

## SIMULATION AND EXPERIMENTAL STUDY ON THE MACHINABILITY OF TUNGSTEN HEAVY ALLOYS USING FEM

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### ABSTRACT

*Laser beam machining of various materials has found wide applications in the industry due to its advantages of high-speed machining, no tool wear and no vibration, precision and accuracy, low cost of machining, etc. Investigations into the laser beam machining of uncommon alloy are still limited and more research is needed in this field. In this paper, an analysis of the laser beam machining of tungsten alloy was performed, for cutting and drilling machining processes. First, an experimental analysis of micro hardness and microstructure on the laser-cut samples was performed, and then the numerical simulation of the laser beam drilling process and its experimental validation was carried out. The fragmentation and penetration of materials having different mechanical characteristics are studied for the development of tungsten heavy alloy fragile projectile. An FEM analysis model for tungsten heavy alloy fragile projectile is established. Simulation of the process of penetration of tungsten heavy alloy with different ratios of tension to compression against the target was carried out with the dynamic nonlinear finite element analysis software MSC-Dytran. Rules of fragmentation and penetration of tungsten heavy alloy are obtained. Analysis of simulation results shows that the power of fragmentation of projectiles increases as tension intensity falls, but the power of penetration increases as tension intensity increases. Numerical simulation and analysis of results offer a theoretical reference for the engineering design of tungsten heavy alloy fragile projectiles.*

**Keywords:** laser beam machining, tungsten heavy alloy, simulation results, FEM analysis

### INTRODUCTION

Corrosion is a major problem in the aerospace and military sectors because of

the extreme working conditions and long periods of storage. Testing mechanical parameters and corrosion characteristics should be done continuously. used microelectronic research, immersion testing, and accelerated testing to study corrosion of high-density sintered tungsten alloy. Excessive storage time might cause corrosion, which can lead to degradation and deformation of WHA KEPs, according to research. Ogundipe et al. performed spectroscopic studies after immersing and wet-dry cycling several grades of WHA. The researchers discovered that galvanic corrosion might affect either the tungsten grains or the binder phase, contingent upon the specific formula. Hamid and Hassan found out how composition and manufacturing techniques influenced the copper, iron, and nickel WHA classes using microelectronic experiments that assessed corrosion rate. It is still important to study corrosion of machined surfaces for applications that are subjected to extremely harsh operating conditions, such as radiation shields and diver-tors, or that require very long-term storage, like KEP, even though WHA has excellent corrosion resistant properties based on its corrosion rates. Researchers have examined the corrosion properties of several materials in connection to the impacts of machining

operations. These materials include steels, aluminium alloys, composites, and more. The effects of corrosion on machined surfaces exposed to WHA working environments remain little unexplored, despite the critical importance of this area. Cutting parameters, standard and non-traditional machining techniques, and the final product all have a significant impact on the material's mechanical and corrosion resistant qualities. The components' surface integrity is thereby compromised. To my dismay, very little study has zeroed in on this particular problem with WHA. This research reviews the surface integrity and corrosion properties of machined WHA samples under different machining conditions. Using these samples in KEPs is standard procedure. Among the most detrimental mechanical deformations that occur during KEP production is thread cutting, which affects the buttress thread. Reasons for this include increased cutting pressures, strain hardening, and rapid material loss. The most common machining process for WHAs, WEDM, and two excellent examples of turning operations immediately come to mind. There are two major topics that this investigation focuses on. Examining the effects of traditional and nontraditional milling methods on surface integrity is our primary objective. Furthermore, we are curious to know if the surface integrity and corrosion properties of the machined samples are negatively impacted by the various turning machining conditions. Using these standards, we examine the micro-structure, hardness, surface polish, yield strength, residual stresses, corrosion resistance, and surface roughness of the WHA machined samples. In that way, we can make sure their surface integrity is thoroughly examined. It is

obvious that the study's results should be used to develop defensive components that are stronger and stay longer.

#### LITERATURE REVIEW

**Yan Bao and Sen Yin (2023)** Tungsten heavy alloy components used in nuclear power plants and other precision machinery must have surface roughness on the millisecond scale. The goal of this project is to create a high-performance UEVC system that can accurately machine tungsten heavy alloy. Building a stepped bending vibration horn begins with developing a new approach to design that streamlines the process and adheres to Yevtushenko's thesis. We study the design and operation of piezoelectric transducers on the ultrasonic vibrator that, in search of dual-bending vibration modes, uses the fifth resonant mode of bending. In order to verify the ultrasonic elliptical vibration locus using the finite element method, a cutting tool may be inserted into the end of the ultrasonic vibration unit. One way to change the vibration unit's three-degree-of-freedom (3-DOF) UEVC characteristics is to move the unit and work-piece relative to each other.

**Samuel Omole (2022)** Tungsten has the highest melting point and density of all metals. Tungsten is an excellent structural material due to its high heat conductivity and remarkable strength, making it a perfect fit for applications like fusion energy. For many, the key to better and more salable power plant designs lies in the ability to manufacture parts with complicated geometry. The special difficulties of dealing with tungsten and related alloys limit mass production of complex geometries to very low numbers. These problems arise because the components are so strong and hard that they have a high

ductile-to-brittle transition temperature (DBTT). Parts with almost no net form may be produced using two processing techniques: powder metallurgy and additive manufacturing. Nevertheless, these solutions cannot be finalized without undergoing subtraction post-processing procedures.

**Liyong Wang (2021)** The remarkable material removal capabilities of laser beam machining (LBM) have caught the interest of the industrial sectors. This non-standard machining process warrants careful modelling and optimization. Drilling, cutting, grooving, and turning are the five most typical LBM processes covered on this page. As the LBM process exhibits non-linear behaviour in many contexts, it is challenging and time-consuming to construct a trustworthy model that incorporates the input and output variables. The geometry, metallurgical properties, surface roughness, and material removal rate (MRR) of the laser-machined work-piece are some of the quality metrics that are produced by LBM. Inputs to this method include materials, process parameters, and system parameters. Artificial intelligence (AI) has recently come to the forefront of academic interest as a possible front runner among computational methods for LBM quality feature optimization and modelling.

**Mohsen Soori (2020)** Because of the friction and heat produced during the chip generation process, the material characteristics of machined components are altered during metal cutting processes. Analysis of cutting zone temperature distributions may help reduce the likelihood of cutting tool failure during machining processes. Predicting and analyzing stress and strain rates in metal cutting settings, as

well as residual stress in machined components, allows for improved performance of these parts in real-world applications. By simulating and analyzing the metal cutting process, including friction, flow stress, and chip formation, the material removal rate may be enhanced. Machining operations may benefit from cutting force prediction and analysis by reducing the likelihood of work-piece deformation and tool deflection errors. Analyzing and reducing work-piece deformation owing to applied forces may improve the precision of the component manufacturing process utilizing machining operations.

#### **Simulation relation and database people**

The pre-processor step is situated at the very end of the process, after the simulation phase. Database development and data modelling are cornerstones of each of these procedures. As part of getting the data ready, you may now choose the parameters for the simulation instructions, including how many steps to simulate, how big each step should be, and how much wear the calculating tools will experience. This is a prerequisite for starting the simulation. Additionally, you could discover the amount of tool wear. The tool's performance is maximized when the cutting settings and instrument specifications are adjusted to perfection.

#### **Machining and turning**

In order to achieve production standards, manufacturers use machining to remove any extraneous material or components from work-pieces. In order to achieve product standards, machining may also be defined as mechanical processing that directly modifies the work-piece's size, shape, relative location, and nature. In their day-to-day lives and at work, people have

always discovered ways to skimp. Around 4000 BC, the ancient Egyptians started making use of cutting tools in their industrial processes. The invention of several machine tools occurred throughout the Industrial Revolutions. Using these traditional tools not only increased output and freed up workers, but they also enhanced precision and quality of the final product. About the same time, a thorough and methodical investigation of machining began. When computer numerical control (CNC) technology was introduced in 1953, it was a huge step forward for machining research.

### **Finite Element Modeling**

Engineers have used differential equations based on Newton's laws of motion, the conservation of mass and energy, thermodynamic principles, and Maxwell's equations to find the connections between variables in mechanical systems. One of the simplest regular geometry tasks we could answer was finding the area inside a circle given just the most basic border limitations. When it comes to distressing difficulties, structural mechanics often turns to the finite element method (FEM). Finite element modelling (FEM) relies on the idea of partitioning the mathematical model into separate, non-overlapping sections of basic geometry, which are referred to as finite elements (or "elements"). After all the pieces are in place, the mathematical model's is roughly estimated from the discrete model's response. As one delves into the study of many systems, both man-made and otherwise, the disconnection-assembly paradigm always emerges. You can easily see the individual parts of a skeleton, engine, bridge, or aeroplane, for instance.

### **Finite Element Simulation of Tensile Behaviour**

They have found usage in the aerospace and, more recently, automotive sectors. The fibre used is Woven E-Glass, which is tougher and more rigid than AA5052. When it comes to coverings, aluminium sheets are quite resistant to environmental influences. The initial concept for fibre metal laminates came from Delft University of Technology and involves alternating layers of thin metal sheets and reinforcing elements made of fibre. Data on the properties of the adhesive bonding between Al and FRP layers treated differently. Incorporating some setting matrices into thermoplastic-based FMLs improves fracture toughness and reduces processing times. The surface pr-treatment has a significant impact on the aluminum's durability. Improving the adhesive joining capacity is the primary goal of the pr-treatment, which entails making the surface clean and readily wet-table. The first step of the pr-treatment is to clean and treat the surface to remove any contaminants. We speed up the adhesive properties by treating them chemically. The ability of aircraft structures to withstand impacts is an important quality

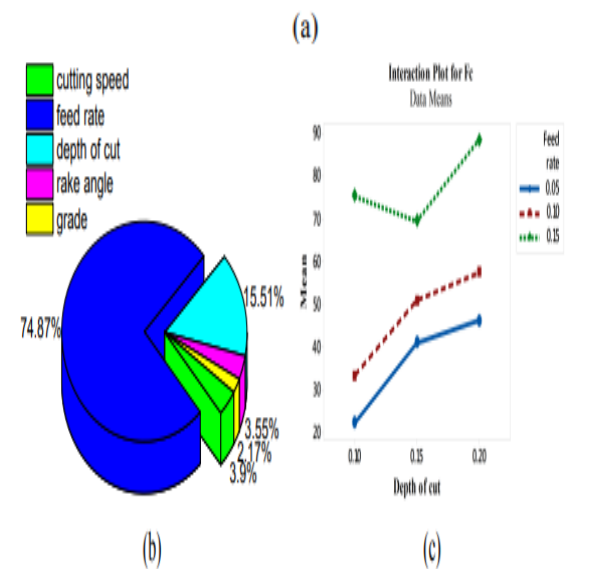
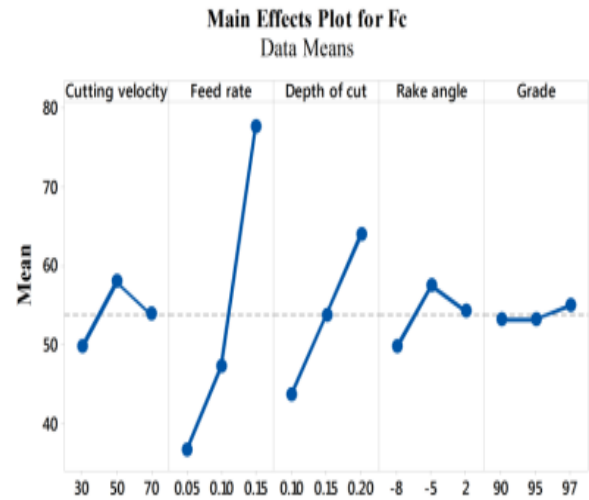
### **METHODOLOGY**

Mechanical, chemical, physical, and micro structural aspects are explored and quantified to characterize materials. Complete details on the methods, additional resources, and investigations of other tungsten heavy alloys material characteristics follow this introduction. Chemical characterization aims, among other things, to reveal the precise chemical make-up of a product. To comprehend the behaviour of a material, one must first be aware of its chemical composition, as this

determines the substance's density, hardness, and strength. Machining trials performed in a dry chamber used work-holding angles (WHAs) of 90 degrees for the purpose of this study. We begin by tracking the evolution of tool life for different tool designs. One has to become an expert in the mathematical intricacies of the cutting mechanics in order to remove metal efficiently and affordably. With the rise in computational capacity, numerical approaches like FE methodology have grown in popularity for cutting process analysis. Rather of spending time and money on trial-and-error experiments, this strategy might be used instead. Determining the precise material model constants and selecting appropriate material and damage models are two of the main challenges with FEM. This study primarily aims to improve and find new methods for material and damage model constants. A two-dimensional finite element model of chip generation under orthogonal cutting settings is the main subject of this study.

**RESULT AND DISCUSSION**

The graphs in Graphic 1 demonstrate the average effect, percentage contribution, and interaction for the cutting components that have a substantial impact on cutting forces. The correlation between cutting forces and feed rate (a) is shown by the mean impact graphs in Graph 1. A higher feed rate results in a thicker uncut chip because more force is needed to remove the chip layer. Consequently, this is to be anticipated. When I think about the depth of cut, I see a similar pattern. It would seem that cutting power is uncorrelated with cutting speed, slope, or rake angle.



**Graph 1: plots showing the average impact (b) A graph illustrating the interplay between the most critical cutting parameters, and (c) a breakdown of the cutting parameters' % contributions to cutting forces**

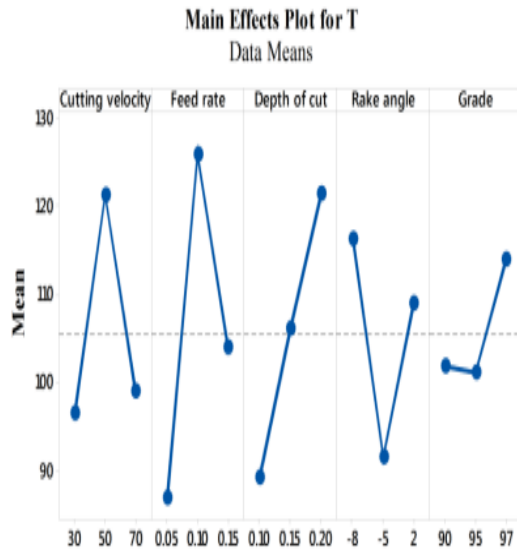
The cutting forces are most impacted by the feed rate (up to 75%), next by the rake angle and the cutting speed (Graph 1 (b)), and the least affected by the depth of cut and the WHA grade. The cutting forces are therefore very sensitive to changes in feed rate. Regardless of the shift in WHA grades, the demands would be constant. Graph 1 (c) displays additional interaction graphs for the main components.

### Cutting temperature

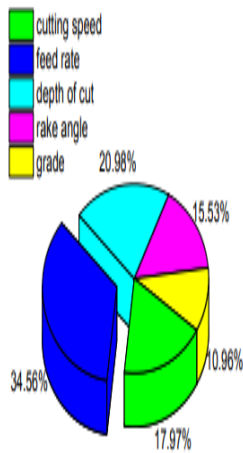
The cutting temperature predictions are made by averaging and considering the impact of all input factors. In graph 2, we can see the graphs representing the average effect, percentage contribution, and interaction for the cutting parameters that have a substantial impact on cutting temperatures.

### important cutting factors influencing cutting temperatures

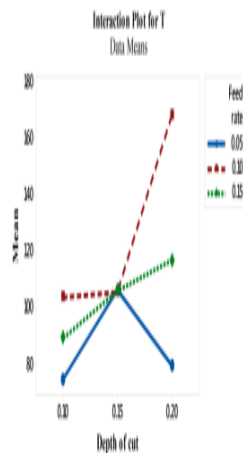
Graph 2 (a) shows the mean effect charts, which demonstrate that all input factors have a significant influence on the cutting temperature. Conversely, it seems to reason that a deeper cut would be the outcome of a greater cutting temperature. Feed rate accounts for 35% and depth of cut for 21% of the total, as shown in Graph 2 (b). Although the input parameters' individual values vary from 11% to 18%, when added together they constitute around 50% of the total. This highlights how complicated temperature effects are in machining.



(a)



(b)



(c)

**Graph 2: (a) A graph showing the average results, and (b) the proportion of the variance attributable to the cutting parameters (c) Plot of interactions including the most**

## CONCLUSION

Cutting factors, especially tool shape and tungsten content, were shown to significantly affect chip morphology. Particularly for rake angles that were positive, this held true. While milling, a number of variables interacted in complex ways, including hardness, ductility/brittleness, and temperature growth. Both the positive and negative rake angle cutting tools performed similarly while milling WHA at the same cutting conditions.

The SEM micro graphs showed wear and adhesion on the tool's worn surface; the latter was more noticeable while cutting WHA for both tool geometries. Through the use of fundamental machining techniques and the analytically-based JC material model constants, it is possible to anticipate all outputs with an average error percentage decreasing below 10%. Experiments conducted under different cutting conditions demonstrated a strong correlation between the projected temperature distributions and surface roughness and tool wear. Verify the material's thermal conductivity, yield strength, hardness, and toughness. When analyzing machining characteristics, it is important to look at cutting forces, tool wear, surface quality, and material deformation. Model and forecast the result using the given machining parameters. Through experimental means, learn about the thermal conductivity, specific heat capacity, stress-strain behaviour, and other material features.

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