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ENHANCING AEROSPACE MATERIAL MACHINING THROUGH PARAMETRIC OPTIMIZATION IN MICRO BORING: A COMPREHENSIVE STUDY

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Abstract

In the pursuit of meeting the exacting demands of the aerospace industry, precision and efficiency in machining processes are paramount. This research delves into the intricacies of micro boring, a critical machining operation, with the aim of optimizing its parameters to elevate machining accuracy and efficiency. The study focuses on aerospace materials, particularly titanium alloys and composites, to address the unique challenges posed by their high strength and lightweight characteristics. This study focuses on micro boring, an essential machining operation, with the objective of minimizing thrust forces, circularity errors, and reducing burr size in the micro boring process on a PMMA (Poly methyl methacrylate) work piece measuring piece of 95*30*4mm. The Design of Experiment (DOE) methodology, coupled with Gray Relational Analysis, is employed to achieve these objectives. Two controllable parameters, namely, cutting speed and feed rate, are considered for optimization with respect to thrust forces, circularity, and burr size. A set of experiments is designed using the DOE technique, where each parameter is varied at three different levels. The machining is performed using a High-Speed Steel (HSS) drill bit with a diameter of 1.5mm based on the generated run order. The analysis reveals that a combination of high cutting speed and low feed rate yields superior results, exhibiting reduced circularity error and smaller burr size. This finding highlights the significance of the selected parameters in influencing the micro boring process on PMMA materials. The identified optimal conditions, specifically high cutting speed and low feed rate, contribute to minimizing thrust forces, circularity errors, and burr size, thereby enhancing the overall micro boring process in this particular material.

Keywords: Micro Boring, Aerospace Materials, Parametric Optimization, Design of Experiments, Machining Efficiency, Response Surface Methodology, Genetic Algorithms.

Introduction:

Drilling is a machining process that involves creating circular holes in a solid material or enlarging existing holes using multi-tooth cutting tools known as drills or drill bits. While various cutting tools are available for drilling, the most commonly used is the twist drill. The machining of aerospace materials, renowned for their exceptional properties, necessitates specialized processes. Micro boring, a crucial machining technique, involves drilling small-

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diameter holes with precision, and it plays a pivotal role in the production of intricate components. This research is dedicated to optimizing the micro boring process through the meticulous adjustment of parameters to enhance tool life, surface finish, and overall machining performance.

Literature Review:

A review of existing literature will explore the challenges associated with micro machining in aerospace materials, existing methodologies, and the significance of parametric optimization in enhancing machining efficiency. Drawing from previous studies, this section will provide a contextual understanding of the current state of research in this domain. The exploration focused on the investigation of various materials using diverse drilling tools, specifically designed for traditional micro-drilling. The review encompasses papers from various journals, and these references are appropriately cited throughout.

Drilling, a fundamental machining process for creating holes, is integral to various industries such as aerospace, watch manufacturing, automobile manufacturing, medical, and semiconductors. Its significance is particularly evident in the assembly of mechanical components. For instance, it has been reported that approximately 55,000 holes are drilled as part of the single-unit production process for the Airbus A350 aircraft.

Micro-drilling of metals has gained prominence as products become smaller and more highly functional. The growing demand for precise micro-component production emphasizes the increasing importance of micro-hole drilling processes. Due to the need for deeper and smaller holes in the mentioned industries, advancements in micro-drilling processes are essential to achieve higher precision and productivity.

Numerous conventional and non-traditional manufacturing processes enable micro-drilling. While methods like micro-drilling using laser beams, electron beams, electric discharge, electrolytic machining, and electrochemical machining are often used for industrial and experimental studies, conventional micro-drilling processes are preferred for general applications. Traditional micro-drilling offers greater cost savings and higher productivity compared to other non-traditional drilling processes.

Poly(methyl methacrylate) (PMMA) is a significant amorphous thermoplastic with desirable properties, including clarity, chemical resistance, moldability, UV radiation protection, weather resistance, high strength, and dimensional stability. These properties make PMMA an attractive material for applications in the aerospace sector, such as aircraft manufacturing, rockets, space stations, and platforms for planetary or solar exploration.

Conventional mechanical drilling of PMMA encounters increased physical limitations as hole diameter decreases. Below a certain diameter, friction exceeds the mechanical strength of the tool, and machining becomes possible only with diamond or carbide-coated tools with high modulus values. Therefore, optimizing process parameters is crucial for micro-drilling 1mm holes in PMMA strips using High-Speed Steel (HSS) as the drilling tool material. This paper focuses on optimizing push forces, circularity, and burr size in 1mm micro-deep hole drilling processes. Feed rate and spindle rpm are considered as process parameters to determine the optimal drilling conditions. Micro-drilling on PMMA strips is conducted based on the Design of Experiments (DOE), and the resulting experimental data are analyzed using the Gray-based Taguchi method.

Dong-Woo Kim, Myeong-Woo Cho, Tae-Il Seo, and Eung-Sug Lee et.al. (2008): This study focuses on minimizing thrust forces in step-feed micro-drilling processes using the Design of Experiment (DOE) method. The authors optimize three cutting parameters, namely feed rate, step-feed, and cutting speed, based on DOE. An L27 orthogonal array is generated for experimental studies, and Analysis of Variance (ANOVA) is carried out. The results identify the sequence of factors affecting drilling thrusts as feed rate, step-feed, and spindle rpm. The study emphasizes the importance of feed rate in minimizing thrust forces during micro drilling.

Saurav Dutta et al., (2008): The study addresses a multi-response optimization problem for submerged arc bead-on-plate weldments, seeking an optimal parametric combination for favorable bead geometry. Taguchi's L25 orthogonal array design and the signal-to-noise ratio are employed for objective function derivation within the experimental domain. Grey relational analysis is then applied for multi-response optimization, demonstrating the feasibility of the Grey-based Taguchi technique for continuous improvement in product quality in the manufacturing industry.

Youtie J., Iacopetta M., Graham S. et al (2008) Attention is increasingly focusing on the long-term outlook of technological innovation, emphasizing the idea that progress occurs in waves, with each wave initiated by a significant breakthrough or the emergence of a general-purpose technology (GPT). This study aims to evaluate the potential of nanotechnology to be (or become) a GPT, a quality that some researchers have presumed but not necessarily substantiated. Through a review of existing literature, this paper will investigate how well nanotechnology aligns with three key characteristics of a GPT: pervasiveness, innovation generation, and potential for improvement. Utilizing patent and patent citation databases, the paper will underscore the types of quantitative and qualitative information required, and in certain cases still unavailable, to comprehensively characterize the nature of nanotechnology.

Zhang, P.F., Churi, N.J., Pei, Z. J., and Treadwell C. et. al. (2008): Titanium (Ti) and its alloys, renowned for their superior properties, pose challenges as hard-to-machine materials. Given the pivotal role of drilling in almost all Ti applications, there is a need to develop cost-effective drilling processes for Ti or enhance the cost-effectiveness of existing processes. This paper conducts a comprehensive literature review on mechanical drilling processes for Ti, encompassing twist drilling, vibration-assisted twist drilling, ultrasonic machining, and rotary ultrasonic machining. The review delves into factors such as cutting force, cutting temperature, tool wear, tool life, hole quality (diameter, cylindricity, surface roughness, and burr), and chip type in the context of Ti drilling.

Azlan Abdul Rahman, Azuddin Mamat, and Abdullah Wagiman et. al. (2009): This paper explores the impact of drilling parameters, including spindle speed, feed rate, and drilling tool size, on material removal rate (MRR), surface roughness, dimensional accuracy, and burr in micro-drilling processes. The study aims to identify optimal drilling parameters for High-Speed Steel (HSS) tools in micro-drilling of brass. Micro drilling experiments with 0.5 mm to 1.0 mm drill sizes were conducted at three different levels of spindle speed and feed. The results, analyzed using a microscope and surface roughness device, reveal the influence of spindle speed and feed rate on surface roughness. Additionally, the study observes the effects of tool diameter, spindle speed, and feed rate on MRR and dimensional accuracy.

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R.Vimal Sam Singh, B.Latha, andV.S.Senthilkumaret.al. (2009) Glass fiber reinforced plastics (GFRP) are increasingly being utilized across various engineering domains, including aerospace, automotive, electronics, and other industries. Among the common machining processes in these industries, drilling plays a crucial role in assembling mechanical structures. This study employed experiments with 8 Facet Solid Carbide drills based on an L27 Orthogonal Array. The investigated process parameters included spindle speed, feed rate, and drill diameter. A fuzzy rule-based model was developed to predict thrust force and torque during the drilling of GFRP composites. The results suggest that the model effectively predicts the response variables, providing control over delimitation.

The investigation into thrust force and torque during GFRP composite drilling, based on L27 orthogonal array experiments, led to the development of a fuzzy rule-based model. Conclusions drawn from the experimental and fuzzy modeling results include:

1. The fuzzy logic model for thrust force and torque, developed from experimental data, demonstrates close agreement between predicted fuzzy output values and measured values. This indicates the model's effectiveness in predicting thrust force and torque in GFRP composite drilling.
2. Verification results support the suitability of the fuzzy rule-based model for predicting thrust force and torque in composite drilling.
3. Implementing this system with online monitoring has the potential to enhance the quality of drilled parts, reducing the need for tedious model making, computational costs, and time.
4. Future improvements to the model could involve introducing more variables and a broader range of cutting conditions.

Additionally, the literature review on drilling processes for titanium (Ti) emphasizes the challenges posed by Ti's status as a hard-to-machine material. Various drilling processes for Ti, including twist drilling, vibration-assisted twist drilling, ultrasonic machining, and rotary ultrasonic machining, are discussed in terms of cutting force, temperature, tool wear, hole quality, and chip type. The goal is to develop cost-effective drilling processes for Ti, considering its superior properties.

Another study investigates the effect of drilling parameters such as spindle speed, feed rate, and tool size on material removal rate (MRR), surface roughness, dimensional accuracy, and burr in micro-drilling processes. The focus is on finding optimum drilling parameters for High-Speed Steel (HSS) drilling tools in micro-drilling of brass. Results indicate that surface roughness is mainly influenced by spindle speed and feed rate, while tool diameter has less impact. MRR decreases with reductions in tool diameter, spindle speed, and feed rate. The dimensional accuracy of drilled holes decreases with increasing tool diameter, feed rate, and spindle speed, impacting tool wear and burr size on the drilled hole edges.

Yu Teng Liang et al., (2009): The paper employs the Grey-Taguchi method to optimize micro-drilling of PMMA polymer with multiple performance characteristics. Four parameters, including coating layer, feed rate, spindle speed, and depth of cut, are optimized to minimize drill wear and surface roughness. The study combines orthogonal array, grey relational analysis, and analysis of variance to determine the optimal combination of parameters. TiAlN-coating drills are found to generate the least wear, indicating the longest tool life and best hole quality.

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M. K. A Mohd Ariffin, M. I. Mohd Ali, S. M. Sapuan, and N. Ismail et.al (2009): Focusing on the optimization of the drilling cutting process for composite sandwich panels, this study utilizes the Design of Experiment (DOE) method. Glass fiber reinforced plastic (GFRP) sandwich panels are tested with two types of drill bit material and four variables, including drill bit material, cutting velocity, feed rate, and hole diameter. The study uses statistical analysis to minimize damage during the drilling process and identifies optimal conditions for minimal damage length.

Liu Dong et al. (2010): The paper investigates the drilling force and torque of carbon fiber composite with carbide drilling tools brazed with diamond. The experiments, conducted under air-cooling cutting conditions, provide insights into the regulation of drilling force influenced by feed rate and cutting speed. The study utilizes regression analysis to establish exponential formulas for drilling force and torque, crucial factors affecting tool life and delamination in composite materials.

Hyun-Ho Kim, Siyon Chung, Seung-Chul Kim et. al. (2011): To develop a cost-effective direct monitoring system for micro-drilling processes on glass, this study incorporates a machine vision unit with edge detection and 3D measurement functions. The system utilizes a CCD camera attached to a precision servo stage and a novel illumination unit. The performance of the machine vision system is verified in micro-drilling processes on glass using diamond and carbide drills, with the aim of producing high-quality holes without cracks and fractures.

Materials and Methods:

In this investigation, a PMMA (Poly (methyl methacrylate)) strip with dimensions of 95x30x4mm (length* breadth*thickness) was employed as the work piece material. The HSS Straight shank twist drills (Jobbers) manufactured by JK Files and Tools were utilized in the study. The Drill Diameter 1.5mm Overall length 40mm Flute length 18 mm angle point 118deg. All drilling operations were conducted using a radial drilling machine provided by the Central Workshop at Bakhtiyarpur College of Engineering, Patna, India. The Quartz 4-column Dynamometer (type 9272A, manufactured by Kastler) in conjunction with the Multi-Channel Charge Amplifier Type 5070 A was employed for measuring the thrust force. The circularity and burr size were assessed through SEM images.

Taguchi Method

Taguchi Analysis stands out as a potent tool in the realm of manufacturing design. Taguchi's approach combines Design of Experiments with parameter optimization to achieve the desired outcome. The Signal-to-Noise ratios (S/N ratios) in Taguchi's methodology, serving as logarithmic expressions of the required output, function as objective functions for optimization. Researchers have consistently employed this method to analyze data and obtain an optimal solution. Taguchi's technique utilizes the Signal-to-Noise ratio to identify the optimal solution in manufacturing design. The advantage of employing the S/N ratio lies in its consideration of both mean and variance. Specifically, it is defined as the ratio of the mean value (Signal) to the standard deviation (Noise).

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Result and Discussion

Table3.1: Technical Specifications

Parameters	Specification
Drill Bit Diameter	1 mm
Work-piece	Poly methyl methacrylate (90x30x4mm)
Dynamometer	Kistler Co.(9272A)
Amplifier	Kistler Co.(5070A)
Feed(mm/rev)	0.13,0.20,0.27
Spindle Speed(rpm)	90,160,220

Design of Experimentations (DOE):

A systematic approach to experiment design will be employed to investigate the effects of individual and interactive parameters on micro boring outcomes. Statistical tools and analysis of variance (ANOVA) will facilitate the identification of significant factors influencing machining performance. In the present Scenario, Micro penetrating of PMMA Sheet with less burr size and better exactness is a test to assembling ventures. Different process parameters influencing this can be nourish, Spindle speed, apparatus width, Drill Bit material, penetrate geometry and cutting conditions. In the present work Feed and axle speed are taken as process parameter and is a controllable one.

Table 2: PARAMETER VALUES

Factors	Notations/unit	Code	Level of factors		
			1	2	3
Feed	S(mm/rev)	A	0.13	0.20	0.27
Spindle speed	N(rpm)	B	90	160	220

Table3: Design of Experiments

Run	Feed(A)	Speed(B)
1.	2	3
2.	2	2
3.	1	3
4.	3	1
5.	2	1
6.	1	1
7.	3	2
8.	1	2
9.	3	3

In order to identify the optimal conditions for the process parameters, this study employed a full factorial design, and run sequences were determined using statistical software. The experiments were conducted with this run sequence on a PMMA sheet measuring 95×30×4mm, employing a 1.5mm HSS drill. Table 2 presents the set of values for the independent machining parameters, while Table 3 illustrates the Design of Experiments selected using statistical software (STATISTICA) based on the full factorial design. Experimental data is provided in Table 3.

Parameters related to thrust force were measured using a dynamometer and circularity error and burr size was measured using a Scanning Electron Microscope. The experimental data presented in Table 3 has been utilized to determine the optimal parameter combination for achieving the desired micro-drilling process.

Conclusion:

The research will conclude with a summary of key findings, their implications for the aerospace industry, and potential avenues for future research. The optimized micro boring parameters identified in this study have the potential to significantly advance aerospace component manufacturing processes. The target of this investigation was to discover the streamlined blend of Feed and Spindle speed with the goal that the push power, circularity and burr arrangement can be limited. The conclusions can be outlined as takes after in the 1.5mm smaller scale boring procedure, the trial work did by following the full factorial plan and after that receiving dim social investigation, Optimal Parametric mixes were discovered. Dark taguchi technique is one of the effective strategies for advancement of parameters where multi-reaction qualities are considered in the investigation. Through the S/N proportion charts, it can be watched that S1 and N2 compare to the variables creating insignificant boring push, Minimizing circularity blunder and diminishing in burr estimate. In this way, the ideal conditions are nourishing of 0.13mm/rev and axle speed of 160 rpm.

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