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Optimization of Hard Material Turning Using Coated Carbide Tools by Experimental and Mathematical Modeling: A Review Approach

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***Abstract*–The present study is a review based on experimental and mathematical modeling to optimise hard material turning utilising coated carbide tools. Modern technology makes hard turning possible. It entails the use of advanced machine tools to manufacture hard materials. With high-precision machining, there are obstacles such as selecting a tool insert with enhanced tool life. Turning hardened materials with a single-point cutting tool has piqued the curiosity of cutting tools, ball bearing, automobiles, gear, and die makers. We have chosen several topic-relevant research articles for a scientific study connected to the optimization of hard material turning in the current paper. Using the utility idea of multi-response optimization, we can infer that optimization of cutting parameters such as cutting speed, feed rate, and depth of cut for hard AISI M7 material with coated carbide tool is not done. The hardness of the material will be between 62 and 64 HRC.**

***Index Terms* – Optimization, Hard Material, AISI M7, Experimental Modeling, Mathematical Modeling.**

INTRODUCTION

Hard turning is now feasible thanks to modern technologies. It comprises the creation of hard materials using modern machine tools. There are challenges in high-precision machining, such as choosing a tool insert with increased tool life. Cutting tools, ball bearings, vehicles, gear, and diemakers are all interested in turning hardened materials using a single-point cutting tool. Hard turning has a number of benefits over traditional grinding, including lower equipment costs, shorter setup times, and fewer process phases, all of which lead to more flexibility and the ability to cut complex shapes. Because hard turning is frequently done without cutting fluid, the storage, handling, and disposal of cutting fluid are minimised. It's good for the operators' health. This review article summarises prior hard turning studies employing a variety of hard turning tools, including PCBN, CBN, Ceramics, and Carbide, among others. The principal hard turning cutting materials, as well as the influence of hard turning process parameters on cutting forces, heat generation during cutting, surface finish, and tool wear, have been evaluated in light of past research results.

LITERATURE REVIEW

This section includes some selected articles for an in-depth investigation to find a research gap or further extension of research in the area of hard turning. The selected papers for the study is as follows:

Alok, A., & Das, M. (2019) [1] executed a new type of coating material, HSN2 with 12 µm thickness on carbide insert by using physical vapor deposition technique for machining hard AISI 52100 steel of hardness 55 HRC is evaluated. DSC and TGA also characterize the coated carbide insert's thermal and oxidative stability. The primary cutting, radial and feed pressures, maximum flank wear, and surface quality of the workpiece are all related to the input process parameters of cutting speed, feed rate, and depth of cut. The impact of cutting parameters on machinability is studied statistically. Also, regression models are created to link input and output process characteristics. This is followed by a response surface optimization and validation test. Percentage errors for main cutting force, radial force, feed force, surface roughness (%), and flank wear (%) were identified in the confirmation test. The greatest tool wear recorded is 292 m, which is acceptable under ISO 3685. Among all output parameters, cutting speed is shown to be the most effective. The current effort is unique in that it involves machining AISI 52100 steel with a 55 HRC hardness at 102–287 m/min with a new coating material HSN2 with a 12 m thickness.

Aouici, H., et al. (2012) [2] investigated experimentally the effects of cutting speed, feed rate, workpiece hardness and depth of cut on surface roughness, and cutting force components in the hard turning. To mill the AISI H11 steel, Sandvik used cubic boron nitride (CBN 7020), which is a mix of 57 percent CBN and 35 percent TiCN. We used four-factor (cutting speed, feed rate, hardness, and depth of cut) and three-level fractional experiment designs using ANOVA. This technique generated mathematical models for surface roughness and cutting force components (RSM). While the depth of cut and workpiece hardness have the greatest impact on cutting force components, both feed rate and workpiece hardness have statistical relevance on surface roughness. Finally, optimal cutting conditions ranges for industrial production are recommended.

Aouici, H., et al. (2011) [3] investigated turning conditions of hardened AISI H11 (X38CrMoV5-1), the effects of cutting parameters on flank wear (VB) and surface roughness (Ra) using the CBN tool. The response surface approach is used in the machining trials (RSM). In this study, the combined impacts of three cutting parameters are investigated (cutting speed, feed rate, and cutting duration) on two performance outputs (VB and Ra) (ANOVA). The optimal cutting conditions for each performance level are derived using a quadratic regression model. The data suggest that cutting time affects flank wear the most, followed by cutting speed. Also, the feed rate seems to have the main influence on workpiece surface roughness.

Azizi, M. W., et al. (2012) [4] investigated the effect of cutting parameters (cutting speed, feed rate, and depth of cut) and workpiece hardness on surface roughness and cutting force components. On AISI 52100 steel with coated Al2O3 + TiC mixed ceramic cutting tools. The experiment was planned using Taguchi's L27 orthogonal array. The response table and ANOVA enabled us to test the linear regression model's validity and identify relevant factors impacting surface roughness and cutting forces. The statistical study shows that the depth of cut, workpiece hardness, and feed rate has a statistically significant influence on the cutting force components than the cutting speed. To connect cutting parameters and workpiece hardness with surface roughness and cutting forces, empirical models were created. The desired function technique for multiple response factor optimization was used to find the optimal machining settings to create the lowest surface roughness with the least cutting force components. Finally, validation experiments were conducted to validate the proposed empirical models.

Azizi, M. W., et al. (2020) [5] optimized machining parameters to achieve the desired technical parameters such as surface roughness, tool radial vibration, and material removal rate using response surface methodology (RSM). The hard turning of EN19 alloy steel with GC3015) cutting tools was examined. In order to achieve the needed surface finish quality and production rate, manufacturers of hard and high precision components confront a major challenge. RSM can handle this issue by creating a mathematical model and conducting tests. The statistical study employed a face-centered central composite design (FCCD) with cutting parameters (cutting speed, feed rate, and depth of cut). It was shown that cutting parameters correlated with surface roughness, tool vibration, and material removal rate. Using a desirability function, numerical and graphical optimization was used to find the best cutting settings for reducing surface roughness, tool vibration, and material removal rate. Finally, validation experiments were conducted to validate the mathematical models.

Bouzid, L., et al. (2015) [6] attempted to statistically model the relationship between cutting parameters (speed, feed rate, and depth of cut), cutting force components (Fx, Fy, and Fz), and workpiece absolute surface roughness (Ra). A chemical vapor deposition–coated carbide tool is used to machine martensitic stainless steel (AISI 420). A full-factorial design (43) is used to examine the experimental findings using both ANOVA and RSM. The optimal cutting conditions are obtained utilizing mutually responsive surfaces and desire functions, with residual values checking the model's adequacy. The findings show that depth of cut (Fx: 86%) dominates (Fy: 58%) and feed rate (Fz: 81%) influences surface roughness behavior (Ra: 81 percent). Also, the anticipated and actual cutting force components and surface roughness were in excellent agreement. The findings are also tested for mistakes (Fx: 6.51 percent, Fy: 4.36 percent, Fz: 3.59 percent, and Ra: 5.12 percent). Finally, ideal cutting ranges for industrial production are anticipated.

Cakir, M. C., et al. (2009) [7] examined the effects of cutting parameters (cutting speed, feed rate, and depth of cut) onto the surface roughness through the mathematical model developed by using the data gathered from a series of turning experiments performed. A second study was conducted to assess the impact of two well-known coating layers on surface roughness. The trials were performed for two CNMG 120408 (ISO designation) carbide inserts with the same geometry and substrate but varied coating layers to assure identical cutting conditions. Cold-work tool steel AISI P20 was machined. A thin TiAlN layer (31micro m) is PVD coated on Insert 2, while a TiCN underlayer, an Al2O3 intermediate layer, and a TiN outer layer are all deposited by CVD on Insert 1. The overall average error of the model was 4.2 percent for Insert 1 and 5.2 percent for Insert 2, proving the equations' dependability.

Chinchanikar, S., et al. (2013) [8] investigated the performance of coated carbide tool considering the effect of work material hardness and cutting parameters during turning of hardened AISI 4340 steel at different levels of hardness. Multiple linear regression models were used to identify relationships between cutting parameters and performance metrics such as cutting forces, surface roughness, and tool life in the area of cutting parameters, the created models are trustworthy and may be utilized successfully to anticipate reactions. An ANOVA was used to identify highly significant parameters (ANOVA). Less cutting force is necessary to machine tougher materials, according to experimental evidence. Cutting forces are influenced by the depth of cut, then feed rate. Surface roughness is influenced by cutting speed, feed, and depth of cut. Particularly when working with tougher materials, cutting speed and depth of cut become the most important elements affecting tool life. Ideal cutting conditions are established by RSM and Desirability Function. Cutting pressures, surface roughness, and tool life was found to be reduced by using lower feed rates, deeper cuts, and restricting cutting speeds to 235 and 144 m/min for 35 and 45 HRC work materials, respectively.

Das, D. K., et al. (2014) [9] investigated surface roughness during hard machining of EN 24 steel with the help of coated carbide insert. The test was done in dry circumstances. The process parameters were optimized using the Grey-based Taguchi method. The adequacy of the surface roughness prediction models constructed using regression analysis was also tested. Hard machining produces a surface roughness of 0.42 microns. The best depth of cut (Ra) and cutting speed (Rz) for the grey-based Taguchi technique were found to be 0.4 mm, 0.04 mm/rev, and 130 m/min, respectively. Feed is the most important parameter for both Ra and Rz. The prediction models have strong R2 values (0.993 and 0.934). This shows a better model fit and is very significant.

Das, S. R., et al. (2015) [10] investigated the dry hard turning of AISI 4140 steel using PVD-TiN coated Al2O3+TiCN mixed ceramic inserts. In this study, the combined influence of cutting parameters (cutting speed, feed, and depth of cut) on performance variables including surface roughness and flank wear is investigated (ANOVA). Cutting feed, followed by cutting speed, is shown to have the greatest impact on surface roughness. Although the depth of cut is not statistically significant, flank wear is a function of the depth of cut. To establish the procedure, SEM observations are done on the machined surface and worn tool. In the examined range, abrasion was the predominant wear mechanism. Tool wear and surface roughness were also investigated. It was used to anticipate the appropriate surface roughness and flank wear. Based on RSM, mathematical models for surface roughness (Ra) and flank wear (VB) were established with 95% confidence. Finally, under optimal cutting circumstances (obtained via response optimization), tool life was tested to justify coated ceramic inserts in hard turning. Because TiN coated ceramic has a longer tool life (51 minutes), it has a lower projected machining cost per item (Rs. 12.31).

Das, S. R., et al. (2017) [11] addressed surface roughness, flank wear, and chip morphology during dry hard turning of AISI 4340 steel (49 HRC) using CVD (TiN/TiCN/Al2O3/TiN) multilayer coated carbide tool. The influence of cutting settings on tool and workpiece flank wear and surface roughness were studied using Taguchi's L9 Orthogonal array (OA) and ANOVA. SEM was used to examine the surface topography of machined workpieces, wear processes of worn coated carbide tools, and chip morphology of produced chips (SEM). Thus, multiple regression analysis was used to create a mathematical model for each answer, and numerous diagnostic tests were run to ensure the model's validity and usefulness. Finally, to demonstrate the economic viability of coated carbide tools in hard turning, a cost study based on Gilbert's method was done (suggested by response optimization technique). The findings reveal that feed and cutting speed affect surface roughness and flank wear statistically. In fact, faster-cutting speed improved surface polish and increased flank wear. Tool wear is generated by abrasion from the flank land rubbing on the machined surface and high cutting temperatures. Chip morphology indicates saw-tooth chip formation with severe serration produced by cyclic fracture propagation driven by plastic deformation. The overall machining cost per item for hardened AISI 4340 steel with a coated carbide tool is $0.13 (i.e. Rs. 8.21 in Indian rupees). The research concluded that a multilayer TiN/TiCN/Al2O3/TiN coated carbide tool for hard turning in dry cutting conditions is a cost-effective alternative to standard cylindrical grinding. It also provides cheaper alternatives to CBN and ceramic tools.

Davoodi, B., et al. (2015) [12] investigated the effects of cutting parameters on tool life of PVD TiAlN-coated carbide tools, and volume of workpiece material removed during the machining of the N-155 iron–nickel-base superalloy is evaluated. Cutting factors included cutting speed and feed rate at five levels. RSM was used to model the interactions between machining parameters and output variables (RSM). ANOVA was used to test the mathematical model and its variables. Overall, the findings demonstrated excellent agreement between observed tool life and material eliminated and model predictions. The cutting tool inserts were also SEM investigated, and wear processes were studied at different cutting speeds. The most common tool failure mechanism was adhesion. Finally, the desired function technique was used to optimize tool life and material removal for optimal productivity.

Davoodi, B., et al. (2014) [13] investigated the effects of cutting speed and undeformed chip thickness on cutting and feed force components, and tooltip temperature was experimentally investigated in order to remove the cutting fluid. AA5083-O wrought alloy with high Mg content (4.5%) was machined dry and wet using coated carbide tools. They used two-factor (cutting speed and undeformed chip thickness) and five-level fractional experiment designs using ANOVA. This method was used to construct mathematical models for cutting and feed force components and tool tip temperature (RSM). The results reveal that the undeformed chip thickness affects the output variables. AA5083 may be machined without cutting fluid at high cutting speed and low undeformed chip thickness. In dry and wet machining, cutting speed and chip thickness have statistical relevance on the cutting and feed force components. Finally, suitable turning conditions for industrial production were provided.

Devi, K. D., et al. (2015) [14] studied an optimization problem that seeks the identification of the best process condition or parametric combination for the said manufacturing process. Single-objective optimization refers to problems involving just one quality feature. It is difficult to pick the ideal option that meets all quality standards concurrently when more than one characteristic is considered. The current research used Response Surface Methodology to solve a Multi-Objective Optimization issue by straight turning brass bar. The research sought to determine the ideal process environment for both quality and productivity. Finally, the research examines the impact of four input factors on output parameters: cutting speed, feed, depth of cut, and coolant type. The estimated ideal setting minimized surface roughness and maximized MRR, tool life, and machinability index. The confirmatory test validated the ideal outcome.

Dureja, J. S., et al. (2009) [15] attempted to model the tool wear and surface roughness, through response surface methodology (RSM) during hard turning of AISI-H11 steel with TiN-coated mixed ceramic inserts. Analyzing the response factors flank wear and surface roughness using ANOVA and factor interaction graphs in the RSM, the influence of machining parameters such as cutting speed, feed rate, depth of cut, and workpiece hardness was explored. This model best fits the experimental data. Optimisation of numerous response components using a desirability function. The validation trials predicted response factors within 5% error. Surface roughness is influenced by feed rate and workpiece hardness, whereas flank wear is influenced by feed rate and depth of cut. The tool wear was monitored using a toolmaker's microscope, and some of the typical inserts were characterized by SEM-EDX. There is abrasion, notch wear, and chipping of the tool surface from rubbing and impingement of hard particles in the work material.

Dureja, J. S., et al. (2014) [16] attempted to investigate tool wear (flank wear) and surface roughness during finish hard turning of AISI D3 steel (58HRC) with coated carbide (TiSiN-TiAlN coated) cutting tool. The Taguchi L9 (3)3 orthogonal array was used for design. They used the S/N ratio and ANOVA to find important factors impacting tool wear and surface roughness. Cutting speed and feed influenced tool wear (flank wear), and feed influenced surface roughness (Ra). Regression analysis was used to generate mathematical models for tool wear and surface roughness. The confirmation trials using Taguchi's optimum parameter combination predicted the response factors with less than 5% error. To decrease tool wear and surface roughness, the Desirability function module in RSM was used. The optimum solution via desirability function optimization was compared to the optimal Taguchi set of parameters. Both strategies provide similar optimization outcomes.

Kaladhar, M., et al. (2013) [17] attempted to explore the influence of machining parameters on the performance measures, surface roughness, and flank wear in turning of AISI 304 austenitic stainless steel with a two-layer chemical vapor deposition(CVD) coated tool. The Taguchi method was used to accomplish this. The data show that cutting speed affects surface roughness and flank wear the most. Also projected are ideal process parameter settings and performance measure ranges.

Kaladhar, M., et al. (2010) [18] studied the optimization of machining parameters in turning AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. A number of process factors are investigated throughout the experiment including speed, feed, depth of cut, and nose radius. The trials were done on a CNC lathe utilizing complete factorial design in the Design of Experiments. ANOVA was also utilized to examine the effect of process factors and their interaction during machining. The research shows that the feed affects the surface roughness the greatest, followed by the nose radius. An effort was made to forecast surface roughness. Validation trials validate the projected values.

Keblouti, O., et al. (2017) [19] investigated the effects of cutting parameters and coating material on the performances of cutting tools in turning of AISI 52100 steel. Uncoated and coated (with TiCN-TiN coating layer) cermet tools were compared. The inserts had the same substrate composition and shape. It was used to build a mathematical model (RSM). The influence of cutting settings on machining surface quality and cutting forces was studied using ANOVA. The findings suggest that feed rate is the most important factor. However, cutting depth affects cutting force components. Coating layer influence on surface quality was also evaluated. Using PVD (TiCN-TiN) coated inserts reduced surface roughness. A second-order regression model with correlation coefficients between 95% and 97% was created.

Keblouti, O., et al. (2017) [20] presented work concerns an experimental study of turning with coated cermet tools with TiCN-TiN coating layer of AISI 52100 bearing steel. The major goals are to investigate the impact of cutting settings and coating materials on cutting tool performance. Second, use a multi-objective optimization to reduce surface roughness (Ra) and increase the material removal rate. It was used to build a mathematical model (RSM). The impact of cutting parameters on machining surface quality and material removal rate was quantified using ANOVA. The results show that feed rate has the greatest impact on surface quality. They also look at how coating layers affect surface quality. The PVD (TiCN-TiN) coated insert has a reduced surface roughness than the uncoated tool. This paper also provides the root mean square deviation and correlation coefficient between theoretical and experimental data, with a maximum computed inaccuracy of 2.65%.

Khellaf, A., et al. (2017) [21] presented a comparison of surface roughness between both ceramic cutting tools namely, TiN coated mixed ceramic CC6050 and uncoated mixed ceramic CC650 when machining hardened hot work steel X38CrMoV5-1 [AISI H11] treated at 50 HRC. Using response surface methodology (RSM), a mathematical model linking surface roughness requirements to primary elements such as cutting radius, cutting speed, feed rate, and depth of cut was constructed. To decrease surface roughness, the influence of cutting settings is examined. Using response surface methods, several linear models were built between cutting parameters and surface roughness. The feed is the most important machining parameter for surface roughness, followed by cutting radius. Also, the ideal conditions identified minimize surface roughness on machining AISI H11 steels within the analyzed parameter ranges. Hard turning with CC650 tools also produced good surface roughness. In terms of surface roughness, coated ceramic tools demonstrated no benefit over CC650.

Kumar, R., et al. (2018) [22] focused on mathematical modeling, multi-response optimization, tool life, and economical analysis in finish hard turning of AISI D2 steel ((55 ± 1) HRC) using CVD-coated carbide (TiN/TiCN/Al2O3) and uncoated carbide inserts under dry environmental conditions. Modeling and multi-response optimization were accomplished using regression and grey relational approaches. The correlation model's appropriateness was tested using comparative economic data for both inserts. The experimental and projected values for all answers were quite near, showing the model's relevance and tight correlation coefficients. The optimum parametric combinations for Al2O3 coated carbide were d1–f1–v2 (0.1 mm depth of cut, 0.04 mm/r feed, and 108 m/min cutting speed), and d1– (0.1 mm)–f1 (0.04 mm/r)–v1 (63 m/min). Using a 0.3 mm flank wear criterion, the coated carbide insert had a 15 times longer tool life than the uncoated carbide insert. The coated carbide insert produced 26.14 times more chip volume than the uncoated carbide insert, allowing for faster material removal. Abrasion, diffusion, notching, chipping, and built-up edge are the main wear processes. When compared to uncoated carbide inserts, the coated carbide tool saved around 3.55 times as much money on machining.

Labidi, A., et al. (2018) [23] developed predictive models for the arithmetic surface finish (Ra), flank wear (VB), and tangential force (Fz). The desirability function was used to optimize (DF). The Taguchi L27 experimental plan was used to hard turn the X210Cr12 hardened steel (56 HRC) using a coated ceramic tool (CC6050). ANOVA was used to assess the impact of cutting parameters (Vc, f, and t) on output parameters (VB, Ra, and Fz). The technical parameters were also modeled using RSM and ANN. The DF method was utilized to find the ideal machining conditions (VB, Ra, and Fz). The data suggest that Vc (Cont. percent = 39.96) dominates VB, followed by f (Cont. percent = 35.36). Also, f and t were discovered to be important determinants impacting Ra, contributing 31.71 and 23.78 percent, respectively. However, t and f contribute 75.74 and 22.66 percent to Fz, respectively. However, ANN and RSM models closely match experimental data. However, ANN outperforms RSM in terms of accuracy and prediction of cutting process parameters. To optimize multi-objective machining, set Vc = 80 m/min, f = 0.08 mm/rev, and t = 4 min.

Laghari, R. A., et al. (2020) [24] established the second-order model of cutting force for obtaining an effective mathematical model for the cutting force. In their work, several cutting factors such as cutting speed, feed rate, and depth of cut were studied using RSM. The optimized mathematical model was built to study the influence of real processing circumstances on cutting force production in SiCp/Al composite turning. The RSM predicted parameters accord well with the experimental data with a small error percentage. ANOVA, main effects plot, interaction effect, residual analysis, and optimization of cutting forces using the desirability function were used to evaluate quantitatively. Higher depth of cut, followed by feed rate, increases cutting force. Higher cutting speed reduces cutting power. An excellent agreement between anticipated and experimental findings for the model of SiCp/Al components has been established.

Laouissi, A., et al. (2019) [25] undertook a comparative study in terms of the surface roughness criterion (Ra), the tangential cutting force (Fz), the cutting power (Pc), and the material removal rate (MRR) in turning of EN-GJL-250 cast iron using both coated and uncoated silicon nitride ceramics (Si3N4). The experiment is designed using the L27 Taguchi method, and the ANOVA method is utilized to discover the cutting factors that most impact the replies. The mathematical prediction models employed in the genetic algorithm optimization strategy were developed using artificial neural networks (ANN) and response surface methodology (RSM) (GA). The ANN and RSM models' prediction skills were evaluated in terms of MAD, MAPE, RMSE, and coefficient of determination (R2). The ANN technique outperforms the RSM method in terms of precision. Moreover, the coated ceramic tool produced superior surface quality and required less cutting force than uncoated ceramic. According to the results of the wear tests, when the flank wear reaches the permissible value of [Vb] = 0.3 mm, the ratios are 0.88, 1.4, and 0.94, respectively.

Manohar, M., et al. (2013) [26] discussed the use of the Box Behnken design approach to planning the experiments for turning Inconel 718 alloy with an overall objective of optimizing the process to yield higher metal removal, better surface quality, and lower cutting forces. The RSM is used to represent the output parameters (responses) that are determined by the input process parameters. RSM measures the link between input parameters and output parameters. RSM designs estimate an interaction and even quadratic effects, giving us an understanding of the response surface's form. The Box-Behnken design is the most efficient for an experiment involving three components and three levels, and it requires fewer tests than a central composite design. The suggested Box-Behnken architecture needs 15 runs of experiments to collect data. The experiment was designed and executed using design expert software. A regression model was built and tested to predict output values under virtually all scenarios. Experiments with three sets of random input values were used to verify the model. The actual output parameters agree well with the model's expected values. The RSM developed was plotted in 2D and 3D using Design-expert software. These graphs show the dominant process variable and its order of dominance, as well as the trend of variable interaction in the process. To improve surface roughness and material removal, this research identified optimal turning parameters for Inconel 718 utilizing coated carbide tools. This study is significant in that a dependable model was built, verified, and optimized with two goals in mind.

Mia, M., et al. (2017) [27] studied the quality characteristics such as cutting force, surface roughness, and specific cutting energy in internal cryogenic cooling assisted milling of hardened steel vis-à-vis mathematical modeling and multiple attributes optimization by using response surface methodology. Cutting speed, feed rate, and cutting condition were investigated in a full factorial design with 27 experimental runs. The cutting condition significantly influences all replies, highlighting the need of selecting the optimum cooling method. The results showed that through-tool cryogenic cooling beats dry and wet cooling. Also, mathematical relations may be used owing to increased forecast accuracy. Cutting speed of 26 m/min, feed rate of 58 mm/min, and through-tool cryogenic cooling were determined to be optimal values for simultaneous quality reduction.

Mia, M., et al. (2018) [28] discussed some of the sustainability issues in machining by studying the cutting energy, surface finish, and Minimum Quantity Lubrication (MQL). Using MQL, the specific cutting energy (Esp) and average surface roughness parameter (Ra) in end milling hardened AISI 4140 steel were studied. The experiment's complete factorial design guided the cutting speed, feed rate, and lubrication flow rate. Comprehensive step-by-step research of RSM was undertaken. The perturbation plot, interaction effects, and 3D response surface plots were used to perform a full statistical analysis. For Esp and Ra, the Taguchi approach was used in addition to Desirability-based duplex optimization in RSM. Esp was affected by cutting speed, but Ra was influenced by lubricant flow rate. The optimal settings are 46 mm/min feed, 32 m/min cutting, and 150 mL/h coolant flow. The RSM and Taguchi-based models produced similar findings, proving their validity. The analyzed statistical indicators also validated the models.

Mia, M., et al. (2018) [29] presented the development of mathematical, predictive, and optimization models of average surface roughness parameter (Ra) in turning hardened AISI 1060 steel using coated carbide tool in dry condition. The mathematical model is RSM, the predictive model is FIS, and the optimization model in SA. All of these models used cutting speed, feed rate, and material hardness as input variables. After the experiments, the data acquired is utilized for model building and validation. The statistical study suggests the quadratic model for Ra in RSM. Error analysis and validation tests validated the models' accuracy. The built model was also compared to an analytical model. The feed rate is the second most important factor, followed by cutting speed. The RSM model had a 99.64 percent coefficient of determination, the FIS model had a 79.82 percent prediction accuracy, and the SA model improved surface roughness by almost 70%. By controlling the hard turning process, these models may obtain an excellent surface quality.

Panda, A., et al. (2017) [30] addressed the assessment, modeling, and optimization study of surface roughness in finish dry hard turning (FDHT) of AISI 4340 steel with the coated ceramic tool by considering the cutting speed, axial feed, depth of cut, and nose radius as machining parameters. The response surface methodology (RSM), particle swarm optimization (PSO), and lastly Gilbert's technique is used for mathematical modeling, response optimization, tool life assessment, and economic analysis. Statistical significance and validity, appropriateness, efficacy, and fitness of data of the suggested model were further checked using ANOVA and Anderson-Darling normal probability test. Based on the results, nose radius and feed are the most important regulated and dominating components for hard turning operations. Minimal surface roughness of 0.2021 m is obtained using the RSM model and PSO approach with the following process parameters: 220 m/min cutting speed, 0.05 mm/rev feed, 0.193 mm depth of cut, and 1.6 mm tool nose radius. Finally, under optimal machining circumstances, tool life was analyzed to justify the use of coated ceramic tools in hard turning. Hard turning has a reduced total machining cost per piece ($0.34) due to longer tool life (44 min), less downtime, and increased savings. Aspects of the present work that are novel are (i) the demonstration of the replacement of expensive and time-consuming conventional cylindrical grinding processes with coated ceramic tools in hard turning processes, and (ii) the contribution to the practical industrial application of finish hard turning.

Panda, A., et al. (2018) [31] addressed the machinability investigation of high strength low alloy grade AISI 4340 steel with coated ceramic tools on surface roughness, tool wear, and economic analysis by considering the hard turning process parameters such as cutting speed, feed and depth of cut. The complete factorial design of studies is used to run 27 trial sets. An analysis of variance is used to investigate parametric influences. Predictive modeling, response optimization, and tool life estimate are then costed. To produce minimal surface roughness of machined components and minimize cutting tool flank wear, feed, and cutting speed are the most important and vital parameters for hard turning operations. The coated ceramic insert had a tool life of 47 minutes under ideal cutting circumstances, resulting in a lower total machining cost per component ($0.29) and less downtime, proving the cost-effectiveness of hard turning. From a techno-economical and ecological point of view, the present study effort provides the costliest CBN tool substitute employing coated ceramic tools in the hard turning process.

Panda, A., et al. (2019) [32] addressed the machinability investigation in finish dry hard turning of high strength low alloy steel with the coated ceramic tool by considering cutting speed, feed, and depth of cut as machining parameters. Technological characteristics such as surface roughness, flank wear, chip shape, and economic feasibility were investigated. An analysis of variance, multiple regression, Taguchi, desirability function approach, and lastly Gilbert's methodology is employed for parametric impact research, mathematical modeling, multi-response optimization, tool life prediction, and economic analysis. To reduce machined surface roughness and tool flank wear, the results show that feed and cutting speed are the most important controllable elements for hard turning. An ideal cutting circumstances, a coated ceramic insert has a tool life of 47 minutes due to abrasions, adhesion, and plastic deformation. Hard turning has a reduced total machining cost per item ($0.29) due to longer tool life, less downtime, and more savings. The present effort replaces the costly and laborious cylindrical grinding technique with coated ceramic tools in the hard turning process.

Panda, A., et al. (2016) [33] investigated the parametric optimization of multi-responses such as flank wear and surface roughness during machining hardened AISI 52100 steel (55±1) steel using mixed ceramic insert under dry environment through grey relational analysis combined with Taguchi approach. Predicted mathematical models of the first and second-order were also built and evaluated for correctness. The second-order mathematical model had a higher R2 value and was better fitted than the first-order model. The model predicts the experimental data well. In a harsh machining environment, the suggested grey-based Taguchi approach showed effectiveness for handling multi-attribute decision-making issues.

Parida, A. K., et al. (2019) [34] performed the hot turning of Monel-400 has been to investigate the influence of four machining factors (cutting speed, feed rate, depth of cut, and workpiece temperature) on flank wear and surface roughness. The workpiece was heated using oxygen and LPG. The studies used a face-centered composite design (CCD). The mathematical simulation of flank wear and surface roughness using Response Surface Methodology (RSM). ANOVA was used to assess each parameter's impact on replies. The regression equation's projected model for flank wear and surface roughness matches the testing data well. The greatest error of flank wear and surface roughness between simulation and experiment is 13% and 7%, respectively.

K.P.Pawar & R.D. Palhade (2015) [35] investigated the effect of insert nose radius and machining parameters including cutting speed, feed rate and depth of cut on surface roughness (Ra), and material removal rate (MRR) in a turning of HSS (M2) using the Taguchi method and ANOVA. It is used to investigate the performance characteristics of Tin coated carbide inserts tools in turning HSS (M2) at nose radiuses of 0.4, 0.8, and 1.2 mm on a CNC turning centre utilizing a three-level, four-parameter design of experiment. During the CNC turning of HSS (M2) material, ANOVA is used to determine the relative contribution of each machining parameter. All tests are performed in a dry environment with a constant spindle speed of 2800 rpm. Confirmation experiments validate the findings. The current study shows that feed rate and nose radius are important variables in material removal rate and surface roughness for turning HSS (M2).

Ramana, M. V., et al. (2012) [36] investigated the optimization of process parameters for surface roughness in turning of Ti-6Al-4V alloy under dry, flooded, and Minimum Quantity Lubrication (MQL) conditions using Taguchi‟s robust design methodology and development of prediction models for surface roughness using multiple regression analysis. The findings suggest that MQL outperforms dry and flooded lubricants in terms of performance and surface roughness reduction. ANOM shows that MQL is acceptable for deeper cuts than dry and flooded lubricant conditions. It is noted from ANOM that, in MQL circumstances uncoated tool exhibits higher performance compared to the CVD and PVD coated tools, but CVD coated tool shows superior performance for dry and flooded lubricant conditions compared to uncoated and PVD coated tools. The ANOVA also shows that feed rate is important in adjusting surface roughness. Using multiple regression analysis, mathematical models are created to predict Surface Roughness for three distinct instruments. These models match the experimental data well.

Ramanujam, R., et al. (2014) [37] presented a statistical approach for optimization of dry turning parameters of Inconel 718. Using Taguchi's L9 orthogonal array, turning tests were performed to assess cutting force, surface roughness, and tool wear. The turning was done on a medium-duty lathe with a PVD-coated carbide cutting insert. The ideal cutting conditions were established using Taguchi's Signal to Noise (S/N) ratio for Ra, Rt, Rz, and Fz. SEM micrographs were used to examine tool wear. Using ANOVA, the findings show that feed rate and depth of cut had the greatest impact on responses. Individual reactions were mathematically modeled using regression analysis with cutting parameters as independent variables. Ra, Rt, Rz, and Fz have strong determination coefficients (R2 = 0.912, 0.943, and 0.882), proving the model's correctness. The projected value from the constructed model and experimental data is quite near, proving the model's importance. On the optimal cutting circumstances, Taguchi's optimization approach was confirmed by trials.

Routara, B. C., et al. (2012) [38] applied response surface methodology to determine the optimum cutting conditions leading to minimum surface roughness in CNC turning operation on EN-8 steel. Using response surface methodology (RSM), second-order mathematical models for machining parameters were constructed for surface roughness prediction. The EN-8 steel was machined using coated carbide tools. The model chosen for optimization has been F-tested. The models on surface roughness were validated using ANOVA (ANOVA). A Genetic Algorithm was used to improve the surface roughness prediction model to identify optimal cutting settings.

Sahoo, A. K., et al. (2011) [39] presented the experimental study, development of the mathematical model, and parametric optimization for surface roughness in turning D2 steel using TiN coated carbide insert using Taguchi parameter design and response surface methodology. The cutting parameters used in the experiments were cutting speed (v), feed (f), and depth of cut (d). The effect of machining parameters on the surface finish has also been studied, as has the optimal cutting condition for reducing surface roughness. V3-f1-d3 is the best parametric combination for the TiN coated cutting insert. Feed is the most important process parameter on surface roughness, followed by cut depth. The research revealed no significance in cutting speed. The RSM model predicts values accurately with 95% confidence intervals. The proposed RSM model can accurately forecast surface roughness in turning D2 steel.

Sahoo, A. K., et al. (2012) [40] presented work deals with some machinability studies on flank wear, surface roughness, chip morphology, and cutting forces in finish hard turning of AISI 4340 steel using uncoated and multilayer TiN and ZrCN coated carbide inserts at higher cutting speed range. The process's effectiveness in hard turning has also been economically justified. The multilayer TiN/TiCN/Al2O3/TiN coated carbide insert outperformed the uncoated and TiN/TiCN/Al2O3/ZrCN coated carbide insert in terms of flank wear and surface roughness. Tools with TiN and ZrCN coatings lasted about 19 minutes and 8 minutes respectively under harsh cutting circumstances. Uncoated carbide inserts for cutting tough steel fractured. The main wear mechanisms in machining include abrasion, chipping, and catastrophic failure. In hard turning, multilayer-coated carbide inserts have lower cutting, thrust, and feed forces than uncoated carbide inserts. Compared to the 1st order regression model, the 2nd order model explains about 98.3% of the variability of responses (flank wear and surface roughness) and suggests a superior match with the data for multilayer TiN coated carbide insert. In the ANOVA analysis, the 2nd order flank wear model matches better than the surface roughness model for ZrCN coated carbide inserts. In harsh machining, adopting multilayer TiN coated inserts saves 93.4 percent compared to uncoated carbide and 40% compared to ZrCN coated carbide inserts. Here is an example of a multilayer TiN coated carbide insert in finish hard turning.

Sahoo, A. K., et al. (2013) [41] presented the mathematical modeling and parametric optimization on flank wear and surface roughness based on response surface methodology and grey-based Taguchi method in finish hard turning of AISI 4340 steel (HRC 47 ± 1) using multilayer coated carbide (TiN/TiCN/Al2O3/TiN) insert under dry environment. The use of a multilayer TiN coated carbide insert was disclosed. Correlation coefficients were used to test model fit. The major impact shows that cutting speed is important for flank wear, followed by the depth of cut and feed. Again, feed, cutting speed, and depth of cut all affect surface roughness. The RSM models constructed have an R2 of above 75%, indicating a significant correlation between experimental and projected values. Rz) are likewise shown to be extremely near to the experimental values, indicating the importance of the models established. In grey relational analysis, the improvement of grey relational grade from initial parameter combination (d2–f3–v4) to optimum parameter combination (d1–f1–v3) is determined to be 0.3093. Optimal parametric combinations for multi-responses reduce flank wear (VBc) and surface roughness parameters (Ra and Rz) by 1.9, 2.32, and 1.5 times. The multilayer TiN coated carbide inserts have a tool life of 47 minutes at their ideal level. It reduces downtime and boosts savings.

Sahoo, P. (2011) [42] applied Taguchi's design of experiment methodology and regression analysis for optimization of process parameters in turning AISI 1040 steel using coated carbide insert under dry environment. The surface roughness and material removal rate were studied using an L9 standard orthogonal array design with three process parameters: cutting speed, feed, and depth of cut. The ideal process parameters for surface roughness based on S/N analysis are: Cutting speed at level 3, feed at level 1, and depth of cut at level 3 (v3-f1-d3). Similarly, the ideal material removal rate process parameters are: Cutting speed at level 3, feed at level 3, and depth of cut at level 3 (v3-f3-d3). Cut-off speed is the most important process parameter for surface roughness and material removal rate, followed by feed. The depth of incision has the least effect on both reactions. Individual response mathematical models were built using regression analysis. The greater R2 value of the suggested regression models makes them statistically significant. According to the normal probability plot of the model, residuals follow a straight line, showing that the variables in the model are significant. Simultaneously, the predicted and experimental values are quite near, indicating the models' importance. Grey relational analysis and Taguchi approach were introduced for simultaneous response optimization. The calculated value (0.779) agrees well with the experimental value (0.821), and the change in grey relational grade from the initial parameter combination (v2-f2-d2) to the best parameter combination (v3-f3-d2) is 0.284. This shows the recommended methodology's improvement.

Sarıkaya, M., & Güllü, A. (2015) [43] presented an approach for optimization of machining parameters with multi-response outputs using the design of experiments in turning. The experimental design used Taguchi's L9 orthogonal array. Process performance parameters such as flank wear, notch wear, and surface roughness were monitored during the turning of cobalt-base superalloy Haynes 25. The process parameters cutting fluid (CFs), fluid flow rate (Q), and cutting speed (Vc) were adjusted concurrently using Taguchi-based grey relational analysis (GRA). To find the optimal combination, Taguchi's signal-to-noise ratio was used. Response surface regression was used to generate three mathematical models. According to the multi-response optimization findings, the best combination was vegetable base cutting fluid, 180 mL/h fluid flow rate, and 30 m/min cutting speed to reduce tool wear patterns and surface roughness. The percentage improvement in GRG with multiple replies was found to be 39.4%. This strategy definitely enhanced the performance metrics.

Selvakumar, S., & Ravikumar, R. (2014) [44] attempted to investigate the effect of process parameters cutting speed, feed rate, and depth of cut on tool wear and surface roughness in micro-turning of titanium alloy using Cermet insert. The studies use rotatable second-order Box-Behnken design and response surface methods. Optimal micro-turning conditions need a mathematical model that predicts tool wear and surface roughness. The best process parameters were found using analytical and graphical optimization approaches. The feed rate has the greatest impact on tool wear and surface roughness, followed by cutting speed and depth of cut. The following cutting settings reduce tool wear and surface roughness: 3180 rpm cutting speed, 8 m/rev feed rate, and 15 µm depth of cut.

Shihab, S. K., et al. (2014) [45] attempted to investigate the effect of cutting parameters (cutting speed, feed rate, and depth of cut) on the cutting temperature in hard turning of AISI 52100 alloy steel using multilayer coated carbide (TiN/TiCN/Al2O3/TiN) insert. Central Composite Design (CCD) was utilized to gather data on machining. Several diagnostic tests were run to verify assumptions. The significance of the cutting parameters was assessed using ANOVA (ANOVA). Proposed model equation for predicting cutting temperature. The ideal cutting parameters were determined using RSM. The ANOVA findings show that all three cutting factors affect cutting temperature. The cutting temperature is very sensitive to cutting speed and feed rate within the tested range. The optimized model suggested that the traditional turning technique was 100% desirable for the economy. The regression equation's predicted values for cutting temperature were found to be quite close to the experimental values.

Singh, D., & Rao, P. V. (2007) [46] investigated the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning of the bearing steel (AISI 52100). The cutting tools were mixed ceramic inserts composed of aluminium oxide and titanium carbonitride (SNGA) with varying nose radius and effective rake angles. The feed determines the surface finish, followed by the nose radius and cutting velocity. Although effective rake angle has little influence on surface quality, the relationship between nose radius and effective rake angle is important. Using the response surface technique, mathematical models for surface roughness were created.

Subbaiah, K. V., et al. (2020) [47] attempted to evaluate the performance of wiper ceramic cutting insert and observe the influence of hardness on Arithmetic Mean Roughness (Ra), Mean depth of roughness (Rz), Total roughness (Rt) and Tool wear (Vb) during the hard turning of AISI4340 steel. Twenty-seven trial runs were designed using the Response Surface Methodology and completed on a CNC lathe. An analysis of variance is used to assess the input parameters' relevance and contribution percentages. The Response Surface Methodology was used to build mathematical models for surface roughness and tool wear. The results show that hardness and feed rate affect surface roughness and tool wear. Finally, using the Desirability function, the experimental data was used to forecast ideal machining settings for multiple response factors optimization.

Yurtkuran, H., et al. (2016) [48] focused on a predictive model for *Ra* and optimization of cutting conditions in high speed hard turning of X40CrMoV5-1 steel by CBN insert. Cutting parameters include cutting speed, feed rate, depth of cut, and coating condition. The Taguchi L32 orthogonal array was used in the studies. Multiple regression analysis has established a first-order mathematical model for the Ra. In dry-cutting optimization research, the feed rate was shown to be the most important negative factor for Ra. The uncoated CBN insert and lower feed rate produced the best surface roughness.

Zahia, H., et al. (2015) [49] focused on the exploitation of the response surface methodology (RSM) to determine optimum cutting conditions leading to minimum surface roughness and cutting force components. An effective statistical model for evaluating the development of surface roughness and cutting forces is created using RSM. Using a PVD-coated ceramic insert, various cutting conditions were tested on hardened steel alloy (AISI 4140) (56 HRC). The surface roughness and cutting force equations were obtained using experimental data and analysis of variance (ANOVA). The findings are expressed as mean values and confidence intervals. The feed rate and depth of cut have the greatest impact on surface roughness and cutting forces. Also, it should be noted that surface roughness is connected to cutting speed, while the depth of cut is related to cutting force development. The ideal machining settings determined in this research reduce cutting force components (Fa, Fr, Ft) by 6.88, 3.65, and 19.05 percent. The letters are compared to starting cutting parameters for hard turning AISI 4140 steel.

By referring to various articles we can conclude that optimization of cutting parameters such as cutting speed, feed rate, and depth of cut are not done for hard AISI M7 material with coated carbide tool using utility concept of multi-response optimization. The material hardness will be 62 to 64 HRC for further investigation of our work.

PROPOSED METHODOLOGY

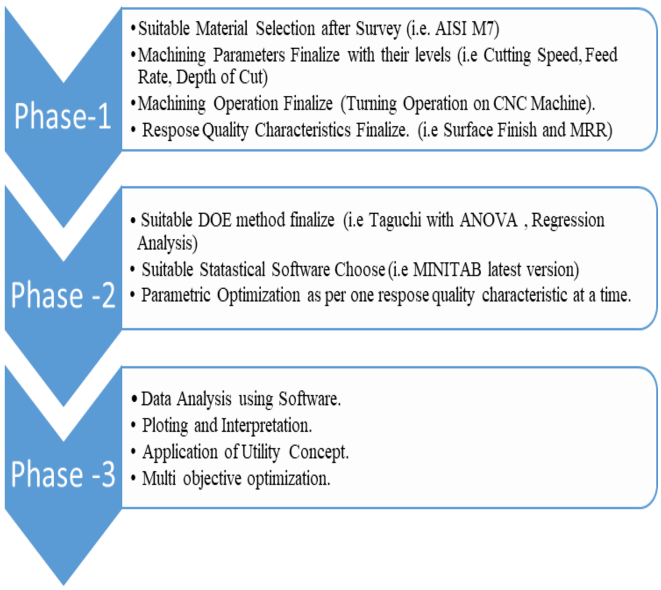

Figure 1. Proposed Research Methodology

During the investigation on parametric optimization of machining parameters for AISI M7 hard material (62 to 64 HRC). turning operation, we are going to follow the above steps. This is the proposed methodology for investigation so nominal changes in steps may possible.

CONCLUSION

It can be concluded that optimization of cutting parameters such as cutting speed, feed rate, and depth of cut are not done for hard AISI M7 material with coated carbide tool using utility concept of multi-response optimization. The material hardness will be 62 to 64 HRC.

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