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Experimental Investigation and Parametric Optimization of Turning Process Using Grey Relational Analysis

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ABSTRACT: Cooling method type significantly affects the turning process performance. In turning processes, there are several input parameters. However, the mode of application of the cutting fluid and the amount of cutting fluid used doesn't have enough attention. The aim of this work is to investigate the effect of different cooling methods such as minimum quantity lubricant (MQL), wet cooling and dry cutting on turning process performance during machining of EN19 steel material. In the present, an attempt will be made to select the optimum turning process parameters using multi objective optimization called Grey relational analysis (GRA). Experiments were conducted based on the Taguchi L12 orthogonal array (OA) design. In this work, cutting speed, feed rate, depth of cut and cooling method will be considered as turning process variables whereas Cutting temperature, tool wear and surface roughness were taken as output characteristics. Grey relational analysis (GRA) optimization technique was applied to select the optimum cutting parameters. From results, the optimum turning process variables determined as spindle speed 800 rpm, feed rate 0.16mm/rev, depth of cut 0.4mm, coolant type MQL respectively using GRA for concurrent optimization of cutting temperature, surface roughness and tool wear.

KEYWORDS: EN19 Steel, Turning Process, Optimization, Grey relational analysis, Surface Roughness, Cutting Temperature, Tool Wear.

I. INTRODUCTION

Turning is the most common lathe machining operation. During the turning process, a cutting tool removes material from the outer diameter of a rotating workpiece. The main objective of turning is to reduce the workpiece diameter to the desired dimension. In any machining process the tool is subjected to three distinct factors: cutting force, cutting temperature and sliding action, due to the relative motion between the tool and the workpiece. Due to these factors, the cutting tool will start giving unsatisfactory performance after some time. The unsatisfactory performance results from tool wear due to its continued rise in high temperatures during metal cutting process. The hardness of the tool decreases with the increase in the cutting temperature and it becomes too soft and fails ultimately. Cutting or machining temperatures significantly affect tool wear, tool failure and hence, tool life.

In a given combination of work and tool material, the cutting temperature depends upon the cutting speed, feed, and depth of cut and to a limited extent cutting fluids. Among of these factors, cutting speed has a predominant effect. One of the important functions of the cutting fluid is to conduct the heat away from the tool and workpiece interface and avoid heat accumulation and temperature build-up in the vicinity of the active cutting edge. The fluid would be carried away by the outward flowing chip more rapidly than it could be forced between the tool and chip. The effectiveness of the fluid in lowering the tool temperature decreases with increase in cutting speeds and at higher speeds the fluids become completely ineffective in reducing the temperature.

In the turning process, higher cutting zone temperatures results in low productivity and high machining cost during machining of difficult to cut materials. For this reason, it is imperative to use cutting fluids at the machining zone to control the cutting zone temperatures during cutting of various types of difficult to cut materials. In the literature, various types of cooling techniques are available to supply the coolant at the machining zone. Particularly, metal cutting industries focused more on environmental friendly cooling techniques like cryogenic, minimum quantity lubrication (MQL) and solid lubrication, etc. to meet the conscious environmental regulation. However, these techniques require costly experimental setups to supply the coolant at the machining zone.

Lin et al. considered the tool life, main cutting force, and surface roughness as multiple quality characteristics in dry turning of S45C steel and observed following improvement 150 %, 136 % and 124 % respectively in the performance in turning using Taguchi incorporated grey relational analysis, also concluded that feed rate is the main affecting cutting parameter for the multiple quality characteristics. Sarikaya and Gullu observed the reduction flank wear, notch wear and surface roughness in turning of super alloy using Taguchi based grey relational analysis (TGRA) under the MQL environment. It was found that TGRA improved the grey relation grade by 39.4 %. Leppert et. al obtained low surface roughness and low cutting force in MQL condition with conventional cutting tool due to good lubrication over dry and wet condition respectively during machining of AISI 316 material. Vasumathy and Meena have made linear grooves on the rake face the tool and conducted dry turning experiments on AISI 316 material using textured and untextured tools respectively. From results they noticed low cutting force and tool wear in textured tools due rise in shear angle low too-chip contact area. Kumar Mishra et al. Circular dimple single pattern textured tools were tested under MQL, nano-MQL condition, dry condition and results were compared with untextured tools in turning of Ti-6Al-4V alloy. It was observed improved machinability indices with textured tools under nano-MQL condition over MQL and dry cutting condition respectively. The reason for positive results with textured tools is accumulation of nano fluid in the texture design leads to low tool chip contact length.

Extensive literature survey shows that limited work has been reported on turning of EN19 steel material. Hence, in the present study, an attempt has been made to optimize the process parameters like spindle speed, feed rate, depth of cut and cooling method considering the multiple characteristics including Cutting temperature, tool wear and surface roughness by using Grey relation analysis. The relation between machining parameters and performance can be found out with the Grey relational analysis.

II. EXPERIMENTAL WORK

EN19 is a high quality alloy metal with tensile strength. With a aggregate of top ductility and surprise resistance, EN19 is appropriate for applications with very excessive loading which includes engine gear containers. It is commonly used in automotive and engineering sectors for parts requiring high shock resistance and fatigue strength, such as gears, shafts, and axles.

Turning experiments were conducted on EN19 steel using CNC lathe machine as shown in Figure 1 under different cooling conditions. The machining zones of conventional (wet) cutting conditions are shown in Figure 2. After machining, workpiece can be seen as depicted in Figure 3. Cutting tools were selected inserted in the tool holder and performed each experiment for 200 mm length of the workpiece. Each experiment was conducted with a new cutting edge for tool wear analysis purposes. The cutting conditions used to perform the experiments are shown in Table 1. Every experiment was conducted three times and the average was considered in each response to provide the accuracy in the data. Experiments were conducted based on Taguchi L9 orthogonal array. The selected process variables were selected based on the trial experiments. ISO 4287-1997 standards were followed to measure the average surface roughness (Ra) using Talysurf tester. Tool wear analysis and measurement were done by using a Metallurgical microscope. Thermal image camera was used to measure the cutting zone temperature during machining. Factors like obstruction of Infrared rays by chip particles and cutting fluid were taken into consideration while measuring cutting zone temperature. Final obtained results were shown in Table 2.

Figure 1 CNC machine

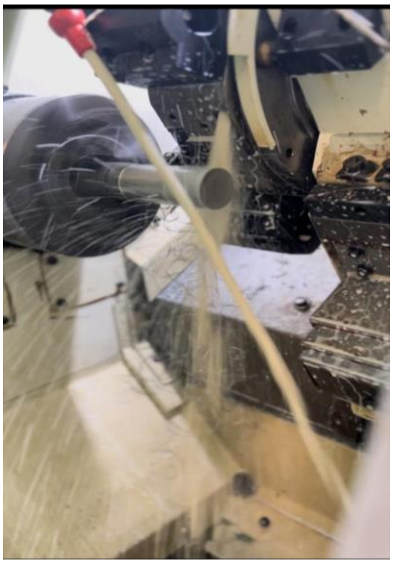

Figure 2 Wet cooling condition

Figure 3 Machining zone images at the wet cooling

Table 1 Details of experimental conditions

Workpiece material and dimensions	EN19 steel round bar (⌀ 30 mm x 150 mm)
Cutting inserts	AlTiN PVD coated tungsten carbide inserts (An ISO designation of SNMG432 KC 910)
Tool holder	ISO specification of PSBNL 2020 K12, WIDIA make
Working insert tool geometry	Inclination angle: - 6o, rake angle: - 6o, clearance angle: 6o, Nose radius: 0.8 mm, major cutting edge angle: 75o
Turning Process parameters	Spindle speed (v): 800 and 1000RPM Feed rate (f): 0.16 mm/rev Depth of cut (ap): 0.2 and 0.4mm
Environmental conditions and coolants used	Conventional cooling (emulsion based flood cooling 1:20 soluble oil) flow rate: 5 l/hr (through external nozzle); Nozzle diameter -⌀ 10 mm MQL:150ml/hr (emulsion based flood cooling 1:20 soluble oil)

Table 2 Experimental results

S. No.	Mode	Spindle Speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)	Coolant type	Cutting Temp (ºC)	Surface roughness (µm)	Tool wear (µm)
1	T	800	0.16	0.4	DRY	63.06	4.852	915
2	T	800	0.16	0.4	WET	54.15	6.941	528
3	T	800	0.16	0.4	MQL	60.05	1.963	414
4	T	1000	0.16	0.2	DRY	61.07	3.649	423
5	T	1000	0.16	0.2	WET	53.5	2.285	908
6	T	1000	0.16	0.2	MQL	58.5	2.431	742
7	UT	800	0.16	0.4	DRY	127.3	2.218	495
8	UT	800	0.16	0.4	WET	72.37	4.343	577
9	UT	800	0.16	0.4	MQL	91.92	3.721	441
10	UT	1000	0.16	0.2	DRY	110.8	1.437	393
11	UT	1000	0.16	0.2	WET	69.15	2.523	345
12	UT	1000	0.16	0.2	MQL	98.92	1.824	310

III.RESULTS AND DISCUSSIONS

Selecting the right alternative among the more available choices is not an easy assignment. Therefore, a systematic and scientific methodology is required to solve such a difficult task. The researchers have shifted their concentration towards GRA because of easy understanding and simple methodology. In the present work, the relation between the process parameters and performance characteristics during turning of EN19 steel material and selection of the right alternative which improves the laser performance is a difficult task. Hence, in the present work GRA was employed to identify the right choice a following steps to choose the right alternative among available alternatives.

Step1: Normalization of experimental data

As the raw data cannot be compared because of different ranges of data and units. For, comparison purpose data processing is required (i.e., normalizing the data between 0 and 1). Normalization is a process of converting the original sequence into a compatible sequence. Experimental data is normalized as $D_p{}^*(q)$ ($0 \le D_p{}^*(q) \le 1$) by the following formulae. Equation (2) is used for the larger-the-better quality characteristic and equation (1) is used for the smaller the better quality characteristic. In the current study, to improve the productivity, cutting temperature and surface roughness were chosen for smaller-the-better characteristics. The calculated normalized values are tabulated in the Table 3.

Smaller - the - better

$$D_p{}^*(q)=\frac{Max\ D_p(q)-D_p(q)}{Max\ D_p(q)-Min\ D_p(q)} \text{ ------------------------(1)}$$

Larger - the - better

$$D_p{}^*(q)=\frac{D_p(q)-Min\ D_p(q)}{Max\ D_p(q)-Min\ D_p(q)} \text{ ---------(2)}$$

Where

$D_p{}^*(q)$= Sequence after data processing, $D_p(q)$= Original sequence, $Max\ D_p(q)$= Maximum value of entity p, $Min\ D_p(q)$ = Minimum value of entity p, p= Number of characteristics (1, 2, 3, 4), q = Number of experimental runs (1, 2,….., 9)

Table 3 Normalized values

Quality Characteristics			
Exp. No.	**Cutting Temp. (°C)**	**Surface roughness (µm)**	**Tool wear (µm)**
1	0.87	0.379	0
2	0.991	0	0.639
3	0.911	0.904	0.828
4	0.897	0.598	0.813
5	1	0.845	0.011
6	0.932	0.819	0.285
7	0	0.858	0.694
8	0.744	0.472	0.558
9	0.479	0.585	0.783
10	0.223	1	0.862
11	0.787	0.802	0.942
12	0.384	0.966	1

Step 2: Calculation of grey relational coefficient (GRC)

The purpose of calculating the Grey relational coefficient is to know the relation between the desirable and real experimental data. The grey relation coefficients $\varepsilon_p(q)$for the all turning performances are calculated using equation (4) and listed in the Table 4.

$\varepsilon_p(q) = \frac{\Delta_{Min} + \zeta\Delta_{Max}}{\Delta_{op}(q) + \zeta\Delta_{Max}}$---------------------------------- (3)

Where $\Delta_{op}(q)$ indicates the absolute difference between current data sequence value $((D_p{}^*(q))$ and ideal value $D_p{}^o(q)$ and ζ is the distinguishing coefficient and it is used to alter the variation of the grey relational coefficients and if lower distinguishing coefficient higher will be the distinguishing ability. ζ is taken as 0.5 by taking into account of all the process variables are equally weighing. Equation (5), (6) and (7) are used to compute the values of$\Delta_{op}(q)$, Δ_{Min}, Δ_{Max} .

$\Delta_{op}(q) = |D_p{}^o(q) - D_p{}^*(q)|$-------------------------(4)

$\Delta_{Min} = \min_p \min_q \Delta_{op}(q)$-----------------------------(5)

$\Delta_{Max} = \max_p \max_q \Delta_{op}(q)$---------------------------(6)

Table 4 Performance characteristics GRC, GRG and its orders.

Exp. No.	Grey relational coefficient			GRG	Order
	Cutting	Surface	Tool		
1	0.793	0.446	0.333	0.524	12
2	0.982	0.333	0.58	0.632	9
3	0.848	0.838	0.744	0.81	1
4	0.829	0.554	0.727	0.703	5
5	1	0.763	0.335	0.699	6
6	0.8	0.734	0.411	0.648	7
7	0.333	0.778	0.62	0.577	10
8	0.661	0.486	0.53	0.559	11
9	0.489	0.546	0.697	0.577	9
10	0.391	1	0.783	0.725	4
11	0.701	0.716	0.896	0.771	3
12	0.448	0.936	1	0.795	2

Step 3: Calculation of Grey relational grade (GRG)

Grey relational grade is useful in evaluating the multiple performance characteristics. Average of all obtained grey relational coefficient gives the grey relation grade. Equation (7) is used to compute the grey relation grade $(\gamma_p(q))$ and obtained results and grey relational grade ranks were tabulated in Table 4.

$\gamma_p(q) = \frac{1}{N}\sum_{i=0}^{N} \varepsilon_p(q)$--------------------------------------(7)

Where N = No. of performance characteristics.

The larger grey relational grade represents how closer the corresponding experimental response to the ideal value. From the Table 4, 3rd experiment with spindle speed 800 rpm, feed rate 0.16 mm/rev, depth of cut 0.4mm, and MQL condition combination has the highest grade among all the orthogonal experiments. Therefore, spindle speed 800 rpm rpm, feed rate 0.16 mm/rev, depth of cut 0.4mm, and MQL condition combination has identified as the optimum cutting condition using GRA Technique.

IV. CONCLUSIONS

In this study GRA is used for optimising the machining parameters of EN19 steel during turning. From the present work, following conclusions were drawn.

- Optimum turning process variables determined as spindle speed 800 rpm, feed rate 0.16 mm/rev, depth of cut 0.4mm, coolant type MQL respectively using GRA for concurrent optimization of cutting temperature, surface roughness and tool wear.
- MQL cooling technique is an efficient alternative solution for metal cutting industries from the stringent environmental regulation point of view. On the other hand, GRA helps to improve the productivity during machining of EN19 steel.
- Manufacturing cost and wastage of material could be reduced by conducting experiments at the Taguchi technique identified optimum cutting conditions during turning of EN19 steel in the production line consists of turning operation.

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