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REVIEW ON INFLUENCE OF COOLING TECHNIQUE ON TOOL WEAR IN TURNING OF TITANIUM ALLOY Ti-6Al-4V

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Abstract: In any metal cutting operation, a lot of heat is generated due to plastic deformation of work material, friction at the tool-chip interface and friction between the clearance face of the tool and work piece. The friction in machining (i.e. dry machining) adversely affects the tool wear and quality of the products produced. Thus, effective control of friction in the cutting zone is essential to ensure less tool wear and good surface quality of the work piece in machining. Cutting fluids have been the conventional choice to deal with this problem.

Cutting fluids are introduced in the machining zone to improve the tribological characteristics of machining processes and also to reduce the tool wear. The advantages of cutting fluids, however, have been called into question lately due to the negative effects on product cost, environment and human health. Later semi-dry i.e. Minimum Quantity Lubrication (MQL) machining has been tried as a possible alternative to the use of fluid.

Minimum Quantity Lubrication machining refers to the use of a small amount of cutting fluid, typically in order of 300ml/hr or less, which are about three to four orders of magnitudes lower than that used in flooded lubricating conditions.

This project work deals with the optimization process parameters for tool wear in turning of titanium alloy (Ti-6Al-4V) under different lubrication conditions such as dry, flooded and Minimum Quantity Lubrication (MQL) conditions using Taguchi's robust design methodology.

The results have been compared among dry, flooded and MQL conditions and it reveals that MQL shows improvement in reduction of tool wear compared to dry and flooded lubricant conditions. From Analysis of Mean (ANOM), it is observed that MQL is suitable at higher cutting speed compared to dry and flooded lubricant conditions. It is observed from ANOM that uncoated tool shows better performance for dry, flooded and MQL lubricant conditions compared to CVD and PVD coated tools.

1. INTRODUCTION : Titanium alloys are metallic materials which contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures), light weight, extraordinary corrosion resistance and ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers, Porsche and Ferrari, also use Titanium alloys in engine components due to its durable properties in these high stress engine environments.

Since the introduction of Titanium and Titanium alloys in the early 1950s, these materials have in a relatively short time become backbone materials for the aerospace, energy and chemical industries. The combination of high strength-to-weight ratio, excellent mechanical properties, and corrosion resistance makes Titanium the best material choice for many critical applications. Today, Titanium alloys are used for demanding applications such as static and rotating gas turbine engine components. Some of the most critical and highly-stressed civilian and military airframe parts are made of these alloys. The use of Titanium has expanded in recent years to include applications in nuclear power plants, food processing plants, oil refinery heat exchangers, marine components and medical prostheses.
Titanium and its alloys are used in airplanes, missiles and rockets where strength, low weight and resistance to high temperatures are important. Further, since Titanium does not react within the human body, it and its alloys are used to create artificial hips, pins for setting bones, and for other biological implants.

The high cost of Titanium alloy components may limit their use to certain applications. The relatively high cost is often the result of the intrinsic raw material cost, fabricating costs and the metal removal costs incurred in obtaining the desired final shape.

Although "commercially pure" Titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications Titanium is alloyed with small amounts of Aluminum and Vanadium, typically 6% and 4% respectively, by weight. This mixture has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. This heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, allowing much easier fabrication of a high-strength product.

In case of machining process, the cutting fluids and the energy consumption are the main sources of environmental impact such as the environmental pollution due to chemical dissociation/break-down of the cutting fluid at high cutting temperature, dermatological problems to operators coming in physical contact with cutting fluid, water pollution and soil contamination during disposal. A diagram to present the input and output for a turning process

The useful life of a tool is limited by tool wear. The principal concern of metal cutting research has been to investigate the basic mechanism of wear by which the life of a tool is governed. During machining, tool wear takes place due the friction of the chip on the rake face and of the flanks and the work piece, and involves abrasion and the removal of the micro particles, as well as microscopic chipping of the cutting edge. It should be noted that friction, causing wear, occurs at high temperatures, high pressures and on relative small areas of contact between the uniform surfaces. The mechanism of tool wear in machining is in fact a very complicated phenomenon. In the present work, Taguchi robust design methodology is used to obtain the optimum conditions of the experimental data. Along with Taguchi method, statistical software Minitab 16.0 is used to obtain results for ANOVA. The results obtained from the Taguchi robust design method is compared with the software results. The validity test has been carried out through analysis of variance (ANOVA) and is validated with confirmation experimental data. The output parameter is tool wear.

The scientific approach to quality improvement is becoming more widespread in industrial practice. Designing high quality products and processes at low cost is an economical and technical challenge to the engineer. A systematic and efficient way to meet this challenge is a method of design optimization for performance, quality and cost called Robust Design.

Robust Design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost. The main idea of Robust design method is to choose the levels of design factors to make product or process performance intensive to uncontrollable variations such as manufacturing variations, deterioration and environmental variations Dr. Genichi Taguchi has popularized the Robust Design method which employs experimental design techniques to help identify the improved factor levels. Experimental design techniques are extremely effective for improving quality in problems that involve in a large number of factors. Taguchi's approach has been successfully applied by engineers in many leading Japanese and American companies for improving performance and competitiveness of their key products.

The Robust Design method uses a mathematical tool called Orthogonal Array to study large number decision variables with a small number of experiments.

The objective of this project work is to find out the set of optimum values for the control factors in order to reduce tool wear using Taguchi's robust design methodology. An extensive literature survey has been carried out for better understanding of importance of dry, wet and minimum quantity lubrication conditions including its manufacturing and performance aspects. As seen from the literature, the MQL technique suggests several advantages in machining processes. Most of the experimental investigations on machinability aspects are limited to the role and effectiveness of MQL over dry and flooded machining. But, in order to achieve good surface quality on a machined surface with minimum specific tool wear, either the cutting conditions should be carefully selected with an optimum amount of MQL or a new tool material is to be developed with lower coefficient of friction and high heat resistance. Hence, an attempt has been made in this project to optimize cutting parameters viz cutting speed, feed rate, depth of cut and also enhance the machinability characteristics in turning of titanium Ti-6Al-4V alloy using three carbide turning inserts under different lubricant conditions like Dry, Flooded and Minimum Quantity Lubricant conditions. In the present investigation, Taguchi method and the utility concept has been employed to determine the best combination of the process parameters to minimize tool wear.

A total of five process parameters with three levels are chosen as the control factors such that the levels are sufficiently far apart so that they cover wide range. The process parameter and their ranges are finalized using literature and machine operator's experience. The five control factors selected are type of lubricant (A) spindle speed (B), feed (C), depth of cut (D) and type of tool (E). Ti-6Al-4V alloy work piece are used in experimentation.

In this work, the cutting tools used are carbide inserts. Three different types of carbide cutting inserts are used in this work. They are

1. Uncoated tool
2. CVD coated tool
3. PVD coated tool

In the recent years a lot of research has been carried out to avoid the cutting fluids from the production. Many Industries and researchers are trying to reduce the use of coolant lubricant fluids in metal cutting to obtain safety, environmental and economical benefits. Dry cutting and semi-dry cutting such as Minimum Quantity Lubrication (MQL) have been favored by the industry. Minimum quantity lubrication (MQL) presents itself as a viable alternative for hard and dry machining with respect to tool wear, machined surface quality.

Experiments have been carried out by turning of a rod of Ti-6Al-4V on lathe using orthogonal array under Dry, Flooded, MQL machining. The flank wear on cutting tool is measured using profile projector per each experiment. Two experiments are conducted for each trial and average tool flank wear of these two experiments are considered for Analysis of mean and Analysis of variance. The summary of average tool wear and its S/N ratio of flank wear under dry, flooded and MQL conditions .

2. LITERATURE SURVEY :

Ahmad Yasir et al. [1] has done research on the machinability of Ti-6Al-4V using Physical Vapor Disposition (PVD) coated cemented carbide tools. The tool was investigated at various cutting condition under dry and near dry (or MQL) machining. Tool life is studied at different flow rates and cutting speeds. Longer tool life is obtained at one condition. At the early stage there is no significant effect of MQL on cutting force and is more effective when tool start to wear out. High value MQL is less effective at high cutting speed. MQL seems to be more effective when worn out tool is applied.

Q. L. An et al. [2] discussed Cold Water Mist Jet (CWMJ) cooling method to obtain a lower cutting temperature during TC9 titanium alloy turning process was carried out by hydrodynamic tests. CWMJ had better cooling effects as compared with other two cooling methods. Cutting temperature was greatly reduced and tool life was improved. The high velocity and small particle size both help to enhance heat transfer and lubrication effect in the cutting zone. Hence tool life was improved effectively.

Vishal S. Sharma et al. [3] performed turning operation to evaluate friction and heat generation at the cutting zone is the frequent problems. The heat generation plays a negative role during machining of modern materials because of their characteristics as poor thermal conductivity, high strength at elevated temperature, resistance to wear and chemical degradation. Major advances in techniques as Minimum Quantity Lubrication (MQL)/Near, Dry Machining (NDM), High Pressure Coolant (HPC), cryogenic cooling results in reduction of friction and heat at the cutting zone. Cryogenic cooling increases tool life without compromising on the environmental conditions. With the MQL/NDM technique machining cost and the amount of lubricant is reduced and is better with the use of vegetable oils. Turning with HPC technique results in formation of segmented chips better penetration at interface and thus lower cutting force better tool life and acceptable surface finish.

Shane Y. Hong et al. [4] worked on Titanium alloy Ti-6Al-4V, it is difficult-to-machine material because of its extremely short tool life. Minimum amount of liquid nitrogen is used between the chip breaker and the tool rake face. Liquid nitrogen is used and cutting temperature is reduced. Micro nozzle is used to inject forced LN2 and is not wasted by cooling unnecessary areas.

E. O. Ezugwu et al. [5] discussed about manufacturing of aero-engine that are based on nickel and titanium alloys. These materials are referred to as difficult-to-cut. Dry machining at high speed conditions, the use of high pressure and/or ultra high pressure coolant supplies, minimum quantity lubrication, cryogenic machining and rotary machining technique are used in their research. Moderate speed conditions when machining of aero-engine alloys leads lower machining productivity. These developments ensure that cutting tool materials maintain their properties at higher cutting conditions.

A. Attanansio et al. [6] have used the MQL technique in turning to determine the tool wear reduction. The results obtained from experimental tests and EDS microanalysis of tools are as follows. Lubricating the rake surface of a tip by the MQL technique does not produce evident wear reduction. Tool life time of a tip used in dry cutting conditions is similar to that of a tip lubricated by MQL on the rake. Lubricating the flank surface of a tip by the MQL technique reduces the tool wear and increases the tool life. Traces of lubricant compounds have been found on the worn surfaces only when MQL has been applied on the flank surface. The conclusion of authors is, the MQL gives some advantages during the turning operation, but it presents some limits due to the difficulty of lubricant reaching the cutting surface.

K. Weinert et al. [7] have proposed reduction of cooling lubricants in the modern cutting technologies of dry machining and MQL has led to significant advancements in machining technology. Today, many machining processes and work piece materials are produced by applying modern cutting tools and coatings, adapted tool designs and machining strategies, as well as optimized machine tools. These high-performance system components ensure economic and highly productive processes, slightly reducing the production times of wet machining processes and improving the work piece quality significantly. Dry machining operations, mainly applied in high-volume, large-scale industries, like automotive manufacturing, still require special solutions. However, it is envisioned that the increasing number of industrial applications and the ongoing research activities in the field of dry machining and MQL will support and ultimately result in the expansion of these modern high-performance technologies to small and medium-sized manufacturers.

M. M. A. Khan et al. [8] have compared the effects of dry, wet and minimum quantity lubrication (MQL) in terms of chip – tool interface temperature, chip formation mode, tool wear and surface roughness. MQL machining was performed much superior compared to the dry and wet machining due to substantial reduction in cutting zone temperature enabling favorable chip formation and chip–tool interaction and it was also seen from the results that the substantial reduction in tool wears resulted in enhanced the tool life and surface finish.

C. Chungchoo et al. [9] have presented a computer algorithm of new quantitative models for flank and crater wear estimation. First, a quantitative model based on a correlation between increases in feed and radial forces and the average width of flank wear is developed. Then another model which relates acoustic emission (*AE*rms) in the turning operation with the flank and crater wear developed on the tool is presented. The flank wear estimated by the first model is then employed in the second model to predict the crater wear on the tool insert. The influence of flank and crater wear on *AE*rms generated during the turning operation has also been investigated. Additionally, chip-flow direction and tool–chip rake face interfacing area are also examined. The experimental results indicate that the computer program developed, based on the algorithm mentioned above, has a high accuracy for estimation of tool flank wear.

E. O. Ezugwu and Z. M. Wang [10] have reviewed the main problems associated with the machining of titanium as well as tool wear and the mechanisms responsible for tool failure. It was found that the straight tungsten carbide (WC/Co) cutting tools continue to maintain their superiority in almost all machining processes of titanium alloys, this paper also discusses special machining methods, such as rotary cutting and the use of ledge tools, which have shown some success in the machining of titanium alloys.

M. Hagiwara et al. [11] have presented a new methodology for optimization of machining performance in contour finish turning operations. Two machining performance measures, chip breakability and surface roughness, are considered as optimization criteria due to their importance in finishing operations. Chip breakability covers two major factors: chip shape and size. Comprehensive case studies are presented to demonstrate the determination and application of optimal cutting conditions through experimental validation.

N. R. Dhar et al. [12] investigated the role of MQL on tool wear and surface roughness in turning AISI-4340 steel at different industrial speed and feed combination by uncoated carbide insert. The results include significant reduction in tool wear rate and surface roughness by MQL mainly through reduction in the cutting zone temperature and favorable change in the chip–tool and work–tool interaction.

Z. G. Wang et al. [13] have investigated the effects of different coolant supply strategies (using flood coolant, dry cutting, and minimum quantity of lubricant [MQL]) on cutting performance in continuous and interrupted turning process of Ti6Al4V. Based on the observation of the cutting forces with the different coolant supply strategies, the mean friction coefficient in the sliding region at the tool–chip interface is obtained and used in a finite element method (FEM) to simulate the deformation process of Ti6Al4V during turning. From the FEM simulation and Oxley's predictive machining theory, cutting forces are estimated under different coolant supply strategies and verified experimentally. Finally the authors concluded that in continuous cutting, MQL is effective at higher cutting and high feed rate and in interrupted cutting, MQL is more effective than dry and flooded cooling.

3. Methodology :

The knowledge of scientific phenomenon and past experience with similar product designs and manufacturing processes form the basis of the engineering design activity. However, a number of new decisions related to the particular design, the process architecture and parameters of the manufacturing processes a large amount of engineering effort is consumed in conducting experiments (either with hardware or by simulation) to generate the information needed to guide these decisions. Efficiency in generating such information is the key to meeting marketing windows, keeping development and manufacturing costs low and having high quality products robust design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost.

3.1 TAGUCHI'S ROBUST DESIGN:

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3.2 ROBUST DESIGN METHODOLOGY:

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The Robust Design method uses a mathematical tool called Orthogonal Array to study large number decision variables with a small number of experiments.

Taguchi's method is a quality improvement technique for efficient characterization of a product or process, combined with statistical analysis, with the ultimate purpose of minimizing its variability so that higher quality products can be achieved. Robust design is based on the principle of optimization in which the objective function is defined as the signal to noise ratio which will help in finding those values of the design parameters at which the response is least sensitive to the different effects of the noise factors. The Purpose of Experimentation is:

1. To improve performance characteristics according to needs.
2. To understand how to reduce and control variation of a product.
3. Decisions must be made concerning which parameters affect performance of the product.
4. By properly adjusting the average and reducing variation, the product losses can be minimized.

3.3.3.1 SIGNAL-TO-NOISE RATIO (S/N RATIO):

Dr. Taguchi developed the concept of signal-to-noise ratio in robust design to evaluate the performance of a system. This is a transformation of the repetition data to another value, which is a measure of the variation present. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio combines both the variance of predictable performance and the variance of unpredictable performance into a signal measure.

Robust design optimizes the S/N ratio in the domain of control factor so that performance could be made insensitive to the noise factors in order to improve product quality. There are three important types of S/N ratios available depending on the type of characteristic.

i) Smaller is better (SB)
ii) Larger is better (LB)
iii) Nominal is best (NB)

3.3.4 STEP 4: SELECTION OF CONTROL FACTORS AND THEIR LEVELS:

The more complex product or process, the more control factors it has vice versa. Typically, six to eight control factors are chosen at a time for optimization. For each control factor some levels are selected, out of which one level usually the starting level. The levels should be chosen sufficiently far apart to cover a wide experimental region because sensitivity to noise factors does not usually change with small changes in control factors settings. Also, by choosing a wide experimental region, it can give details of good region, as well as bad regions, for control factors.

3.3.5 STEP 5: DESIGN OF MATRIX EXPERIMENT:

The matrix consists of a set of experiments that can change settings of the various product or process parameters to be studied from one experiment to another. Conducting matrix experiments using special matrices called orthogonal arrays, allows the effect of several parameters to be determined efficiently and is an important technique in Robust Design. Design the matrix experiment and define the data analysis procedure. Using orthogonal arrays is an efficient way to study the effect of several control factors simultaneously, the factor effects thus obtained are valid over the experimental region and it provides a way to test for the additive of the factor effects. The experimentation effects needed are much smaller when compared to other methods of experiments, such as guess and test (trial and error), one factor at a time and full factorial experiments. The data analysis is easy when orthogonal arrays are used.

Orthogonal arrays are simple and useful tools for planning industrial experiments. An experiment plan can easily be constructed by assigning factors to columns of orthogonal array then matching the different symbols of columns with the different factors levels. Orthogonal arrays were originally developed by Taguchi to control experimental error. OA's are constructed in such a way that, for each level of any factor all levels of other factors occur an equal number of times thereby giving a balanced design. As compared with a full factorial design, the numbers of experiments in Taguchi's technique are thereby substantially reduced.

3.3.5.1 CONSTRUCTING AN ORTHOGONAL ARRAY:

Selection of orthogonal array contains three major steps. These steps are illustrated below:

a. Finding the number of factors, number of levels for each factor and any specific interactions between the factors is the basic step in selection of orthogonal array.
b. Calculating the minimum number of experiments to be conducted. Minimum number of experiments is equal to total degrees of freedom of individual factors plus one. Number of degrees of freedom associated with a factor is equal to one less than the number of levels for that factor.
c. Finally based on the number of factors, number of levels, interactions and total degrees of freedom choose an appropriate orthogonal array from the standard orthogonal array list.

Taguchi has tabulated 18 basic orthogonal arrays called standard orthogonal arrays. In many case studies, one of the arrays from the standard orthogonal array can be used directly to plan a matrix experiments. An orthogonal array's name indicates the number of rows and columns it has and also the number of levels in each of the columns. For example, the array $L_4(2^3)$ has four rows and three 2-levels columns. Here number of rows represents the number of experiments to be conducted, 3 denotes the maximum number of factories assigned to the array and 2 denotes the number of levels of each factor.

3.3.6 STEP 6: CONDUCTING THE MATRIX EXPERIMENT:

The purpose of product or process development is to improve the performance characteristic of the product or process relative to customer need and expectations. The purpose of experimentation should be to understand how to reduce and control variation of a product or process; subsequently decision must be made concerning which parameter affect the performance of a product or process. Conducting matrix experiments using orthogonal arrays is an important technique in robust design. It gives more reliable estimates of factor effects with fewer experiments when compared to the traditional methods. After designing the experiments it is apparent that, during conducting the experiments from one experiment to next, levels of several control factors must be changed. This poses a considerable amount of difficulty to the experiments. Meticulousness in correctly setting levels of the various control factors is critical to the success of a robust design project. By meticulousness, mean ensuring that the measurements of control factors must be set to their proper levels failure to set the levels of a factor could destroy the valuable property of orthogonally. Consequently, conclusions from the experiments could be erroneous. If the conclusions from the matrix experiments are to be valid in actual manufacturing, the results must not be sensitive to inherent variations in the measuring system, by keeping these variations out of the experiments the loss of ability to test for robustness against such variations occurs. The matrix experiment, coupled with the verification experiment, has built in check for sensitivity to such inherent variations.

The matrix experiment, through somewhat tedious to conduct is highly efficient. It generates more dependable information about more control factors with the same experiment effort compare to other optimizing processes.

3.3.7 STEP 7: ANALYZE THE DATA, DETERMINE OPTIMUM LEVELS FOR THE CONTROL FACTORS AND PREDICT PERFORMANCE UNDER THESE LEVELS:

This step of robust design is to analyze and interpret the experimental results to improve the performance characteristics of the product or process relative to customer needs and expectations. The various steps involved in analyzing the data resulting from matrix experiments are described. S/N ratios and other summary statistics are first computed for each experiment. Then, the factor effects are computed and ANOVA performed. The factor effects along with their confidence intervals are plotted to assist in the selection of their optimum levels.

ESTIMATION OF FACTOR EFFECTS:

After the data from the experiments are summarized, the next step in data analysis is to estimate the effect of each control factor on the quality characteristic of interest and to perform analysis of variance.

3.3.7.1 ANALYSIS OF VARIANCE (ANOVA):

Analysis of variance is a statistically based, objective decision making tool for detecting any differences in average performance of group of items tested. The decision rather than using pure judgment, takes on variation into account. This method was developed by Sir Ronald Fisher in 1930's as a way to interpret the results from agricultural experiments.

The main advantage of performing ANOVA is to evaluate the relative importance of factors and the other variance. ANOVA is one of the major tools used in Robust Design in calculating of this will give the percent contribution of the factor towards the process or quality characteristic.

3.3.8 STEP 8: CONDUCTING THE VERIFICATION EXPERIMENT AND FUTURE PLAN:

Verification experiment purpose is to verify that the optimum conditions suggested by the matrix experiments do indeed give the projected improvement. If the observed and the projected improvements match, we adopt the suggested optimum conditions, if not then conclude that the additive model underlying the matrix experiments has failed and find ways to correct that problem. The corrective action includes finding better quality characteristic, signal to noise ratio or different control factors and levels etc., the optimum conditions will be adopted for real time process if the results exhibits the improvements.

5. Conclusions:

- The cutting performance of MQL machining expected shows favorable and better results compared to dry and flooded conditions.
- The MQL machining shows advantage mostly by reducing Tool wear as well as environmental problems, which reduces the friction between the chip & tool interaction.

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