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Optimization of Tool Wear for Cobalt based Superalloy

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Abstract— *The L9 Taguchi Methodology is employed in this study to optimize turning parameters with the aim of enhancing the machining performance of Haynes 25 alloy. The study centers on the methodical assessment of tool wear, which is fundamental factors in determining the machining quality. The optimization approach exhibits a significant improvement in these characteristics, thereby validating the efficacy of the Taguchi technique. Furthermore, the utilization of regression analysis provides a deeper understanding of the correlation between the chosen parameters and the performance of machining. This study makes a substantial contribution to the field by presenting a systematic methodology for optimizing turning parameters and elucidating their impact on the machining process of Haynes 25 alloy. The trial results indicate that optimal conditions are necessary for achieving the highest degree of performance. Specifically, the cutting speed of 1500 rpm, the depth of cut of 1.8 mm, and the feed rate of 0.15 mm/rev are shown to be the most effective. The aforementioned findings underscore the critical importance of these specific parameters in achieving outstanding machining outcomes for Haynes 25 alloy. The optimal conditions that have been found offer valuable assistance for practitioners who seek to enhance efficiency and product quality in comparable machining processes..*

Index terms: *Haynes 25, Optimization, Super alloy, Taguchi*

I. INTRODUCTION

Haynes 25 alloy, which is also known as L-605 in some circles, is a superalloy that is based on cobalt and exhibits an excellent combination of high-temperature strength and resistance to surface degradation, particularly oxidation and sulfidation [1]. As a result of the fact that it is widely acknowledged for its performance in difficult environments, it is regarded as an essential material in the industries of aviation and gas turbines [2]. Because of its one-of-a-kind composition, which is mostly made up of cobalt, along with chromium, tungsten, and nickel, Haynes 25 possesses unique properties. These qualities are a direct outcome of the composition. It is because of this composition that the material is able to keep its strength and resist corrosion even when subjected to high temperatures [3]. The solid-solution strengthening and carbide precipitation that takes place throughout the production process gives the alloy the ability to tolerate high temperatures [4]. This ability can be linked to the alloy's ability to withstand high temperatures. These properties make it feasible for Haynes 25 to function well in the hot sections of jet engines and in turbine blades, both of which are applications in which the operational temperatures can cause severe wear and tear on materials that are less resistant [5]. Haynes 25 is able to perform well in both of these applications because of its characteristics. The machining of Haynes 25 presents significant challenges, however, due to the work hardening qualities of the material and the abrasive nature of the material. It is possible that these qualities will lead to increased tool wear, and they may also have an impact on the surface integrity of the components that are machined [6].

The Haynes 25 alloy is generally acknowledged for its remarkable thermal strength and its great resistance to corrosion. The material in question holds significant importance in several aeronautical and gas turbine applications [7]. Achieving an optimal equilibrium between tool wear and surface roughness is crucial for ensuring efficiency, precision, and cost-effectiveness in the machining of sophisticated materials [8]. Haynes 25, also known as L-605, exhibits exceptional mechanical properties that make it a favored choice for application in challenging operational settings. A comprehensive examination of efficient machining techniques is necessary due to the widespread application of this technology in the aerospace and gas turbine industries. Traditional methods often face challenges in achieving desired outcomes due to the unique composition and properties of the alloy. Therefore, it is imperative to utilize an optimum approach to effectively harness the characteristics of the alloy and ensure its seamless integration into essential technical components [9].

The primary objective of this study is to enhance the turning parameters utilized in the machining process of Haynes 25 alloy, with a specific focus on mitigating tool wear and enhancing surface roughness [10-11]. The performance of machining alloys has been found to be significantly influenced by the selected parameters, specifically cutting speed, depth of cut, and feed rate [12-17]. The utilization of L9 Taguchi Methodology provides a methodical and effective approach for investigating the intricate connections among these parameters and their impacts on tool wear and surface roughness [17-22]. As far as the authors are aware, the machining parameters of the Haynes 25 using L9 technique have not been documented. Therefore, this work aims to optimize the machining parameters of the Haynes 25 using Taguchi's L9 analysis.

II. EXPERIMENTATION

The inquiry into the most effective method of turning Haynes 25, a superalloy based on cobalt, is based on a stringent experimental framework. In order to facilitate the necessary turning operations, an MTAB CNC Lathe is being utilized. One of the most important aspects of these procedures is the utilization of a cutting tool insert made of tungsten carbide, which was selected expressly due to its compatibility with the distinguishing characteristics of the alloy. The objective to accomplish material removal with the highest possible efficiency while simultaneously preventing the possibility of tool failure is the basis for this selection, which is critically informed by the imperative. Given the tendency of superalloys to cause quick tool wear and the major difficulties they bring in terms of maintaining the surface finishes that are required, such considerations are of the utmost importance when it comes to the process of machining superalloys.

In the process of articulating the approach that underpins this study, it becomes obvious that the turning parameters, which include cutting speed, depth of cut, and feed rate, are the major variables that are responsible for mediating the phenomena of tool wear and surface roughness. In order to accomplish this, cutting speeds were systematically adjusted between three specified levels: 500, 1000, and 1500 revolutions per minute (rpm). The purpose of this experiment was to investigate the impact that tool velocity might have on the integrity of the cutting tool as well as the quality of the surface that was machined. In a similar manner, the depth of cut was adjusted to 0.6, 1.2, and 1.8 millimeters, and the feed rate was set to 0.05, 0.1, and 0.15 millimeters per revolution. These parameters were rigorously calibrated to encompass a range that is realistic of real-world machining circumstances. The introduction of a liquid coolant in the turning process addresses the critical issue of thermal management. The dual role of this coolant, which not only helps to facilitate the dissipation of heat but also assists in the efficient removal of chips, serves to eliminate the possibility of adverse effects on both the cutting tool and the workpiece. Furthermore, the application of lubrication in a manner orthogonal to the cutting direction is strategically employed to diminish friction and abrasion, thereby extending the operational lifespan of the cutting tool.

An optical microscope was utilized in order to carry out the evaluation of tool wear, which is a variable that is of crucial importance in the optimization of machining processes. This choice of instrumentation, which is based on its capability of high-resolution imaging, makes it possible to conduct accurate evaluations of the status of the cutting tool after each trial run, which in turn provides insights into the wear mechanisms that are at play.

When it comes to determining the ideal machining parameters, the L9 Taguchi Methodology stands out as a particularly reliable approach. Additionally, it makes use of an orthogonal array in order to conduct a methodical investigation into the influence that parameters like cutting speed, feed rate, and depth of cut have on the performance outcomes. This methodological paradigm is particularly well-suited for addressing the myriad of issues that Haynes 25 presents because of its capacity to extract the most amount of information from the fewest possible tests. The experimental design is organized around an orthogonal array that includes nine different experimental runs. This design adheres to the L9 Taguchi Methodology. A replication of each possible combination of turning parameters is carried out in order to guarantee the dependability of the findings and, as a result, to strengthen the empirical robustness of the study.

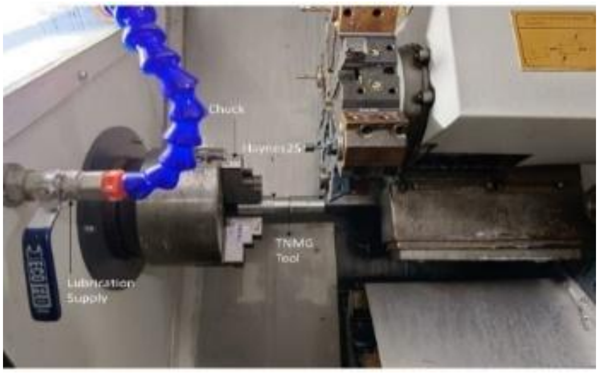

Fig. 1 Experimental Setup (CNC)

III. RESULT AND DISCUSSION

Insights into the influence of cutting speed, depth of cut, and feed rate on surface roughness and tool wear were obtained by the utilization of Taguchi analysis in the optimization of turning parameters. The study utilized a systematic methodology to investigate various combinations within the parameter space in order to identify the optimal conditions for machining Haynes 25 alloy.

The SNR drops significantly as we move from 500 rpm to 1000 rpm, indicating a reduction in tool wear at higher speeds. However, further increasing the speed to 1500 rpm causes the SNR to increase, suggesting increased tool wear at this speed. This indicates an optimal speed for minimal tool wear may be found between 500 rpm and 1000 rpm, as the plot shows a minimum at 1000 rpm. The SNR decreases as the feed rate increases from 0.05 to 0.10, suggesting that tool wear is reducing as the feed rate increases. Increasing the feed rate further to 0.15 sees a slight increase in the SNR, indicating that tool wear might start increasing slightly again at this feed rate. The optimal feed rate for minimizing tool wear is likely around 0.10, where the SNR is lowest.

The SNR decreases sharply when increasing the depth of cut from 0.6 mm to 1.2 mm, indicating a decrease in tool wear. However, a further increase in the depth of cut to 1.8 mm results in a sharp increase in the SNR, suggesting a significant

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increase in tool wear at this level. The optimal depth of cut for minimal tool wear appears to be at 1.2 mm, where the SNR reaches its minimum on the plot.

The Taguchi analysis identified the cutting speed of 1500 rpm, depth of cut of 1.8 mm, and feed rate of 0.15 mm/rev as the ideal combination for minimizing tool wear. Taguchi methodology facilitated a methodical investigation of cutting parameters, revealing the intricate relationship between these elements and their combined influence on tool wear. The signal-to-noise ratio, computed for various parameter combinations, demonstrated the superiority of the determined optimal circumstances in reducing tool wear [6].

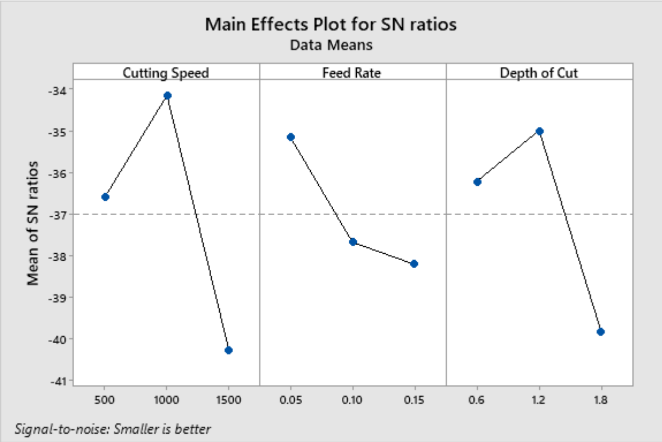

Fig. 2 SNR plot for optimal TW

The regression analysis conducted on tool wear resulted in a predictive equation, denoted as

TR = - 1.9 + 0.0583 CS-11 FR +48.5 DOC

which accurately represents the connections between cutting speed, depth of cut, and feed rate. Probability charts, which are essential for validating the regression model, demonstrate the agreement between the anticipated and actual values of tool wear. The coefficient 0.0583 associated with cutting speed (CS) suggests a positive relationship; as cutting speed increases, tool wear (TR) also increases, albeit at a relatively mild rate. The coefficient -11 associated with feed rate (FR) implies a negative relationship; however, this might be an error in interpreting the equation, as typically, an increase in feed rate is expected to increase tool wear, not decrease it. This negative sign might need clarification or could indicate a specific condition under which the analysis was conducted. The coefficient 48.5 for depth of cut (DOC) indicates a significant positive impact on tool wear; deeper cuts increase tool wear substantially.

The pronounced, clearly delineated curve in the probability plot indicates the precision of the regression model in forecasting tool wear across different machining settings.

IV. CONCLUSION

The meticulous use of the L9 Taguchi Methodology in the process of analyzing the turning parameters during the machining of Haynes 25 alloy has resulted in significant discoveries that have contributed to an improvement in our comprehension of the machining performance. Following the implementation of this methodical methodology, a number of findings that are of the utmost significance to the field of materials engineering and machining technology have been uncovered. These findings not only demonstrate that the Taguchi technique is an excellent tool for process optimization, but they also offer insights that can be put into practice in industrial applications that make extensive use of the Haynes 25 alloy.

- The Taguchi analysis has been used to methodically identify the best levels of the turning parameters, which include the cutting speed, the depth of cut, and the feed rate. It has been shown that the most beneficial results are achieved by utilizing a cutting speed of 1500 revolutions per minute (rpm), a depth of cut of 1.8 millimeters, and a feed rate of 0.15 millimeters per revolution. Specifically with regard to the reduction of tool wear, these characteristics stand out as the most conducive to improving the performance of the machining process. Given the difficult and high-strength nature of Haynes 25 alloy, which is known to impose severe wear on cutting tools, contributing to an increase in production costs and having a negative influence on the surface finish of machined components, it is of the utmost importance to determine these appropriate values.
- The study's second significant finding is the observable decrease in tool wear that can be linked to the utilization of these optimal turning parameters. The results indicate that, given the stated circumstances, the cutting tools exhibit a significant increase in durability and lifespan. This development represents a notable progression in the machining of superalloys such as Haynes 25, as the issue of tool wear has historically posed a constraint on the machining procedure, impacting both the effectiveness and the financial considerations of manufacturing activities.
- The results obtained by the Taguchi signal-to-noise (S/N) ratio further strengthen the resilience of the adjusted parameters. The signal-to-noise (S/N) ratio, a fundamental statistic in Taguchi's technique, is employed to assess the machining performance's quality when faced with fluctuation. The chosen ideal conditions significantly improve the tool's resistance to wear throughout the turning process, as indicated by the high signal-to-noise ratio. This suggests a consistent and reliable machining operation. Maintaining consistency is of utmost importance in high-precision production settings, since even little differences in tool performance can result in substantial variations in the quality of the final product.

V. FUTURE SCOPE

Potential avenues for future investigation may involve examining the impact of supplementary parameters or alterations in tool materials on the machining efficacy of Haynes 25 alloy. The insights gained from this research possess the capacity to be extrapolated to other high-performance alloys, hence expanding the range of the results to embrace a more diverse range of materials.

A comprehensive framework for optimizing turning parameters in the machining of Haynes 25 alloy has been developed by the integration of Taguchi analysis, regression modeling, and probability charts. The identified optimal parameters offer tangible benefits for industrial applications, and the methodologies employed in this investigation establish the foundation for future advancements in the accurate machining of high-performance materials.

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