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Experimental Optimization of Surface Finish and MRR in EN24 Steel Turning

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ABSTRACT

This study is basically an experimental investigation on the optimization of cutting parameters in dry CNC turning of EN24 steel using TT Casting and TT Steel carbide inserts. A Taguchi L9 orthogonal array was used to design the experiments by using the varying the cutting speed, feed rate, and depth of cut. Surface roughness as well as the rate of material removal have been chosen as the performance measures and investigated using the signal-to-noise ratio and analysis of variance to determine the significant factors and the optimum conditions of machining. The results show the superiority of the TT Casting insert in terms of surface finish with a minimum surface roughness of 0.481 um and the TT Steel insert has better productivity with a maximum material removal rate of 0.552631 g/s. Statistical analysis shows that the cut speed is the most important parameter that controls the surface roughness of the TT Casting insert while for the TT Steel insert the feed rate plays the dominant role. For the most part, both are the most significant contributors to productivity for both of these inserts. The optimized parameters for surface quality and productivity are different, which confirms existence of a clear trade-off between quality-oriented and productivity-oriented machining. The findings serve the practical purpose of machining guidelines for tool insert and cutting parameters for EN24 steel under the present industrial dry turning conditions.

Keywords- ANOVA, EN24 steel, Surface roughness, Taguchi method

1. INTRODUCTION

The turning is extensively used in the production of components for cars and airplanes where the surface roughness and MRR of the parts are predetermined during production, which can impact fatigue strength and production speed [1], [2]. In the last decade the studies have progressed from single parameter optimization to multi-response strategies incorporating advanced statistical and computational methods [3], [4]. The practical significance lies in optimizing cutting parameters to enhance surface finish and productivity while minimizing tool wear and environmental impact [5], [6]. EN24 steel, with its medium carbon content and high tensile strength, constitutes a challenging work material for machining as a result of increased cutting forces and wear of the cutting tools due to raised temperatures, thus the need to find optimal tool-material combinations [7]. The particular issue that is to be tackled is an absence of comparative comprehensive analyses between dry turning of EN24 steel using TT Casting and TT Steel carbide tool inserts, with the aim to obtain a practical optimization of cutting parameters, with better surface roughness and MRR. Despite many explorations on coated carbide tools and multi-criteria optimization techniques, there is knowledge gap on the interaction effect of tool material and cutting conditions under dry machining environment [8], [9]. Conflicting results are available on the comparative importance of all, with some studies placing more emphasis on feed rate being dominant [10], while others highlight the same [11], [12]. This controversy makes universally-applicable machining guidelines difficult to establish. The consequences of such a gap are suboptimal tool selection and parameter settings resulting in increased production costs and compromised component quality [13].

Turning is a fundamental machining operation process that is mostly used in manufacturing industries because the surface quality and production rate directly affect the performance of the components and the workflow. EN24 steel, because of its high strength and toughness, offers machining difficulties that require careful selection of cutting parameters and cutting tools. In this study dry Machining trials were conducted on a CNC lathe using TT Casting and TT Steel carbide inserts in an attempt to understand the synergy of three parameters of cut on SR and MRR.Literature Review This section maps the research landscape of the literature on

Comparison of TT Casting vs TT Steel carbide inserts (VNMG 160404) under dry CNC turning of EN24 steel.

Table 1 Summary of Recent Studies

Study	SR	MRR	TWR	Cutting Parameter Optimization	Insert Material Performance
[2]	Optimized Ra via Taguchi-WASPAS; feed major factor	MRR improved with optimized parameters; depth of cut significant	Tool wear not primary focus	Feed, speed, depth optimized using hybrid algorithms	TT Steel inserts implied; coating effects noted
[3]	Surface roughness minimized with evolutionary algorithms	MRR maximized with optimized parameters	Tool wear minimized	Speed, feed, depth optimized	Tungsten carbide inserts
[4]	Cutting speed most affects surface roughness	Depth of cut most affects MRR	Tool wear not primary focus	Speed, feed, depth optimized	Cemented carbide tools
[5]	Surface roughness reduced with coconut oil mist cooling	MRR not primary focus	Tool wear reduced with mist cooling	Speed, feed, depth optimized	Biodegradable coolant used
[6]	Surface roughness minimized under high MQL flow rate	MRR not primary focus	Tool wear minimized with MQL	Speed, feed, depth optimized	MQL flow rate studied
[8]	AlCrN/TiAlN-coated tools yield best surface finish	MRR improved with coated tools	Coated tools reduce flank wear	Speed, feed, depth optimized via Taguchi L9	Coated carbide inserts compared
[9]	Surface roughness not primary; tool wear modeled	Tool wear reduced under cryogenic cooling	Tool wear rate modeled with speed, feed	Speed, feed, cooling optimized	Uncoated tungsten carbide inserts
[11]	Cutting speed major effect on surface roughness	MRR maximized at 200 m/min speed	Tool wear minimized with low feed	Speed, feed, depth optimized	EN8 steel, coated carbide
[13]	296 m/min optimal for SR	MRR maximized at 1.33 mm	minimized	Speed, feed, depth optimized via GA	Coated carbide inserts
[14]	Surface roughness minimized at 1500 rpm, 0.05 mm/rev feed	MRR concurrently optimized with surface finish	Tool wear not detailed	Speed, feed, depth, nose radius optimized via PSI-Grey	Carbide inserts used; material specifics limited
[15]	41.88% improvement in surface roughness with Taguchi L9	51.14% increase in MRR at optimized parameters	Tool wear not primary focus	Depth, feed, speed optimized for SR and MRR	Tungsten carbide inserts used
[16]	Surface texture reduced to 0.567 µm; feed rate critical	MRR up to 2511 mm^3/min; feed rate dominant	Tool wear not emphasized	Feed rate most significant; speed least	TT Steel carbide inserts assumed

[17]	Surface roughness minimized using TiCN/TiN coated tools	MRR not primary focus	Tool wear minimized with coated tools	Speed, feed, depth optimized	TiCN/TiN coated inserts
[18]	Feed rate major influence on surface roughness	MRR maximized with depth of cut	Tool wear not primary focus	Feed, speed, depth optimized via hybrid methods	Triple coated carbide inserts
[19]	significant for SR	optimized at specific cutting parameters	Tool wear not primary focus	Speed, feed, depth optimized	Hybrid ceramic inserts
[20]	Feed rate and speed majorly affect surface roughness	MRR not primary focus	Tool wear not detailed	Speed, feed, depth optimized	EN353 steel, carbide tools
[21]	Feed rate and nose radius optimize surface roughness	MRR maximized with optimal parameters	Tool wear not detailed	Speed, feed, depth optimized	Coated carbide tools
[22]	Feed rate and cutting environment affect surface roughness	MRR optimization reviewed	Toolwear discussed generally	Speed, feed, depth optimized	Various tool coatings reviewed
[23]	Surface roughness modeled with RSM and GA	MRR not primary focus	Tool wear modeled	Speed, feed, depth optimized	Dry machining of EN24
[24]	Surface roughness minimized using Taguchi and WOA	MRR not primary focus	Tool wear not detailed	Speed, feed, depth optimized	HSS tool used
[25]	Surface roughness and tool wear reduced with MQL	MRR not primary focus	Tool wear reduced with lubrication	Speed, feed, depth optimized	Tool type and lubrication studied
[26]	Surface roughness predicted with ANN models	MRR not primary focus	Tool wear predicted with ANN	Speed, feed, depth optimized	Data-driven modeling
[27]	Surface roughness modeled with Taguchi and optimization	MRR and energy consumption optimized	Tool wear not primary focus	Speed, feed, depth optimized	Energy-efficient machining

Despite the many research works that focus on the same way, there is still a gap in the comparative experimental evaluation of commercial TT Casting and TT Steel carbide inserts in dry CNC turning of EN24 steel. Most of the previous works have been dedicated to advanced coated tools, cooling systems, or computational optimization methods without much attention to tool-material-specific performance under practical shop floor conditions. Moreover, the literature has conflicting conclusions on the relatively important role of main parameters, which has led to uncertainty in the development of machining guidelines. In addition, many works focus on the surface roughness or tool wear, while little work is done on the optimization of SR and MRR in combination for EN24 steel. The present study fills these gaps by a systematic Taguchi-based experimental study using industrially relevant inserts and realistic CNC turning conditions.

2. METHODOLOGY

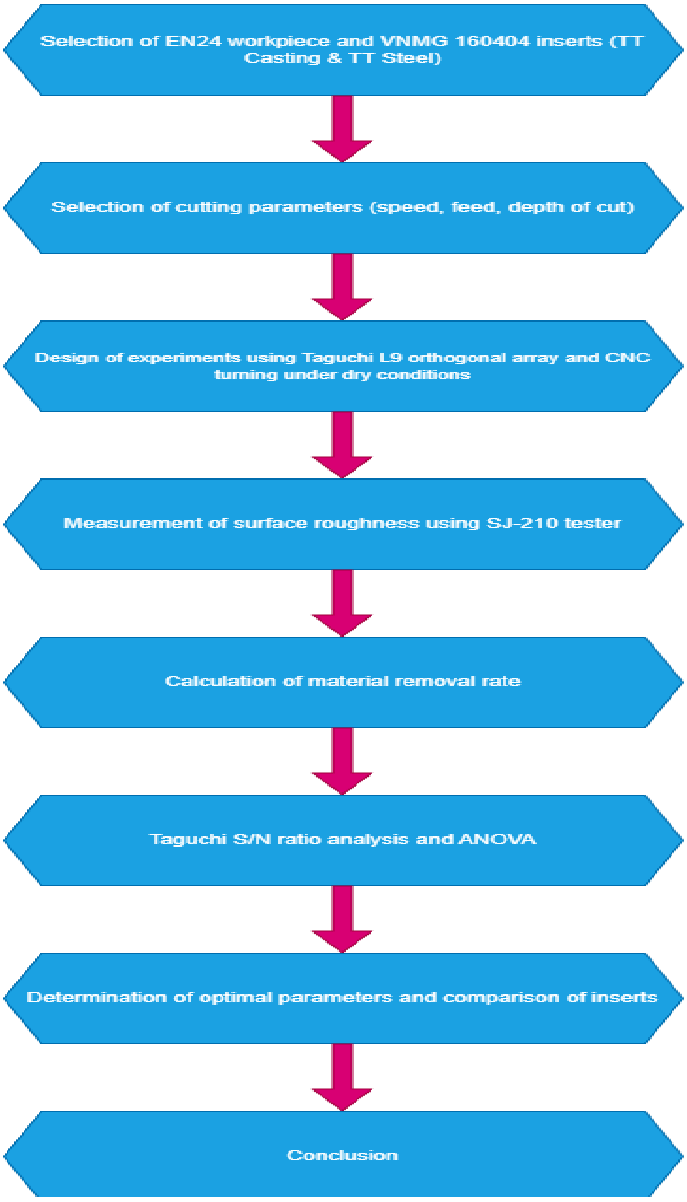

Fig 1 Methodology Chart

3. RESULT AND DISCUSSION

- **Optimization of Cutting Parameters**

Surface roughness was found out with orthogonal array. Experimental trials were set up for varying combinations and the corresponding surface roughness value was noted.

- **Design and Analysis**

Experimental results were analyzed by S/N ratio and Anova to find significant parameters and to know the optimum condition for cutting.

- **S/N Ratio Analysis**

The S/N ratio was used as a way to assess the process robustness and reduce variations. Three quality characteristics were considered, i.e. “lower-the-best”, “higher-the-best”, and “nominal-the-best”. The objectives of the analysis were

(i) determination of optimal parameter levels (ii) contribution of each factor and (iii) prediction of performance in optimal conditions.

4.1 Surface Roughness – TT Casting Insert

The experimental results indicate minimal value of experimental surface roughness was obtained at (150,

/0.06/0.6), which was 0.481 um. This proves that increase in cutting speed with a decrease in the feed rate gives better surface finish.
From the results of the ANOVA, it can be seen that the most influential reducing parameters are cutting speed, because it has the largest influence of 41.21% as the study parameter, followed by the cutting depth which has the influence of 26.37%, and the least influence is feed rate which has the influence of 24.52%. This sets the surface finish using TT Casting insert as being controlled mainly by the cutting speed.
Based on Taguchi optimization by TT Casting insert was recommended parameters respectively as per study (150, /0.06/0.4), This optimized combination is a statistically robust setting in spite of the fact that the absolute minimum Ra occurred at a slightly different depth of cut during experimentation.

4.2 Surface Roughness – TT Steel Insert

The relatively higher surface roughness values obtained with the TT Steel insert had been made under most of the machining conditions. Experimental lowest surface roughness values were found 0.718 um and 0.734 um which are high values respectively compared to those of TT Casting insert which show high surface finish capability.
Before examining the results of the ANOVA, it finds that feed rate is the very important parameter in the surface roughness of TT Steel insert, which has a contribution of 46.07%, followed by both remaining which contribute 23.55% and 15.67% respectively. This shows clearly that surface quality using TT Steel insert is subject to feeling sensitivity to the feed variation.

4.3 MRR – TT Casting Insert

The rate is increased with increase of all three parameters with the TT Casting insert. The highest experimental MRR value of 0.447368 g/s was obtained at a (150, /0.06/0.5).
The results of the analysis with complete random design (ANOVA) indicate that cutting speed (37.15%) and feed rate (33.68%) are the significant factors for MRR, and the effect of depth of cut (25.20%) is more relevant than the effect of the other factors. This means that the productivity aspect with TT Casting insert is primarily controlled by cutting speed and feed rate.

4.4 MRR – TT Steel Insert

The higher the productivity was consistently achieved with the TT Steel insert Max. experimental MRR was found to be 0.552631 g/s at (150, /0.06/0.5), which is found to be greater than maximum MRR obtained using TT Casting insert.
The results from an ANOVA confirm that feed rate is the most significant parameter that affects MRR as it has a contribution of 45.00% followed by cutting speed (37.84%) and depth of cut (15.84%). This indicates that productivity by using TT Steel insert is controlled mainly by feed rate.

4.5 Comparative Performance of Inserts

A difference in performance can be clearly found between the two inserts. The surface finish got a much better surface finish from the TT Casting insert showing a minimum of 0.481 micrometers of surface roughness while 0.718 micrometers were obtained by the TT Steel insert. Conversely, the TT Steel insert yielded a better productivity with a maximum MRR of 0.552631 g/s, compared with 0.447368 g/s with the TT Casting insert.
These results confirm a clear quality–productivity trade-off:

- TT Casting insert is more suitable for applications where surface quality is critical.
- TT Steel insert is more suitable for applications where higher material removal rate and productivity are prioritized.

5. CONCLUSION

The experimental results have confirmed that parameters described were influenced significantly both the surface roughness and the material removal rate, and their importance depend upon the tool insert. For the roughness of the surface, the best performance was the TT Casting insert with the minimum experimental value of the Ra parameter=
0.481 um. The results of the ANOVA showed that the cutting speed played a primary role (41.21%) the surface finish by using this insert. The optimum parameter values of minimum surface roughness using TT Casting insert were determined to be at 150 m/min cutting speed, 0.06 mm/rev feed rate and 0.4 mm depth of cut.
In contrast, in case of TT Steel insert the lowest values of surface roughness obtained experimentally were 0.718 um and 0.734 um which are higher than that obtained with TT Casting insert. Statistical analysis proved that feed rate was most dominant parameter (46.07%) affecting the surface roughness for this insert. The optimized parameter combination of minimum surface roughness using TT Steel insert was found to be 150

m/min cutting speed, 0.08 mm/rev feed rate and 0.6 mm depth of cut. With respect to the productivity, the TT Steel insert had a better performance in terms of MRR. The experimental MRR of 0.552631 g/s was the highest obtained for TT Steel insert as compared to 0.447368 g/s for TT Casting insert. From the obtained results of the ANOVA, seen that feed rate (45.00%) and cutting speed (37.84%) were the most influencing parameters to control MRR using TT Steel insert.

Overall, the study definitely establishes a quality-productivity trade-off between the two tool coatings. The TT Casting insert is better suited for applications where better surface finish is important, and the TT Steel insert is better suited for applications where higher material removal rate and productivity are important. The application of the Taguchi method was found to be effective in reducing the number of experiments without losing optimization and statistical understanding of the process. These results offer practical machining recommendations for the choice of cutting parameters and tool inserts in industrial turning of EN24 steel in dry conditions, in order to achieve better process efficiency, surface integrity, and cost-effective production.

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