the output parameter is carried out using the lower the better approach [17].

For LB : $$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (1)$$

where, $x_i^0(k)$ refers to a value after grey relational generation, min and max $x_i^0(k)$ refers to smallest and largest value of $x_i^0(k)$ and $x_i^0(k)$ refers to the original value. Grey relational coefficient was determined by data preprocessing using following equation [17].

$$\zeta_i(k) = \frac{\Delta_{min} + \xi \Delta_{max}}{\Delta O_i(k) + \xi \Delta_{max}} \quad (2)$$

where, ξ is identification coefficient $0 < \xi > 1$. ΔO_i is difference in reference and normalisation value. Δ_{min} and Δ_{max} are the minimum and maximum value among difference sequence from reference series. In the present case, ξ = 0.5 is used. Smaller the value used, puts the markable difference in calculations. Here the value is selected as 0.5 WHICH is widely accepted [2]. After averaging the grey relational coefficients, Grey relational degree is estimated using following equation.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_{i(k)} \quad (3)$$

Various factors in real condition carries unequal weights. So the normalised weight factor in the above equation is taken as 1. The degree shows the relationship among the sequence. The higher the degree, strong is the relation between reference and comparable sequence.

4 Results

4.1 Optimal combination of experimental parameters

In present analysis, surface roughness of EN 24 components and tool wear of insert under MQL condition is studied. Entire experiment is performed with two replications (i.e. n=2). As it is not possible to measure the surface roughness and tool flank wear during the experimentation, the off line measurement of surface roughness and tool wear is done. The measurement of surface roughness after the experiment was performed using Surf test surface roughness tester (Ra – µm) with a cut of distance of 0.8 mm. Present study requires to minimise the surface roughness of component therefore Ra is measured at three different locations, 120^0 apart on a plane and on three measurements per plane. The tool makers microscope was used to measure the tool flank wear (TW). Experimental measured data have been processed [15, 16] through first step: Normalisation. This is shown in table 4. Minimum values of surface roughness and tool flank wear are the indicators of good machining process. So they are analysed using smaller the better criteria. Equation 2 is used for grey relational coefficient calculations which are further used to find out grey relational grade given in table 4 and shown in fig. 1 graphically. Optimal combination is referred as the grade carrying the higher value which is calculated using equation 3. The overall mean grades are shown in table 5. The experimental design used in this study is orthogonal, therefore further it is possible to separate out the effect of individual parameter on grey grade at various levels. This can be observed in table 5. From the table it can be seen that the larger the grey relational grade, better is the performance characteristics. To determine the output parameter affecting the process the higher max-min values The optimal input parameter settings to multi performance turning of AISI 4340 steel is fifth level of Quantity of mixture, third level of distance of nozzle block from cutting point, and second, first, first level of cutting speed, feed and depth of cut respectively which are can be seen in table 5. (A5 B3 C2 D1 E1 - Discharge - 500 ml/hr, Distance of nozzle - 4.5 cm, Cutting Speed 110 m/min, Feed rate 0.1 mm/rev and Depth-of-cut 0.1 mm).

It can be noticed that, the larger (5th level) quantity of mixture allows the proper penetration of cutting fluid and air mixture at the junction of cutting point and workpiece. This separates the cutting point and workpiece causing reduction in friction with increase in surface finish and reduction in tool wear. The moderate level of distance (3rd level) maintains the reach of jet at the exact intersection.

Further increase in cutting speed (2nd level) is desirable for good surface finish at the same time it increases temperature during machining, same time softens the material which reduces the wear rate of tool. To have a good surface finish and minimum tool wear, feed and depth of cut should be low, which are also seen from the optimal combination.

Table 3. Experimental layout of L25 orthogonal array and measured values

Trial No	Discharge (ml/hr)	Distance of nozzle (cm)	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness (Ra)	Tool wear (TW)
1.	1	1	1	1	1	0.88	0.04375
2.	1	2	2	2	2	1.05	0.08500
3.	1	3	3	3	3	1.09	0.26500
4.	1	4	4	4	4	1.14	0.36000
5.	1	5	5	5	5	1.19	0.65000
6.	2	1	2	3	4	1.14	0.13250
7.	2	2	3	4	5	1.06	0.20000
8.	2	3	4	5	1	0.99	0.10500
9.	2	4	5	1	2	0.85	0.26500
10.	2	5	1	2	3	1.13	0.06500
11.	3	1	3	5	2	1.30	0.11500
12.	3	2	4	1	3	0.81	0.10200
13.	3	3	5	2	4	0.91	0.33000
14.	3	4	1	3	5	1.14	0.13000
15.	3	5	2	4	1	1.15	0.16000
16.	4	1	4	2	5	1.01	0.10750
17.	4	2	5	3	1	1.05	0.13000
18.	4	3	1	4	2	1.23	0.0700
19.	4	4	2	5	3	1.17	0.25500
20.	4	5	3	1	4	0.71	0.13250
21.	5	1	5	4	3	1.04	0.15000
22.	5	2	1	5	4	1.19	0.15750
23.	5	3	2	1	5	0.52	0.09050
24.	5	4	3	2	1	0.66	0.09250
25.	5	5	4	3	2	1.05	0.10500

Table 4. Calculation of grey grade, deviation sequence and order

Trial No	Data Preprocessing (Grey relational generation)		Deviation sequence		Grey relational coefficient (with ξ = .5)		Grey relational grade	Order
	Surface Roughness (µm)	Tool wear principal (mm)	Surface Roughness (µm)	Tool wear principal (mm)	Surface Roughness (µm)	Tool wear principal (mm)		
1	0.5472	1	0.4527	0	0.5247	1	0.7624	3
2	0.3234	0.9319	0.6765	0.0680	0.4249	0.8802	0.6526	7
3	0.2770	0.635	0.7229	0.3649	0.4088	0.57806	0.4935	22
4	0.2070	0.4783	0.7929	0.5216	0.3867	0.4894	0.4381	24
5	0.1432	0	0.8567	1	0.3685	0.3333	0.3509	25
6	0.2121	0.8536	0.7878	0.1463	0.3882	0.77352	0.5809	15
7	0.3060	0.7422	0.6939	0.2577	0.4187	0.6598	0.5393	20
8	0.3943	0.8989	0.6056	0.1010	0.4522	0.8319	0.6421	8
9	0.5805	0.6350	0.4194	0.3649	0.5437	0.5780	0.5609	21
10	0.2250	0.9649	0.7749	0.0350	0.3921	0.9344	0.6633	6
11	0	0.8824	1	0.1175	0.3333	0.8096	0.5715	16
12	0.6370	0.9039	0.3629	0.0960	0.5793	0.83881	0.7091	5
13	0.5006	0.5278	0.4993	0.4721	0.5003	0.5143	0.5073	19
14	0.2014	0.8577	0.7985	0.1422	0.3850	0.7784	0.5818	14
15	0.1971	0.8082	0.8028	0.1917	0.3837	0.7228	0.5533	17
16	0.3707	0.8948	0.6292	0.1051	0.4427	0.8262	0.6345	10
17	0.3251	0.8577	0.6748	0.1422	0.4255	0.7784	0.6020	12
18	0.0856	0.9567	0.9143	0.0432	0.3535	0.9203	0.6369	9
19	0.1728	0.6515	0.8271	0.3484	0.3767	0.5893	0.4830	23
20	0.7671	0.8536	0.2328	0.1463	0.6822	0.7735	0.7279	4
21	0.3316	0.8247	0.6683	0.1752	0.4279	0.7404	0.5842	13
22	0.1389	0.8123	0.8610	0.1876	0.3673	0.7271	0.5473	18
23	1	0.9228	0	0.0771	1	0.8663	0.9332	1
24	0.8236	0.9195	0.1763	0.0804	0.7392	0.8614	0.8004	2
25	0.3180	0.8989	0.6819	0.1010	0.4230	0.8319	0.6275	11

Table 5. Grey relational grade response table

Sl. No.	Quantity of mixture	Distance	Cutting speed	Feed	Depth of cut
1	0.539	0.626	0.638	0.738	0.672
2	0.597	0.611	0.640	0.651	0.609
3	0.584	0.642	0.626	0.577	0.586
4	0.616	0.572	0.610	0.550	0.560
5	0.698	0.584	0.521	0.519	0.607
Max-Min	0.159	0.069	0.119	0.219	0.111
Rank	2	5	3	1	4

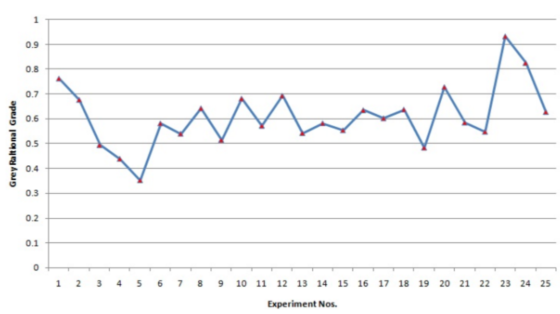

Figure 1 Grey relational grade for multi response

4.2 Confirmation Test

Optimal parameters of machining are further verified for improvement of performance characteristics. In confirmation experiment, tests are carried out with optimal level of input parameters. The predicted grade, with optimum level of parameter is calculated as

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{n}(\overline{\gamma_m} - \gamma_m) \quad (4)$$

where γ_m = total mean of grade, $\overline{\gamma_m}$ = mean at optimum level. Equation 4 helps to find out predicted grade for grey relational analysis. It means the estimated Grey relational grade is equal to mean of Grey relational plus the summation of difference between overall mean Grey relational grade and mean grey grade for each individual factor at optimal level.

Table 6 gives the comparison of results of confirmation test (predicted) with actual by using optimal parameter combination. The test reveals improvement in results by using GRA in MQL turning process. The result of the experiment shows that using optimal parameter setting both output parameters assumes lower values. It is observed that improvement in Grey grade from initial combination [16] set at all first levels (0.785) to the experimental combination (0.603) is 0.182 (18.20%) which shows good agreement. This indicates effectiveness of grey analysis while solving multiple parameter problems.

Table 6. Confirmation test result

	Initial factor levels	Optimal process parameters	
		Predicted	Experimental
Level of factors	1-1-1-1-1	5-3-2-1-1	5-3-2-1-1
Overall grey relational grade	0.785	0.963	0.603
Improvement in GRG (Initial and confirmation)			0.182

5. Conclusion

In this study, Taguchi array using L25 runs and grey approach is applied to find optimal parameter of multiple responses in turning of AISI 4340 like Surface roughness and Tool Wear. The multiple responses viz Surface roughness and Tool wear were converted into single performance characteristic using Grey relational analysis.

- The various parameters viz. quantity of mixture of cutting oil and air, distance of nozzle block from cutting point, cutting speed, feed and depth of cut each at five (5) levels are used.
- It was observed from grey relational grade response table that feed is the most significant factor in all input parameters used in experiment.
- This study gives following optimum combination of MQL turning parameters with their levels: A5-B3-C2-D1-E1 (i.e. Discharge - 500 ml/hr, Distance of nozzle - 4.5 cm, Cutting Speed 110 m/min, Feed rate 0.1 mm/rev and Depth-of-cut 0.1 mm).
- It is observed that improvement in Grey grade from initial combination (0.785) to the

experimental combination (0.603) is 0.182 (18.20%) which shows good agreement.

- The optimization approach used in this study found effective and simple for multiple performance characteristics.

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Nomenclature

Symbol	Meaning
min $x_i^0(k)$	Smallest value of $x_i^0(k)$
max $x_i^0(k)$	Largest value of $x_i^0(k)$
	Grey relational coefficient
ξ	Identification coefficient
γ_i	Grey relational degree
Δ_{min}	Minimum value among difference sequence
Δ_{max}	Maximum value among difference sequence
$\hat{\gamma}$	Predicted Grade
γ_m	Total mean grade

Mean at optimum level

