A Review on Surface Hardness Optimisation Through Controllable Factors in Turning Operation

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Abstract. Surface hardness is a critical quality attribute in machined components, directly influencing wear resistance, fatigue strength, and overall performance. Optimizing surface hardness during turning operations is essential for achieving superior product quality and extending component lifespan. This study reviews advancements in optimizing surface hardness through controllable factors such as cutting parameters, tool material and geometry, workpiece properties, cooling and lubrication techniques, and machining environments. Experimental design methodologies, including Taguchi methods and Response Surface Methodology (RSM), alongside modeling techniques like Finite Element Analysis (FEA) and machine learning, are explored. The review highlights significant findings, identifies gaps in existing research, and emphasizes the importance of sustainable and hybrid approaches for achieving optimal surface hardness. Emerging trends, such as the integration of AI and IoT in machining, are also discussed, offering insights into future directions for improving surface quality and operational efficiency in turning processes.

***Keywords:* -** Surface hardness, RSM, FEA, Optimization.

Introduction

Surface hardness is a vital characteristic in machined components, playing a key role in determining their wear resistance, fatigue life, and overall mechanical performance. In industrial applications such as aerospace, automotive, and precision manufacturing, achieving an optimal surface hardness during machining operations is essential to meet stringent quality and durability requirements.

Turning, one of the most widely used machining processes, offers a versatile and efficient method for shaping components. The quality of the machined surface, particularly its hardness, is influenced by several controllable factors, including cutting speed, feed rate, depth of cut, tool material and geometry, and the use of cooling and lubrication systems. These factors not only affect the surface properties but also contribute to the overall machining efficiency and tool life.

The optimization of surface hardness in turning operations is a complex process that involves understanding the interplay between machining parameters, workpiece material properties, and external environmental conditions. Advanced methodologies, such as experimental design techniques (e.g., Taguchi methods and Response Surface Methodology) and modeling approaches (e.g., finite element analysis and machine learning), have been employed to identify optimal settings and predict outcomes effectively.

II. Literature Review

Adel Mahammod Hassan et al (2000), In this exploration paper determine the impact of machining parameters and work piece hardness on surface harshness of machined segments and to build up a superior comprehension of the impact of procedure parameters on the machined surface. The gathered information was broken down utilizing parametric investigations of difference (ANOVA) with surface completion as the needy variable and hardness of the work piece material, cutting instrument position from the outside of the clipping gadget (hurl), profundity of cut, cutting speed, and cutting feed as free factors. The outcomes demonstrated that surface harshness is altogether influenced by the work piece hardness, cutting feed, cutting pace, profundity of cut, cutting instrument position from the toss, and their associations with one another.[1]

J. Paulo Davin et al (2001) This exploration paper has a note on the assurance of ideal cutting conditions for surface completion got utilizing structure of analysis. He found the impacts of cutting condition on surface completion with controlled parameter feed, cutting speed, profundity of cut. He found the connection between's these parameters.[2]

Hari singh et al (2006) In this exploration paper the ideal setting of turning parameters (cutting pace, feed rate, profundity of cut) bringing about an ideal estimation of feed power when machining EN 24 steel with TiC tungsten covered carbide embeds. The impact of chosen turning parameters on feed power and consequent ideal setting of parameters have been practiced utilizing Taguchi parameters configuration approach.[3]

S. Thamizhmanii, et al (2007) Purpose of this exploration work is focussed on the examination of ideal slicing condition to get lower surface unpleasantness in turning activity by Taguchi technique.[4]

G. Akhyar, et al (2008) In this paper it is demonstrates that the nature of configuration can be improved by improving quality and efficiency in broad exercises. Taguchi's parameter configuration is a significant apparatus for hearty structure, which offers a straightforward and methodical way to deal with streamline a plan for execution, quality and cost.Taguchi improvement strategy is connected to streamline cutting parameters in turning. The turning parameters assessed are cutting velocity of 55, 75, and 95 m/min, feed pace of 0.15, 0.25 and 0.35 mm/rev, profundity of cut of 0.10, 0.15 and 0.20 mm and device evaluations of K313, KC9225 and KC5010, each at three levels. The investigation of results demonstrate that the ideal mix of parameters are at cutting pace of 75 m/min, feed pace of 0.15 mm/min, profundity of cut of 0.10 mm and apparatus evaluation of KC9225. [5]

Sijo M. T. et al (2010) In this examination paper Taguchi parameters streamlining philosophy is connected to cutting parameters in turning. The turning parameters assessed are cutting speed, feed rate, profundity of cut, nose range of hardware and hardness of material each at two levels. The consequence of examination demonstrates that the feed rate, cutting speed and nose span have present noteworthy commitment superficially unpleasantness and profundity of cut and hardness of material have less critical commitment superficially harshness.[6]

PD Kambl et al (2011) In this paper an endeavour is made to survey the writing on enhancing the machining parameters in turning Processes. Different customary methods utilized for machining streamlining incorporate geometric programming geometric in addition to direct programming, Non-Linear Programming, objective programming, consecutive unconstrained minimization system and dynamic programming and so on. The most recent systems for advancement incorporate fluffy rationale, disperse search strategy, subterranean insect settlement procedure, hereditary calculation, Taguchi procedure and reaction surface philosophy are being connected effectively in modern applications for ideal choice of procedure factors in the territory of machining. Taguchi strategies is most recent plan systems generally utilized in ventures for making the item/process heartless toward any wild factors, for example, natural factors.[7]

Suleiman Abdulkareem et al (2011) In this examination work shows an exploratory examination of the impact of the three most significant machining parameters of profundity of cut, feed rate and shaft speed on surface unpleasantness during turning of mellow steel. In this investigation, the structure of trial which is an incredible asset for trial configuration is utilized to enhance the machining parameters for compelling machining of the work piece.[8]

Dr.S.S.Chaudhari, et al ( )The presentation of the made items is frequently assessed by a few quality attributes and reactions and trial systems. In the present examination a solitary trademark reaction enhancement model dependent on Taguchi Technique is created to improve process parameters, for example, speed, feed, profundity of cut, and nose span of single point cutting apparatus. Taguchi's L9 symmetrical cluster is chosen for exploratory arranging. The exploratory outcome investigation demonstrated that the blend of larger amounts of cutting velocity, profundity of cut and lower level of feed is fundamental to accomplish concurrent augmentation of material expulsion rate and minimization of surface unpleasantness.[9]

Puneet mangla, et al (2011) In this examination work the connection between change in hardness caused on the material surface because of turning activity as for various machining parameters cutting velocity, feed, profundity of cut has been explored. Taguchi strategy has been utilized to design the investigation. EN 9 and Aluminium chose for work piece material and covered carbide instrument as an apparatus material.[10]

K. Mani Lavanya et al (2013) maker are investigating the parameters affecting the obnoxiousness of surfaces conveyed in the turning strategy for the material AISI-1016 Steel. Structure of examinations was coordinated for the assessment of the effect of the turning parameters, for instance, cutting pace, feed rate and significance of cut externally cruelty. The eventual outcomes of the machining tests for AISI-1016 were used to portray the standard factors affecting surface obnoxiousness by the Analysis of Variance (ANOVA) method. The feed rate was seen to be the most gigantic parameter affecting the surface repulsiveness in the turning method been plotted.[11]

Rahul Davis et al (2014) Surface completion is one of the indispensable worries during machining of different materials in the machining tasks. In this manner it is fundamental for controlling the required surface quality to have the decision of streamlined cutting parameters. The present trial study is worried about the streamlining of cutting parameters (profundity of cut, feed rate, axle speed) in wet turning of EN24 steel (0.4% C) with hardness 40+2 HRC. In the present work, turning activities were completed on EN24 steel via carbide P-30 cutting device in wet condition and the mix of the ideal degrees of the parameters was gotten. The Analysis of Variance (ANOVA) and Signal-to-Noise proportion were utilized to think about the presentation attributes in turning activity. The consequences of the investigation demonstrate that none of the elements was observed to be huge. Taguchi technique demonstrated that feed rate pursued by profundity of cut and shaft speed was the mix of the ideal degrees of variables while turning EN24 steel via carbide cutting device. The outcomes gotten by this examination will be valuable to other comparative sort of study and can be useful for further inquire about on apparatus vibrations, cutting powers and so on.

S. K. Madhavi (2015) - study is to improve sturdiness and hardness of building material by changing the machining parameters of turning process. By applying Taguchi technique, the nature of produced products, and building structures are created by examining varieties. In this work, an endeavour has been made to tackle the connected numerous criteria advancement issue of turning process by considering three distinctive procedure parameters viz. cutting-speed, feed and profundity of cut. Dim Relational Analysis has been embraced to change over various targets of the enhancement issue into a solitary target work, signified as Gray Relational Grade. The general Gray Relational Grade has been enhanced by utilizing Taguchi technique. Examination of fluctuation (ANOVA) has been led for Gray social evaluation (GRG) to locate the ideal procedure parameters. Sign to Noise (S/N) Ratio has been found for GRG to locate the ideal degrees of the procedure parameters. At long last an adaptation test has been made for three distinct materials and the outcomes have been plotted. [13]

Mahadev Naik (2016) - In the cutting edge world the nature of surface completion is most significant necessity for some, turned work piece because of which makers are trying to stay focused in market. Taguchi parameter configuration is useful asset and productive strategy for advancing quality and execution yield of assembling process. This paper researches the parameters influencing the surface unpleasantness produce in turning process for material AISI 410 Stainless Steel. Plan of investigation was led for examination of impact of the turning parameters, for example, axle speed, feed, and profundity of cut on Surface harshness. The aftereffects of the machining. Experiments for AISI 410 Stainless Steel where used to portray the principle components influencing the surface unpleasantness by the Analysis of Variance (ANOVA) strategy. The feed rate was observed to be the most noteworthy parameter impacting the surface unpleasantness in turning process. Affirmation Test additionally has been performed to foresee and check the ampleness of model for deciding ideal attributes of reaction. The outcome gotten by above strategy will be helpful to other research works for comparative kind of concentrate for further inquire about on device vibrations, cutting powers, rake point and so on.[14]

S. Mohan Kumar (2017) Manufacturing of any item requires distinctive machining procedures to get The ideal completed segment. This task alludes to the streamlining of procedure parameters in turning procedure utilizing Taguchi technique (L9) so as to acquire proficient Material Removal Rate (MRR). EN 24 is utilized as workpiece for doing trial to advance Material Removal Rate which is affected by three machining parameters to be specific shaft speed, feed rate and profundity of cut. Various trials are finished by fluctuating one parameter and keeping other two fixed so that streamlined estimation of every parameter can be acquired. In this task dry turning activity of EN 24 evaluated steel is performed utilizing HSS apparatus. The scope of cutting parameters at three levels are axle speed (200, 350 and 500 rpm), feed rate (0.1, 0.15 and 0.2 mm/rev), profundity of cut (1.0, 1.5 and 2.0 mm) separately. Taguchi technique is a decent strategy for streamlining of different machining parameters as it decreases number of examinations. Taguchi symmetrical exhibit is planned with three degrees of procedure parameters and ANOVA is connected to know the impact of every parameter on Material Removal Rate. For the given arrangement of conditions, axle speed impacts more on Material Removal Rate pursued by feed rate and profundity of cut.[15]

Mukesh et al ( ) In this research, the Taguchi method was employed to optimize feed force and cutting force during the turning of EN 8 steel. The input process parameters considered were feed rate, spindle speed, and depth of cut. Experiments were conducted using Taguchi's L9 orthogonal array. ANOVA (general linear model) and Signal-to-Noise ratio analysis were utilized to determine the optimal process parameters. The results revealed that depth of cut had the most significant impact on feed force, followed by feed rate and spindle speed.[16]

Bhat, R et al (2022) The hardness of all samples is assessed after the aging process. Calcium carbonate plays a critical role, as higher moisture content consistently leads to a reduction in the composite's hardness. After 60 days of aging, the hardness of 6 mm, 8 mm, and 10 mm composites decreased by 25.64%, 10.92%, and 4.63%, respectively, compared to untreated material. This reduction is primarily attributed to microstructural changes, including increased porosity.[17]

Barkur Shrinivasa Somayaji et al (2024) Taguchi's analysis confirmed the findings and emphasized opportunities for process optimization. Grey relational analysis identified that the optimal combination of parameters included a speed of 130 m/min, a feed rate of 0.1 mm/rev, a depth of cut of 0.15 mm, and minimal quantity lubrication (MQL) as the coolant flow method. This combination achieved the highest GRG value of 0.704, ranking first among all tested parameter sets. The results highlighted that superior outcomes were generally achieved with higher speeds, lower feed rates, and moderate depths of cut under MQL conditions, offering valuable guidance for enhancing machining processes.[18]

III. Research Gap

This paper aims to provide a comprehensive review of the latest advancements in surface hardness optimization during turning operations. It explores the impact of various controllable factors, evaluates the effectiveness of different optimization techniques, and discusses emerging trends, including sustainable machining practices and the integration of smart technologies. By synthesizing findings from recent studies, this review seeks to guide future research and industrial practices toward achieving superior surface hardness and machining efficiency

IV. Problem Formulation

In modern machining processes, achieving optimal surface hardness in turned components is a critical challenge due to the diverse range of factors influencing the machining outcome. Surface hardness is directly tied to the functional performance of a component, impacting its wear resistance, fatigue strength, and dimensional stability. However, determining the ideal combination of controllable factors in turning operations to achieve the desired surface hardness remains a complex task.

The primary issues arise from the interdependent nature of the influencing parameters, which include:

1. **Cutting Parameters:** Variations in cutting speed, feed rate, and depth of cut can significantly alter the thermal and mechanical conditions at the cutting zone, directly affecting surface hardness.
2. **Tool Geometry and Material:** The material and design of the cutting tool, including rake angle, nose radius, and coatings, influence the machining forces and heat generation, thereby impacting the workpiece surface characteristics.

3. **Workpiece Material Properties:** Different materials exhibit varied responses to machining, depending on their hardness, thermal conductivity, and microstructure.
4. **Cooling and Lubrication:** The choice of cutting fluids, lubrication methods, or the absence of lubrication in dry machining can alter the cooling rate and friction at the tool-workpiece interface.
5. **Machine and Environmental Factors:** Rigidity of the machine tool, vibration control, and external temperature conditions also play a significant role.

V. Conclusion

Optimizing surface hardness in turning operations is a multifaceted challenge that requires careful consideration of various controllable factors, including cutting parameters, tool material and geometry, workpiece properties, and cooling techniques. This review highlights that achieving optimal surface hardness involves a balance between these factors to ensure enhanced mechanical properties and improved product performance. Advanced methodologies, such as the Taguchi method, Response Surface Methodology (RSM), and soft computing techniques, have proven effective in identifying and optimizing these factors.

Emerging technologies, including artificial intelligence and IoT-enabled machining, offer promising opportunities to further enhance the precision and efficiency of optimization processes. However, gaps remain in understanding the interplay between less-studied variables, such as unconventional cooling methods and hybrid machining environments. Future research should focus on sustainable machining practices, the development of robust predictive models, and the integration of real-time monitoring systems to address these gaps.

By adopting a holistic and innovative approach to optimization, manufacturers can achieve superior surface hardness, contributing to enhanced durability, efficiency, and sustainability in critical industrial applications.

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