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Research Article

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Parametric Optimization on Drilling Duplex Stainless Steel 2205 Through Multi-objective TOPSIS under Sustainable Machining

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Abstract

Due to its relative hardness to other materials, duplex stainless steel 2205 is difficult to cut. Sustainable machining is thus used to increase machinability. In this work, drills coated with TiAlN (Titanium aluminium nitrate) were utilized to drill into duplex stainless steel (DSS) 2205 under dry, minimum quantity of lubrication (MQL), and liquid carbon dioxide machining conditions (LCO_2). The Taguchi-TOPSIS approach is used for parametric optimization after experimental work. Finally, it was discovered that a liquid carbon dioxide (LCO_2) cooling environment, a high spindle speed (1120 rpm), and a low feed rate (0.02 mm/rev) are the ideal process parameters for drilling on DSS 2205 in multi-objective. This is because selecting the right process parameters has a significant impact on manufacturing process efficiency.

Keywords

Dry machining, Minimum quantity of lubrication, Liquid carbon dioxide, Sustainable machining, Taguchi method, TOPSIS

Introduction

In industrial companies specializing in metal cutting, increasing productivity while ensuring that machining conditions are free of environmental hazards is a modern-day problem. Because of its wide range of uses in a number of current critical industries. A highly sought-after method of long-term production is cryogenic machining. DSS is employed in a variety of industries, including the marine, aerospace, chemical, and nuclear sectors [1] because of its exceptional qualities, including corrosion resistance, high strength, and high ductility. Due to the high cutting temperature used in dry cutting, DSS 2205 suffers from poor surface quality and increased built-up edge formation on solid carbide drills. Because cryogenic machining significantly lowers the temperature in the machining zone, cryogenic coolant is employed there. The application of cooling methods establishes a stable environment with the potential for improved machinability and, consequently, cutting conditions. Examples include using a TiN-coated cutting tool and machining on AISI P20 in dry, flood, and cryogenic conditions. After extensive testing, cryogenic machining was found to reduce tool wear (15 - 17%) when compared to flood and dry machining [2]. Parametric optimization through Taguchi-TOPSIS approach with input parameters e.g., feed rate, the pressure of coolant, cutting velocity, depth of cut while surface roughness (Ra), tool tip temperature, and MRR as output responses. The main objective of that minimizes the value of all the responses [3]. In this study, parametric optimization through Taguchi L9 set of experiments with Ra and MRR as response variables [4]. Studied CNC milling and parametric optimization through Taguchi and TOPSIS with the depth of cut, feed rate, and spindle speed as input parameters while thermal stress and MRR as response variables [5]. This paper is an experimental study on turning operation through Taguchi. Also, for multi-objective TOPSIS with tool wear, Ra, and MRR as response variables [6].

On the basis of experimental data, an effort has been made to pinpoint the ideal settings that would produce the highest-quality results when milling AISI M2 steel with an electric discharge machining tool constructed of a tungsten-thorium electrode. Together with TOPSIS and GRA, the Taguchi technique has been utilized to look at the possibility of maximizing output performance characteristics. It has been studied how output parameters are impacted by input parameters like MRR, EWR, and SR [7]. The Taguchi-TOPSIS method is used for multi-objective optimization with an L27 set of experiments Mg hybrid composite was developed using Boron Nitride particles, enhanced E-waste, and Cathode Ray Tube panel glass reinforced using powder metallurgy [8].

In the current study, experiments were conducted on DSS 2205 using solid carbide drills that were coated in TiAlN under three different cooling conditions, including dry machining, MQL machining, and LCO_2 machining. For parametric optimization and the best drilling process parameters on DSS 2205, the Taguchi-TOPSIS approach is used.

Experimental Procedure

Materials

The DSS 2205 was used for all experimental work, and TiAlN solid carbide drills were used. Sustainable conditions included dry machining, MQL machining, and machining with LCO_2. The description of the experimental work is shown in table 1.

Design of experiment

For the set of designs of the experiment, the Taguchi method is used. Taguchi is a statistical approach for parametric analysis and optimization [8]. The cooling environment, spindle speed, and feed rate were the three input factors chosen for this study, while Ra and hole deviation were the response variables. Table 3 and table 4 show the level of input parameters and experimental results. Figure 1 illustrates the usage of a coordinate measuring machine and a surface roughness tester for response measurement.

Multi-objective optimization through TOPSIS

The study's objective is to achieve the lowest Ra and hole deviation possible. The TOPSIS method involves the following steps:

Table 1: Description of experimental work.

Drill tool	TiAlN coated solid carbide drill
Machining environment	Dry, MQL, and LCO_2
Hole type	Through
The flow rate of LCO_2	18 l/m
LCO_2 cylinder pressure	35 bar
Pressure of MQL	3 bar

Table 2: Level of process parameter.

S. No.	Process Variables	Units	Level		
			1	2	3
1	Environment (E)	-	Dry (1)	MQL (2)	LCO2 (3)
2	Spindle Speed (N)	rpm	720	920	1120
3	Feed rate (V_f)	mm/rev	0.02	0.04	0.06

Table 3: Observation of a set of experiments.

Exp. No.	Input Parameters			Output Parameters	
	Environment	Spindle speed	Feed rate	Ra	Hole deviation
1	1	720	0.02	0.686	0.0754
2	1	720	0.04	0.618	0.0689
3	1	720	0.06	0.615	0.0723
4	2	920	0.04	0.585	0.0543
5	2	920	0.06	0.531	0.0489
6	2	920	0.02	0.471	0.0452
7	3	1120	0.06	0.573	0.0291
8	3	1120	0.02	0.426	0.0238
9	3	1120	0.04	0.390	0.0195

Table 4: Normalised decision matrix.

$$\begin{bmatrix} 0.414528 & 0.036075 \\ 0.373438 & 0.030123 \\ 0.371625 & 0.033169 \\ 0.353497 & 0.018709 \\ 0.320866 & 0.015173 \\ 0.28461 & 0.012964 \\ 0.346246 & 0.005373 \\ 0.257418 & 0.003594 \\ 0.235665 & 0.002413 \end{bmatrix}$$

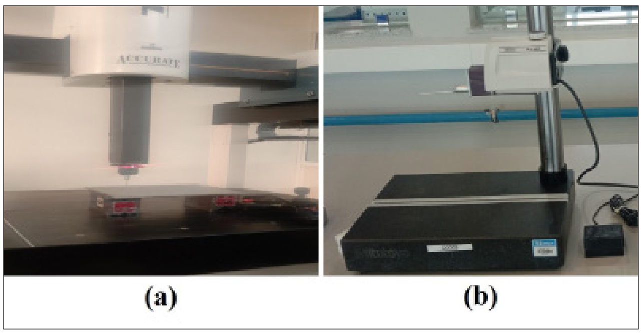

Figure 1: (a) Coordinate measuring machine and **(b)** surface roughness tester.

Step 1:

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}; \; i = 1, 2, \ldots 8; \; j = 1, 2. \tag{1}$$

Step 2:

$$\vartheta_{ij} = w_j * r_{ij} \text{; i = 1, 2,…8; j = 1, 2.} \quad (2)$$

Step 3:

$$S^+ = \{[\max(S_{ij}) | j \in J] or[\min(S_{ij}) | j \in J'], i = 1, 2, ...8\} \quad (3)$$

Step 4:

$$D_{ij}^+ = \sqrt{\sum_{i=1}^{27} (\vartheta_{ij} - S_j^+)^2} \text{ ; where i = 1, 2, 3,…8} \quad (4)$$

Step 5:

$$CC_i = \frac{D_i^-}{D_i^- + D_i^+} \text{; where I = 1, 2,…8; } 0 \le C_i \le 1 \quad (5)$$

Results and Discussion

Surface roughness

Spindle speed and feed rate have a direct impact on Ra during the drilling process. According to the interaction plot in figure 2, it was discovered that LCO_2 is a more effective cooling method for Ra than MQL. In terms of spindle speed, it was found that the Ra value falls as the spindle speed rises. Ra is inversely related to spindle speed. Additionally, it was discovered that the feed rate and Ra value are closely proportional.

Hole deviation

In the drilling process, hole deviation is directly affected by spindle speed and feed rate. According to the interaction plot in figure 3, it was observed that LCO_2 is an efficient cooling approach compared to MQL, dry respectively for hole deviation. In terms of spindle speed, it was observed that if spindle speed increases, then the hole deviation value decreases. For feed rate, it was observed that if the feed rate increased then hole deviation also increased.

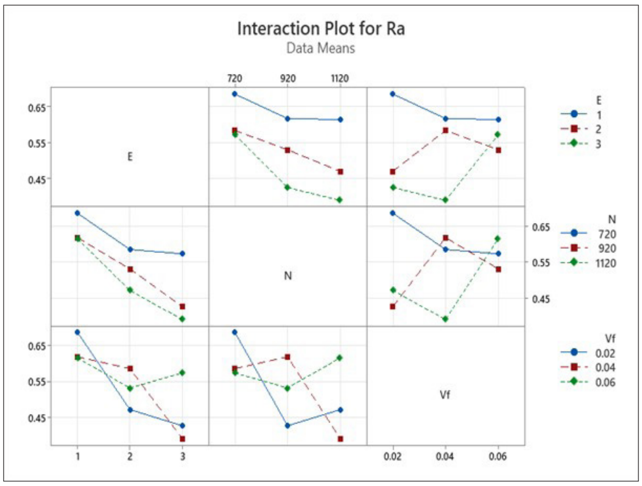

Figure 2: Interaction plot for Ra.

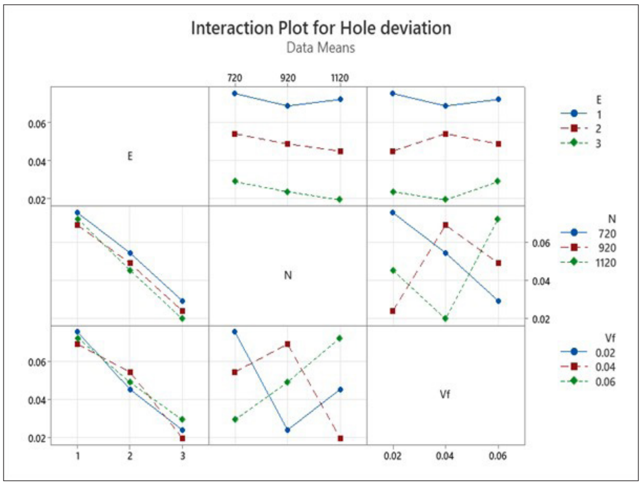

Figure 3: Interaction plot for hole deviation.

TOPSIS

Table 8 displays their related rank orders. The best performance for the ideal solution is determined using the greatest preference value, which denotes relative proximity to the ideal solution. As a result, performance is gauged using the highest rank that is assigned the highest value. The normalised matrix is in table 4. the matrix from equation 1 normalised. Similarly, table 5 shows a weighted matrix, these is values are calculated by using equation 2.

Table 5: Weighted matrix.

0.207264	0.018037
0.186719	0.015062
0.185813	0.016585
0.176748	0.009355
0.160433	0.007587
0.142305	0.006482
0.173123	0.002687
0.128709	0.001797
0.117832	0.001206

Table 6: Positive ideal and negative ideal.

Criteria	Ra	Hole Deviation
Positive Ideal Solution	A^*_{Ra} 0.117832	$A^*_{\text{hole deviation}}$ 0.0012602
Negative Ideal Solution	A^-_{Ra} 0.207264	$A^-_{\text{hole deviation}}$ 0.018037

Conclusion

In order to perform drilling on DSS 2205, this study illustrates the implementation of the TOPSIS technique, which aids process engineers in determining the ideal process parameter from a large number of competing factors. The ranking of the preferred order in the selection of the best process parameters for drilling DSS 2205 under sustainable machining was done using results from how close the results were to

Table 7: Separation table.

D_j^+	D_j^-
0.091002	0
0.070267	0.020759
0.069698	0.021501
0.059477	0.031727
0.043076	0.047983
0.025035	0.065979
0.055311	0.037433
0.010893	0.080216
0	0.091002

Table 8: Closeness coefficient.

D_j^+	D_j^-	CC_j^+	Rank
0.091002	0	7.444069	8
0.070267	0.020759	2.701385	6
0.069698	0.021501	1.161878	5
0.059477	0.031727	1	9
0.043076	0.047983	0.714215	7
0.025035	0.065979	0.565151	4
0.055311	0.037433	0.329982	3
0.010893	0.080216	0.316198	2
0	0.091002	0	1

the ideal solutions. It has been found that the combination of an LCO_2 cooling environment, an 1120 rpm spindle speed, and a 0.02 mm/rev feed rate results in the least amount of Ra and the least amount of hole deviation. It is evident that applying TOPSIS is a successful technique for delivering a more practical solution to the choice of ideal process parameters.

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None.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Credit Author Statement

Rajeev Sharma: Methodology, Writing - original draft preparation; Binit Kumar Jha and Vipin Pahuja: Writing - review and editing. All the authors read and approved the manuscript.

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