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Optimization of face milling process parameters by GRA with deep cryogenic treated milling cutter

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ABSTRACT

Cryogenic based machining has significant consideration in both research as well as in the industry because it will improve the machinability even on difficult to machine the materials, hence the tool life increases, in which it will further significantly improve the productivity in machining. Despite of the industrial usage of cryogenic machining systems, it has a considerable research gap in the selection and identification of cutting parameters for cryogenic based machining. Because of its wide application, Taguchi's process parameters optimization technique is applying extensively to identify the optimized process parameters. Taguchi method is employed in this investigation for studying the effects of cryogenic treatment on carbide face milling-cutting tool for machining the EN-8D work material. This work analyzes the influence of various operating parameters on rate of removing material and surface quality through Taguchi Grey Relational Analysis (GRA). The optimal operating conditions determined in terms of cutting speed, depth of cut, and feed rate. In order to ensure influence on tool treatment, the cryogenically treated tool (CT) and non-cryogenic treated tool (NCT) included for Scanning Electron Microscopy (SEM) examination. Finally, it was observed that the cryogenically treated industrial carbide tool is outperformed than the conventional non-cryogenic treated tool under the same operating environment in terms of wear resistance on cutting edges and hardness on the tool surface.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the Cryogenic is derived word from Greek with the meaning of cold. The heat treatment applied to harden at very low temperatures is known as a cryogenic treatment. It is ancient technology which helps to alter the mechanical properties of materials positively. The conventional liquid lubricants are utilized in machining operations to produce components are par with intended value, required surface quality and also used in the purpose of extending tool life. They were also useful in the reduction of temperature and removing metal particles while machining. Though the make use of conventional liquid lubricants (fluids used while metal cutting operation) is effective, it has several harmful effects. The cutting fluids used in machining industries are full of chemical constituents unsafe for operator and pollute disposed areas. When Minimum Quantity Lubrication conditions were used in machining 6061 alloy, the material sticking together on the surface of tool experienced nose as well as flank wear [1–3]. The dry machining in

turning aluminium alloys resulting higher temperatures in the cutting zone and Built-Up Edge formation. This also leads to high dimensional inaccuracies and excessive tool wear [4–6]. The environment-friendly coolant viz, cryogenic liquid nitrogen is used to overcome these difficulties. The Cryogenic LN2 is used by many researchers to carry out experiments for machining other materials and reduced required forces on cutting the material, temperature improved surface quality and wear of tool [7–9]. It has also experimented that when low-temperature LN2 was utilized as cutting fluid gent to machining the Ti-6Al-4 V alloy and AISI 4045 Steel to reduce above said parameters significantly [10–13]. from the

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literature it is understood that Various researchers utilized gases and water vapor also as lubricants and carried out research in machining various metals [14]. [15] studied the factors influenced in cryogenic treatment on tool to machine (High speed turn) of inconel work material. The cryogenic treatment uses −196 °C in the period of 24 h after the treatment a homogenous carbide distribution increases the hardness of the tool was increased and wear resistance also obtained. [16] investigated the influence of cryogenic treatment condition of −176 °C in the period of 24 h on carbide / cermet turning tool in both coated and uncoated case. The treated tools experienced small cutting force and improved surface quality on work. [17] introduced a deep cryogenic treatment method on M2 HSS drill bit causes wear resistance increased and thereby tool life extended. The cryogenic treatment condition was −196 °C in the period of 24 h after the treatment a fine and homogenous carbide distribution improves 77% of the tool life and tempering increased 126%. [18] used cryogenically treated tungsten carbide milling tool at −150 °C in a period of 24 h after the treatment 38.6% of the tool life increased. [19] adapted deep cryogenic at −195 °C for 24 hrs treating the high-speed steel tool of AISI T42 grade for enhancing the hardness and the resistance to wear. [20] preferred such treatment in the range of temperature of −110 °C and −195 °C in the period of 18 and 38 h for tungsten carbide turning tool insert which already coated by TiAlN. The investigation proved that boosted up tool life time as well as reduced the strength of adhesion.

2. Materials and methods

The influence deep cryogenic treatment on carbide face milling cutter in face milling of EN-8D work material is main objective of this study.

2.1. Work and tool selection

The widely applied work material EN-8D preferred in this study. The 16 X 150 mm carbide milling cutter employed for this study.

2.2. Cryogenic treated carbide milling cutter

The objective of this investigation is to explore the benefits of deep cryogenic treatment on carbide milling cutter. Hence the carbide milling cutter is treated under the deep cryogenic classification. The treatment specifications furnished in Table 1.

2.3. Experimental Design

The deep cryogenic treated carbide milling cutter is used to mill the EN-8D work with consideration of following milling operation variable at predefined three levels. These parameters are obtained from the trail machining, milling machine specifications and previous investigation history. The considered operating parameters and their levels in Table 2.

Table 1
treatment specification for carbide milling cutter.

Description of the Parameter	Specification
Treatment Type	Deep cryogenic
Medium	LN_2
Time period for Soak	24 h
Temperature while Soak	−195.79 °C

Table 2
Controllable Process Variables and Their Levels Considered.

Code	Milling process parameters	Levels of Milling Operational parameters		
		Level 1	Level 2	Level 3
A	Cutting Speed (Speed) in rpm	2300	2500	2700
B	Rate of Tool Feed (Feed Rate) in mm/min	540	550	560
C	Cutting Depth (Depth of cut) in mm	0.4	0.5	0.6

Table 3
Taguchi Experimental Design of L9 orthogonal array.

Trial No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3. Experimental results and optimization through grey relational analysis

The experiments were carried out as per designed experiments stated in the Table 2 and corresponding responses measured. The experimental results that is the details of parameters preferred and responses measured on the work after machining tabulated in Table 3. This kind of information is usually called as response table.

3.1. Grey relational analysis

In this kind of optimization, the Taguchi technique provides the comfort to the researcher to minimize the variance to the Trails (experiments) to find the optimal operating parameters. It is the most effective tool in the single response optimization, the effectiveness of the Taguchi technique, precision and quality-oriented system based on the orthogonal array (OA). As it provides comfort to analyze the inter-relationships amongst the several responses, It is preferred for optimizing parameters in multi-response system. Grey relational analysis. In this study the machining rate (metal removal rates) usually abbreviated as MRR and corresponding quality of the surface measured in terms of surface roughness (SR) are used as responses for finding the worth of machining experiments and optimize the same by using Taguchi Grey method.

3.1.1. Step 1

The responses shown in Table 4 like machining rate (or) material removal rate (MRR) and surface quality that is roughness (Ra) values are transformed into S/N ratio (*Yij*). The transformed values are tabulated in Table 5.Table 6.

3.1.2. Step 2

After transforming the response values in to Signal to Noise ratio, then it must be normalized that is the values are in between 0 and 1 that is Zij ($0 \leq Zij \leq 1$). The formula employed for the same is described below. For material removal rate (MRR) larger the better is preferred so the following equation is used to normalize the Signal to Noise ratios of material removal rate values.

Table 4
Experimental Results.

Trail Run	Factor	Response			
	Speed (A)	Feed Rate (B)	Depth of Cut (C)	MRR	Ra
1	2300	540	0.4	0.0695	2.301
2	2300	550	0.5	0.0737	2.187
3	2300	560	0.6	0.0723	2.386
4	2500	540	0.5	0.0723	2.204
5	2500	550	0.6	0.0702	1.634
6	2500	560	0.4	0.0681	1.918
7	2700	540	0.6	0.0674	1.382
8	2700	550	0.4	0.0681	2.210
9	2700	560	0.5	0.0650	1.727

Table 5
Trail wise S/N ratios for Material Removal Rate and Surface Roughness.

Trail Run	Factor			Response		S/N Ratio	
	Speed (A)	Feed Rate (B)	DOC (C)	MRR	Ra	MRR	Ra
1	2300	540	0.4	0.0695	2.301	−20.15	−4.23
2	2300	550	0.5	0.0737	2.187	−19.64	−3.79
3	2300	560	0.6	0.0723	2.386	−19.81	−4.54
4	2500	540	0.5	0.0723	2.204	−19.81	−3.85
5	2500	550	0.6	0.0702	1.634	−20.06	−1.25
6	2500	560	0.4	0.0681	1.918	−20.33	−2.65
7	2700	540	0.6	0.0674	1.382	−20.42	0.20
8	2700	550	0.4	0.0681	2.210	−20.33	−3.88
9	2700	560	0.5	0.0650	1.727	−20.73	−1.74

Table 6
S/N ratios and their Normalized values.

Trail Run	S/N Ratio		Normalized S/N Ratio	
	MRR	Ra	MRR	Ra
1	−20.15	−4.23	0.58	0.93
2	−19.64	−3.79	1.00	0.84
3	−19.81	−4.54	0.84	1.00
4	−19.81	−3.85	0.84	0.85
5	−20.06	−1.25	0.61	0.31
6	−20.33	−2.65	0.37	0.60
7	−20.42	0.20	0.28	0.00
8	−20.33	−3.88	0.37	0.86
9	−20.73	−1.74	0.00	0.41

Table 7
The trail wise quality loss and grey relational coefficient.

Trail Run	Normalized S/N Ratio		Quality Loss		Grey Relational Coefficient	
	MRR	Ra	MRR	Ra	MRR	Ra
1	0.58	0.93	0.42	0.07	0.70	0.93
2	1.00	0.84	0.00	0.16	1.00	0.86
3	0.84	1.00	0.16	0.00	0.86	1.00
4	0.84	0.85	0.16	0.15	0.86	0.87
5	0.61	0.31	0.39	0.69	0.72	0.59
6	0.37	0.6	0.63	0.4	0.61	0.71
7	0.28	0.00	0.72	1.00	0.58	0.50
8	0.37	0.86	0.63	0.25	0.61	0.80
9	0.00	0.41	1.00	0.59	0.50	0.63

$$ij = \frac{\mathrm{Yij} - \min(\mathrm{Yij}, \mathrm{i} = 1, 2, 3, \ldots \mathrm{n})}{\max(\mathrm{Yij}, \mathrm{i} = 1, 2, \ldots, \mathrm{n}) - \min(\mathrm{Yij}, \mathrm{i} = 1, 2, \ldots\ldots, \mathrm{n})} \quad (1)$$

In case of surface roughness (Ra) smaller vales gives the smoothness hence smaller the better is preferred so the following equation is used to normalize the Signal to Noise ratios of surface roughness values material removal rate values.

$$Zij = \frac{\min(\mathrm{Yij}, \mathrm{i} = 1, 2, 3, \ldots \mathrm{n}) - \mathrm{Yij}}{\max(\mathrm{Yij}, \mathrm{i} = 1, 2, \ldots, \mathrm{n}) - \min(\mathrm{Yij}, \mathrm{i} = 1, 2, \ldots\ldots, \mathrm{n})} \quad (2)$$

The signal to Noise ratio and respective normalized values are tabulated in the Table 5 which referred as normalized table.

3.1.3. Step 3

After normalized the signal to noise ratios of responses, the GCij that is grey relational coefficient computed by using the below relation.

$$\mathrm{GCij} = \frac{\Delta\mathrm{min} + \lambda\Delta\mathrm{max}}{\Delta\mathrm{ij} + \lambda\Delta\mathrm{max}}$$

Table 8
Trail wise grey relational grade for gray rational coefficients of MRR and Ra.

Trail Run	Gray Rational Coefficients		Grey Relational Grade
	MRR	Ra	Gi
1	0.70	0.93	0.82
2	1.00	0.86	0.93
3	0.86	1.00	0.93
4	0.86	0.87	0.87
5	0.72	0.59	0.66
6	0.61	0.71	0.66
7	0.58	0.50	0.54
8	0.61	0.80	0.71
9	0.50	0.63	0.57

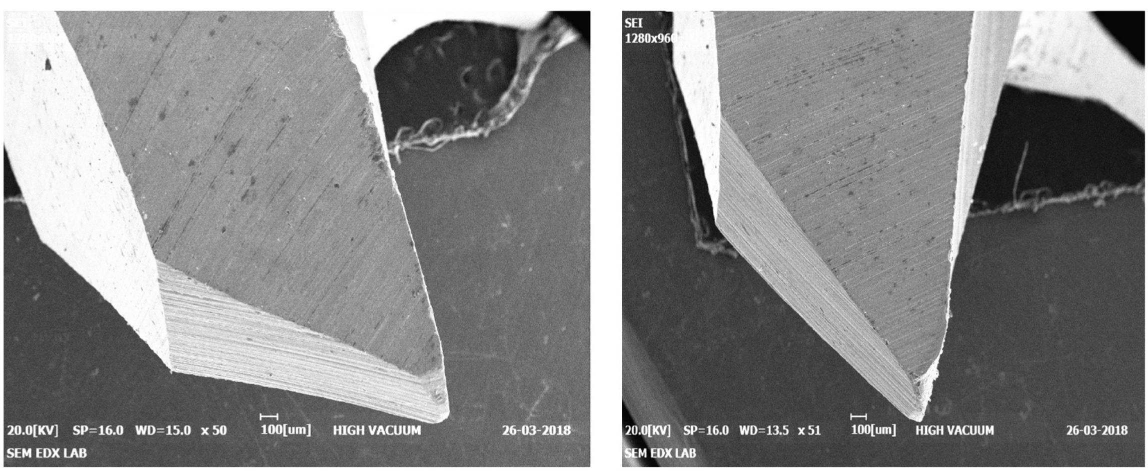
The Δ is the quality loss, which can be obtained from the absolute difference between Yoj and Yij. For both the cases of material removal rate and surface quality in terms of surface roughness the value of ‘Yoj’ considered as unity. The distinctive coefficient λ ($0 \le \lambda \le 1$). The trail wise normalized signal to noise ratio, quality loss in surface quality and machining rate (MRR), the calculated grey relational coefficient for obtained surface quality (Ra) and machining rate (MRR) are consolidated and presented in the Table 7.

3.1.4. Step 4

The grade *Gi* calculated by using the below relation which is often referred as grey relational grade.

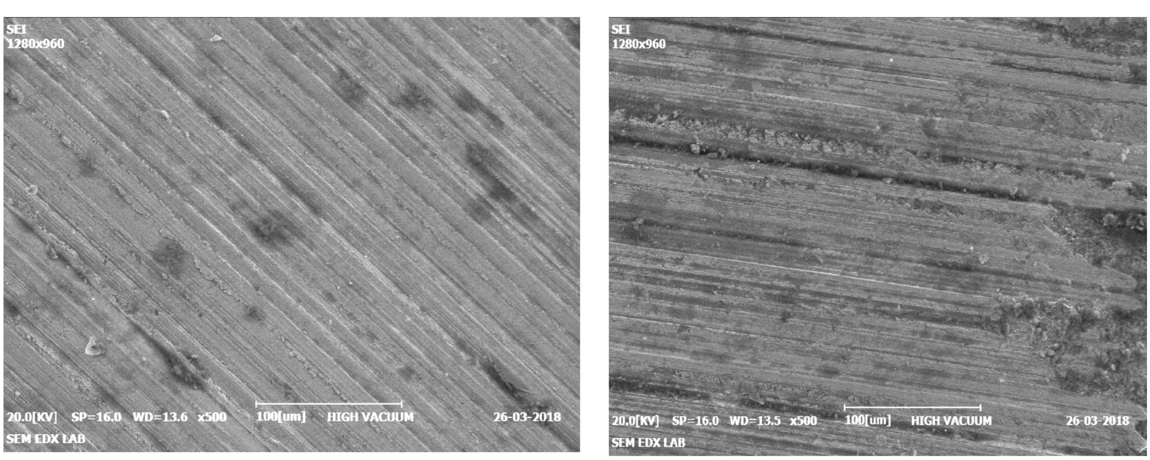
Table 9
Process parameter wise level wise mean MRPI.

Code	Milling process parameters	Parameter setting of Milling Operation		
		Level 1	Level 2	Level 3
A	Cutting Speed (Speed) in rpm	0.89	0.73	0.61
B	Rate of Tool Feed (Feed Rate) in mm/min	0.74	0.77	0.72
C	Cutting Depth (Depth of cut) in mm	0.73	0.79	0.71



(a) (b)

Fig. 1. SEM images of cutting edge of (a) Cryogenically treated tool (CT) (b) Un treated tool (NCT).



(a) (b)

Fig. 2. SEM images of Cutting surface of (a) Cryogenically treated tool (CT) (b) Un treated tool (NCT).

$$Gi = \frac{1}{m}\sum GCij$$

The trail wise grey relational grade for each gray rational coefficients of surface quality and machining rate is presented in the Table 7.

3.1.5. Step 5

Now parameter optimization phase is ahead, that is the maximum grade is optimal parameters. The mean MRPI gives main effects of it that is the parameters for maximum machining rate with better surface quality. The Table 8 shows the parameters (factors) wise level wise average values of grey relational grades.

It can be noticed from the Table 9 that the maximum values against the parameters A, B, C are A1, B2, and C2 respectively. That the maximum value for factor A, B and C are 0.89, 0.77 and 0.79 respectively. The respective factor setting value can be obtained from Table 2 that cutting speed of 2300 rpm with work feed rate of 550 mm/min under the depth of cut of 0.5 mm are the optimal parameters.

4. Surface morphological analysis

The popular analysis namely SEM that is Scanning Electron Microscopy employed for inspecting topographies of specimens at a higher range of image magnifications. The combined effect of higher magnification, effective representation of the depth of field, higher resolution, clarity in compositional and crystallographic information makes the SEM one of the most popular instrument for researchers as well as industrial applications.

In this analysis the cryogenically treated (CT) tool and untreated (NCT) tools included to analyse the effect of deep cryogenic treatment on carbide milling cutter. The Fig. 1a and Fig. 1b are scanning electron microscopy images of cutting edges of cryogenically treated (CT) tool and untreated (NCT) tools respectively. The Fig. 2a and Fig. 2b are the scanning electron microscopy images of cryogenically treated (CT) tool and untreated (NCT) tools respectively. The SEM analysis ensured that the wear of cutting edges reduced by deep cryogenic treatment. The surface topography also ensured that the deep cryogenic treatment on carbide milling cutter increases its hardness.

5. Conclusions

The works illustrated the detailed analysis of deep cryogenic treated carbide milling cutter for machining the EN-8D work. The Taguchi L9 experimental followed to conduct experimental trails and the GRA employed for optimization of process parameters. The following points derived from the experimental results and analysis.

- The cutting speed of 2300 rpm , 2500 rpm and 2700 rpm were preferred in which the 2300 is found optimal speed for the sated work material and preferred tool
- The feed rate of the work material of 540, 550 and 560 mm/min were preferred in which the 550 is found optimal feed rate for the sated work material and preferred tool
- The depth of cut on work material of 0.4, 0.5 and 0.6 mm were preferred in which the 0.5 mm is found optimal feed rate for the sated work material and preferred tool
- The scanning electron microscopy analysis ensured that the cutting edges wear is greatly reduced by the deep cryogenic treatment on the milling cutter.
- Similarly the scanning electron microscopy analysis ensured that the surface hardness of milling cutter increased significantly by the deep cryogenic treatment on the milling cutter.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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