ISSN : 2455-9679
SJIF Impact Factor : 6.008

IJRTSM

INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"AN EXPERIMENTAL INVESTIGATION AND PARAMETRIC OPTIMIZATION UNDER DRY AND WET TURNING OF SG IRON"

***Shoaib Akhtar* [1], *Abhilesh Dubey* [2], *Manish Joshi* [2], *Girish Khare* [2]**

[1] *Research Scholar, Department of Mechanical Engineering, Oriental Institute of Science and Technology, Bhopal*

[2] *Professor, Department of Mechanical Engineering, Oriental Institute of Science and Technology, Bhopal*

ABSTRACT

The current study presents an experimental investigation and parametric optimization of surface roughness during dry and wet turning of spheroidal graphite (SG) iron. Turning experiments were conducted using a Taguchi L9 orthogonal array by varying spindle speed, feed rate, and depth of cut at three levels. Surface roughness was measured for both machining environments, and signal-to-noise ratio analysis was employed to identify the dominant parameters affecting surface quality. The results indicate that feed rate is the most influential factor in both dry and wet turning, followed by spindle speed and depth of cut. Wet turning consistently produced lower surface roughness due to improved lubrication and thermal stability. Optimal machining conditions were identified for minimizing surface roughness in each case and were validated through confirmation experiments. In addition, a machine learning–based predictive model demonstrated high accuracy, with R^2 values close to unity, confirming its effectiveness in capturing nonlinear relationships among process parameters. The findings provide practical guidance for achieving improved surface finish in SG iron turning operations.

Key Words: Iron, Turning, Surface roughness, Taguchi method, Optimization

I. INTRODUCTION

Manufacturing implies change of crude materials into completed products for the fulfillment of human needs. To change the crude material distinctive manufacturing processes are applied due to which the shape, size and physical properties of given material are adjusted. Turning is a type of machining, a material evacuation process, which is utilized to create rotational parts by cutting ceaselessly undesirable material as appeared in figure1.1. The turning process requires a turning machine or machine, work piece, installation, and cutting device. The work piece is a piece of pre-molded material that is secured to the apparatus, which itself is attached to the turning machine, and permitted to pivot at high speeds. The cutter is typically a solitary point cutting instrument that is additionally secured in the machine, albeit a few tasks utilize multi-point devices. The cutting device feeds into the pivoting work piece and cuts away material as little chips to create the ideal shape as shown in figure 1.

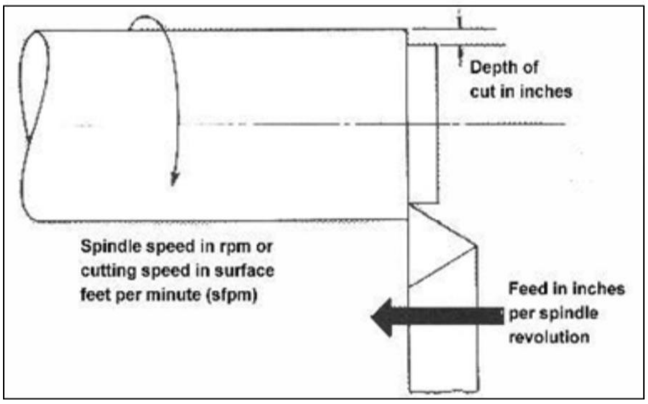

Figure 1. Turning Process

ISSN : 2455-9679
SJIF Impact Factor : 6.008

Turning is used to convey rotational, commonly axi-symmetric, parts that have various features, for instance, holes, grooves, strings, decreases, diverse distance across steps, and even formed surfaces. Parts that are created absolutely through turning normally incorporate sections that are used in constrained sums, perhaps for models, for instance, hand crafted shafts and clasp. Turning is in like manner routinely used as a helper process to include or refine features parts that were produced using a substitute process. Because of the high resistances and surface completes the process of thatturning can offer, it is perfect for adding accuracy rotational features to a section whose fundamental shape has recently been encircled.

Choosing the proper cutting device material for a particular application is vital in accomplishing proficient activities. Expanding slicing velocity to build profitability is just conceivable to a restricted degree as this abbreviates the instrument life, expanding apparatus re-pounding/substitution costs and expanding interferences to creation. No single material meets all prerequisites. The properties required by cutting instruments mean trade off is required, for instance expanding hardness by and large outcomes in lower strength.

II. Literature review

Sieben et al. (2024) used plan and assessment of PC tests (DACE) for the exploratory demonstrating of hard turning of AISI 6150 steel. PCBN tool was used hence. The different parameters picked were feed, profundity of cut and cutting rate. The DACE technique can be used to show complex non-direct factors.

Cappellini et al. (2023) used AISI 52100 circles to consider the improvement of white and dull layers in hard cutting. Thus, Polycrystalline Cubin Boron Nitride (PCBN) installs were used. The essayists found that as the temperature goes above austenizing temperature, the martensite is quickly smothered and white layer is formed. Cutting speed and feed rate were the parameters. The white layers surrounded were seen under Scanning Electron Microscope (SEM). It was furthermore considered that to be the tool wears the thickness of layers extended. As the speed extended or the feed rate extended thicker white layers were molded and progressively thin diminish layers were encircled.

D. PhilipSelvaraj, P. Chandramohan (2023) used AISI 304 Austenitic treated steel to consider the effect of cutting parameters like cutting rate, feed rate and profundity of cut superficially unpleasantness. A plan of assessments subject to Taguchi's technique has been used to pick up the data. A symmetrical exhibit, the sign to uproar (S/N) extent and the assessment of contrast (ANOVA) are used to look into the cutting qualities of AISI 304 austenitic solidified steel bars using TiC and TiCN secured tungsten carbide cutting tool. Finally, the certification tests that have been finished to differentiate the foreseen characteristics and the preliminary regards assert its ampleness in the assessment of surface unpleasantness.

R. Ramanujam, R. Raju, N. Muthukrishnan (2022) presents another technique for the optimization of the machining parameters on turning Al-15%SiCp metal network composites. Optimization of machining parameters was done by an examination called appealing quality limit assessment. Taguchi's L27 symmetrical cluster is used for preliminary arrangement. The machining methodology parameters, for instance, cutting velocity, feed rate and profundity of cut are streamlined with various execution considerations to be explicit surface harshness and power use. The perfect machining parameters have been recognized by a composite appealing quality worth got from charm work assessment as the introduction list, and important responsibility of parameters would then have the option to be managed by examination of progress. Certification test is similarly prompted endorse the test result. Exploratory results have shown that machining execution can be improved effectively through this strategy.

J.S. Senthilkumaar, P. Selvarani (2022) used Inconel 718 to improve surface unpleasantness and flank wear in complete turning. Slicing examinations were coordinated by the full factorial structure under dry cutting conditions. The effects of the machining parameters on the show evaluations surface unpleasantness and flank wear were investigated. The association between the machining parameters and the presentation measures were set up using the non-straight backslide examination. Taguchi's optimization examination shows that the components level, its criticalness to affect the surface harshness and flank wear for the tuning and defying structures. Attestation tests were aimed at a perfect condition to make an assessment between the preliminary outcomes anticipated from the referenced connections.

2.1 Process Variables and their Limits

ISSN : 2455-9679
SJIF Impact Factor : 6.008

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected using MINITAB 17 software. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 1.

Table 1 Process variables and their limits

Parameters/Factors		Level		
		I	II	III
A	Spindle speed (rpm)	160	320	620
B	Feed rate (mm/rev)	0.3	0.4	0.5
C	Depth of cut (mm)	0.7	0.8	0.9

III. METHODOLOGY

3.1 Design of Experiment

Experiments have been carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of 9 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue prepared by Taguchi, L9 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. Experimental design has been shown in Table 2.

Table 2 Cutting Parameters and Levels for Dry and Wet Turning

Experiment No.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), A
1	160	0.3	0.7
2	160	0.4	0.8
3	160	0.5	0.9
4	320	0.3	0.8
5	320	0.4	0.9
6	320	0.5	0.7
7	620	0.3	0.9
8	620	0.4	0.7
9	620	0.5	0.8

3.2 Material Used

The material selected was SG IRON bars (of diameter 50 mm and length 140 mm) on the basis that it was suitable for most engineering and construction applications. SG iron is a low-cost alloy, medium-carbon steel with adequate strength and toughness characteristics, SG IRON is valuable for induction- or flame-hardened components. The hardness of bar is 187 HB.

3.3 Experimental Setup

The diameter of bar is 50 mm and of length 140 mm. The size was measured with the help of digital vernier caliper. The experiment was done on a piece nine times of SG IRON steel bars having same composition to measure the value of surface roughness and to determine which value of cutting parameters will be optimum to minimize it. The work piece has been shown in figure 2.

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SJIF Impact Factor : 6.008

Figure 2 Picture of work piece before machining

Table 3. Experimental Data Related to Surface Roughness Characteristics for dry turning

Experiment No.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), d	Surface roughness, Ra (µm)	S/N ratio of surfaces roughness
1	160	0.3	0.7	2.24	-7
2	160	0.4	0.8	5.67	-15.07
3	160	0.5	0.9	5.93	-15.46
4	320	0.3	0.8	5.34	-14.55
5	320	0.4	0.9	4.87	-13.75
6	320	0.5	0.7	6.07	-15.66
7	620	0.3	0.9	2.91	-9.27
8	620	0.4	0.7	3.78	-11.54
9	620	0.5	0.8	5.05	-14.06

Table 4 Experimental Data of Surface Roughness Characteristics for Wet Turning

Experiment No.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), d	Surface roughness, Ra (µm)	S/N ratio of surfaces roughness
1	160	0.3	0.7	2.12	-6.52
2	160	0.4	0.8	3.40	-10.62
3	160	0.5	0.9	3.62	-11.17
4	320	0.3	0.8	2.37	-7.49
5	320	0.4	0.9	3.69	-11.34
6	320	0.5	0.7	2.8	-8.94
7	620	0.3	0.9	2.11	-6.48
8	620	0.4	0.7	3.78	-11.54
9	620	0.5	0.8	2.80	-8.94

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IV. RESULTS AND DISCUSSION

4.1 PIE Chart Representation of Percentage Contribution of Process Parameters for Surface Roughness in Dry and Wet Turning

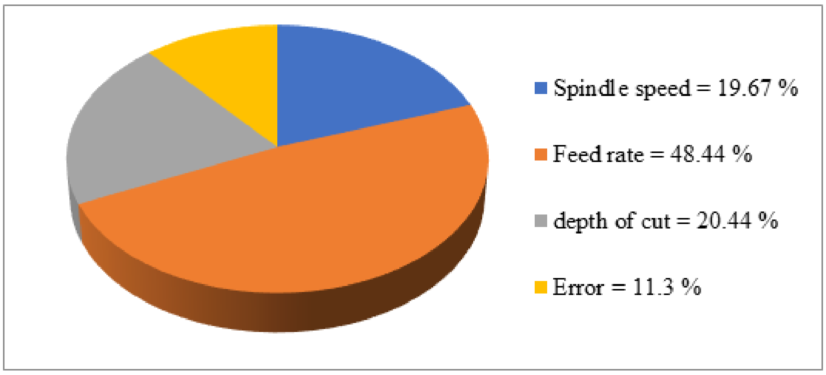

Figure 3 Percentage contribution of process parameters on surface roughness in dry turning

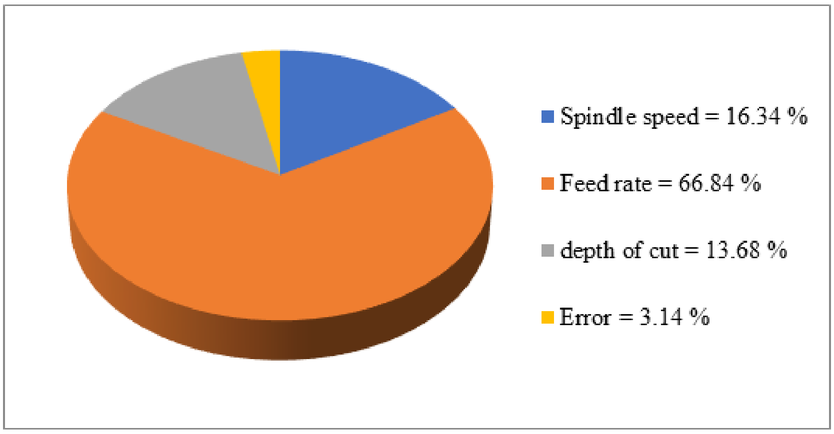

Figure 4 Percentage contribution of process parameters on surface roughness in wet turning

4.2 Determination of Optimum Solution

Optimum condition of the turning process is concerned with minimizing the surface roughness but this cannot be achieved simultaneously with a particular combination of control parameter settings. Optimal parameter setting for surface roughness in dry and wet turning has been determined from figure. The optimal settings and the predicted optimal values for surface roughness in dry and wet turning are determined individually by Taguchi's approach. Table 5 & 6 shows these individual optimal values and its corresponding settings of the process parameters for the specified performance characteristics. Optimal result has been verified through confirmatory test showed satisfactory result.

Table 5 Parameters and selected levels for optimal surface roughness in dry turning

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	(620 rpm)
B	Feed rate (mm/rev), f	(0.3 mm/rev)
C	Depth of cut (mm), d	(0.7 mm)

Table 6 Parameters and selected levels for optimal surface roughness in wet turning

Parameter designation	Process parameters	Optimal levels
A	Spindle speed (rpm), N	(620 rpm)
B	Feed rate (mm/rev), f	(0.3 mm/rev)
C	Depth of cut (mm), d	(0.8 mm)

ISSN : 2455-9679
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Table 7. Machining performance metrics

Machining Condition	R^2	MAE	RMSE
Dry Turning	0.99	9.41×10^{-5}	1.13×10^{-4}
Wet Turning	0.99	2.52×10^{-5}	2.93×10^{-5}

The extremely high R^2 values, approaching unity for both dry and wet turning conditions, indicated that the developed machine learning models were able to explain nearly all the variance in surface roughness as a function of spindle speed, feed rate, and depth of cut. This confirmed the strong predictive capability of the adopted Gradient Boosting Regression model. The mean absolute error (MAE) values were found to be very small, indicating minimal average deviation between predicted and experimental surface roughness values. The MAE was lower for wet turning compared to dry turning, reflecting the improved stability and reduced variability of surface finish under coolant-assisted machining. Similarly, the root mean square error (RMSE) values were extremely low for both conditions, with wet turning exhibiting lower RMSE than dry turning. This trend suggested that the ML model achieved more consistent predictions under wet machining due to reduced frictional fluctuations and thermal effects.

V. Conclusion

Based on the ML-based predictive analysis, the following key findings were obtained:

- The ML model accurately predicted surface roughness for both dry and wet turning conditions.
- Feed rate was identified as the most dominant parameter influencing surface roughness in both machining environments.
- Wet turning exhibited improved prediction accuracy and lower surface roughness values due to enhanced cutting stability.
- The ML framework effectively captured nonlinear interactions among machining parameters without requiring explicit empirical formulations.

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