A

Dissertation Report on

Development of a Compounding Drill Tool

Submitted

in partial fulfillment of the requirements for the degree of

Master of Technology

in

Mechanical Design Engineering

by

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CERTIFICATE

This is to certify that, Mr. Raosaheb Patil (Roll No- 2321004.) has completed the dissertation work and submitted the dissertation report on "Development of Compounding Drill Tool" for the partial fulfillment of the requirement for the degree of Master of Technology in Design Engineering from the Department of Mechanical Engineering., as per the rules and regulations of Rajarambapu Institute of Technology, Rajaramnagar, Dist: Sangli.

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DECLARATION

I declare that this report reflects my thoughts about the subject in my own words. I have sufficiently cited and referenced the sources referred to or considered in this work. I have not misrepresented, fabricated or falsified any idea/data/fact/source in this submission. I understand that any violation of the above will be cause for disciplinary action by the Institute.

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ABBRAVATIONS

CAD	Computer-Aided Design
ANSYS	Analysis System
UG-NX	Unigraphics NX
D&C	Drilling and Completions
D	Drill Diameter
Vc	Cutting Speed
f	Feed Rate
C	Material Constant

ABSTRACT

This study presents a comparative analysis between experimental and analytical results to evaluate the mechanical and dynamic behavior of a material component under various loading conditions, using ANSYS Workbench as the primary simulation tool. Key parameters such as normal deformation, equivalent and normal elastic strain, shear strain, and different stress components were analyzed and compared. The analytical results demonstrated a high level of accuracy, with deviations from experimental data generally within 5%, confirming the reliability and effectiveness of the model. Furthermore, the frequency and maximum deformation at resonance showed close agreement, validating the model's dynamic prediction capabilities. The study highlights the capability of ANSYS Workbench to simulate complex physical behaviors accurately, making it a powerful tool for predictive analysis and design validation. The outcomes not only reinforce the importance of simulation in modern engineering but also provide a foundation for future enhancements involving more advanced materials, multi-physics simulations, and optimization techniques.

Keywords: ANSYS, Workbench, Deformation, Strain, Stress, Frequency, Vibrations, Cutting Speed, Drill, Tool, Feed rate, Unigraphics NX.

CHAPTER 1

INTRODUCTION

Drilling is one of the most essential machining processes used in manufacturing, mining, construction, and oil and gas industries. It involves the removal of material to create round holes using a rotary cutting tool, commonly referred to as a drill bit. While traditional drill tools have served a wide range of applications effectively, the increasing complexity of modern engineering requirements has exposed their limitations particularly in demanding operational environments characterized by high forces, extreme temperatures, abrasive materials, and the need for higher precision.

In response to these challenges, compounding drill tools have emerged as a promising evolution in tool design. Unlike conventional single-point or straight-fluted drill bits, compounding drill tools integrate multiple design features into a single tool body. These features can include stepped geometries, different cutting-edge angles, variable flute shapes, and even multi-material compositions. The main advantage of such a design is its ability to perform multiple operations in a single pass or to increase stability, cutting speed, and durability thereby reducing tool changeover time, improving surface finish, and lowering operational costs.

However, the development of such advanced tools is not straightforward. Physical prototyping and testing of new designs can be time-consuming and expensive, especially when working with high-strength materials or custom geometries. Furthermore, evaluating tool performance under complex working conditions such as varying torque, axial force, and thermal loads requires detailed analysis. This is where modern simulation tools such as ANSYS Workbench play a crucial role.

ANSYS Workbench is a powerful platform for performing finite element analysis (FEA), allowing engineers to simulate and evaluate how a component behaves under real-world physical conditions. It supports structural, thermal, modal, and fatigue analysis—all of which are relevant in assessing the performance of a compounding drill tool. Using ANSYS, one can model the drill tool in 3D, apply relevant boundary conditions (such as drilling forces, rotational speed, and material constraints), and obtain detailed results such as stress distribution, deformation, and temperature gradients. These insights are invaluable for identifying weak points in the design, optimizing the geometry, and selecting the most suitable materials.

Moreover, the integration of CAD tools with simulation environments allows for an iterative design process. Engineers can rapidly adjust design parameters such as flute angle, cutting tip shape, or shank diameter and immediately assess the effect of those changes in simulation. This leads to faster innovation cycles and more robust final products.

The ongoing development of high-performance materials and the need for sustainable, efficient production processes continue to drive innovation in cutting tool technology. By using simulation-driven design, particularly with platforms like ANSYS Workbench, engineers can create more advanced, reliable, and efficient compounding drill tools tailored to specific applications. This study focuses on leveraging such capabilities to design and analyze a compounding drill tool that meets modern engineering demands.

1.1 Drill Bit

A drill is a device equipped with a cutting or driving tool attachment, typically a bit, that is used for creating holes in a wide range of materials or for joining components with fasteners. When the drill's gripping attachment is positioned against the target material, it rotates within a chuck, and the tip of the cutting tool, along with its edges, slices through the material. Drills are capable of performing various operations such as adjusting, counterboring, grinding, slicing, and removing sections of the workpiece. While multiple machine tools can be used to create holes, drilling machines are specifically designed to perform this task quickly and efficiently. During drilling, the bit, firmly fixed in the spindle, rotates and cuts into the material. For accurate positioning, a center punch is used to mark the surface before drilling. Drill bits are particularly valuable in oil and gas exploration, where they are used to bore holes into the Earth to access hydrocarbons. The drill bit gouges and crushes geological formations, while drilling mud cools the bit, removes cuttings, lubricates the surface, and maintains pressure in the borehole. Several factors, including rotary speed, bit weight, mud density, and drill pipe strength, influence drilling efficiency. Drill bit evaluation is a systematic process that assesses bit performance based on penetration rate, footage drilled, rotary speed, weight, and cost, among other criteria. Drill bits, being cutting tools, are designed to create cylindrical holes and are available in numerous sizes and applications. They are connected to a drill that applies axial force and torque. The part gripped by the chuck is known as the shank, while the cutting edges perform the actual drilling. The geometry of the drill bit significantly affects performance spiral or twist rate influences chip removal, while the point angle determines effectiveness in various materials. A sharper angle is used for soft materials, while a broader angle suits harder materials. Additionally, lip geometry controls how much support the cutting edge receives, affecting performance and durability.

A drill bit is attached to a rotating drill, which imparts the necessary cutting action to penetrate the workpiece. The bit is held firmly by the drill's chuck through its **shank**, the upper portion of the bit that interfaces with the drill. For general consumer use, straight shanks are the norm, compatible with conventional three-jaw chucks.

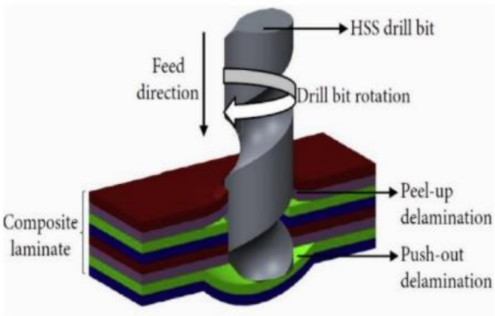


Fig.1. 1 Drill Bit

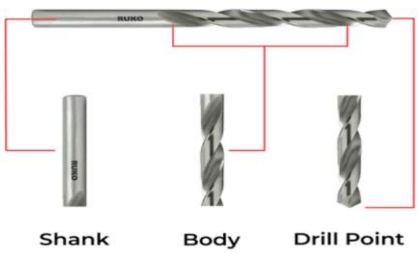


Fig.1. 2 Drill Elements

Drills are essential tools used across a wide range of applications, including woodworking, metalworking, construction, and do-it-yourself (DIY) projects. Beyond these common uses, specially designed drills also play a critical role in fields such as medicine and space exploration. For example, surgical drills are used in orthopedic and dental procedures, while space missions utilize specialized drills to collect soil samples from other planets. Drills are available in various types and configurations, each offering specific power and capacity to suit different tasks. They can be powered manually, electrically, or pneumatically, with electric drills being the most commonly used due to their efficiency and ease of operation. Pneumatic drills, which use compressed air, are often preferred in industrial environments. Hammer drills, which combine rotary and percussive action, are ideal for drilling into hard materials like concrete, brick, and stone. Larger drilling systems, known as drilling rigs, are used to bore deep holes in the Earth to extract water, oil, or geothermal energy. In addition to drilling, some hand-held drills are designed to drive screws and fasteners, making them multifunctional tools. Certain small appliances, such as pumps or grinders, can even be powered by a drill. With advancements in technology, modern drills now include features like variable speed control, torque adjustment, reversible rotation, and ergonomic designs that enhance user comfort and precision. These developments make drills not only indispensable in everyday tasks but also vital in specialized industrial and scientific operations.

1.2 Types Of Drill

Based on Design and Cutting Mechanism

Twist Drill

- The most common type.
- Has two helical flutes that remove material as the bit rotates.
- Used for general-purpose drilling in wood, metal, and plastic.

Step Drill

- Conical shape with steps of increasing diameter.

- Suitable for drilling multiple hole sizes with a single bit, especially in sheet metal.

Center Drill

- Short and rigid with a pointed tip.
- Used to make a small starter hole (pilot hole) to guide larger drill bits or lathe operations.

Spade Drill

- Flat cutting blade mounted on a shank.
- Ideal for large-diameter, rough holes in wood and soft materials.

Brad Point Drill

- Special tip for precise wood drilling without wandering.
- Common in carpentry and cabinetry.

Countersink Drill

- Used to create a conical hole that allows the head of a screw or bolt to sit flush with or below the surface.

Masonry Drill

- Tipped with carbide for drilling into stone, concrete, or brick.
- Used with hammer drills for impact-driven drilling.

Forstner Bit

- Used for flat-bottomed holes in wood.
- Ideal for drilling precise, clean holes with no splintering.

Auger Drill

- Large, spiral-shaped bit used for deep holes in wood.
- Has a screw tip to draw the bit into the material.

Gun Drill

- Used for deep-hole drilling (e.g., in the automotive or aerospace industries).
- Includes internal channels for coolant delivery.

Fig.1. 3 Types of Drill Bit

Fig.1. 4 Types of Shank

1.3 Shank Configurations

- **Straight shanks**, cylindrical and easy to grip, are fevered in most household and small workshop environments. They provide reliable centring and are compatible with a range of chucks and collets.
- **Tapered shanks**, such as Morse tapers, are used in industrial equipment where self-locking with the spindle enhances torque transmission.
- **Hex shanks**, with six flat sides, enable higher torque and prevent slippage—ideal for impact drivers and quick-change systems. These are popular in DIY and professional settings

Fig.1. 5 Drill Bit Materials

Sizing and Drill Length

Drill bits typically maintain a diameter-to-length ratio between 1:1 and 1:10. This balance ensures sufficient rigidity and minimizes deflection. However, specialized applications such as aerospace deep-hole drilling or oil-well manufacturing use extremely long bits like “aircraft-length” twists and gun drills to meet unique depth requirements, although controlling deflection becomes significantly more challenging

1.4 Problem Statement

In modern machining and manufacturing industries, the demand for drilling tools that are both high-performing and cost-effective has significantly increased. Drilling operations on hard materials such as stainless steel, cast iron, and composite alloys require tools that offer superior wear resistance, high hardness, and good heat dissipation. Traditional single-material drill tools often fail to meet all these requirements simultaneously, leading to increased wear, frequent replacements, and higher operational costs.

To overcome these limitations, a new hybrid tool design known as the Compound Drill Tool Step Drill with HSS Shank has been introduced. This innovative tool combines two distinct materials: solid carbide for the cutting section and high-speed steel (HSS) for the shank. The carbide cutting portion enhances tool life and cutting efficiency due to its high hardness, wear resistance, and thermal stability. Meanwhile, the HSS shank offers mechanical flexibility, ease of fabrication, and cost savings, while being compatible with a wide range of machine tool holders.

The tool has been precisely designed in CATIA V5 CAD software, with a total drill diameter of 20 mm and an overall length of 160.34 mm. The step drill geometry is tailored to improve chip evacuation, reduce cutting force, and allow multi-diameter drilling in a single operation. The joining mechanism between the two segments is achieved using soldering, a method chosen for its ability to provide a strong metallurgical bond, ensuring structural integrity and efficient torque transfer during high-speed drilling.

Despite the potential advantages, this compound design also presents technical challenges that must be evaluated and addressed. These include the stress distribution across the joint interface, the thermal conductivity mismatch between HSS and carbide, and the overall durability of the soldered joint under cyclic loading and heat exposure. Furthermore, improper design or analysis may result in premature failure at the interface or cutting edge, which would negate the benefits of using two distinct materials.

To ensure the tool performs reliably under operational conditions, it is crucial to carry out a comprehensive simulation and analysis using advanced engineering tools such as ANSYS Workbench. Finite element analysis (FEA) can accurately predict the tool's behavior under mechanical loads, thermal stress, and dynamic conditions. These simulations help identify critical failure points, verify joint strength, and optimize tool geometry before proceeding to physical prototyping and testing.

Therefore, this study focuses on evaluating the mechanical and thermal performance of the compound drill tool. The main objective is to validate the effectiveness of the hybrid design through simulation, and propose improvements that enhance the tool's reliability, functionality, and cost-efficiency in industrial drilling operations. This work aims to bridge the gap between theoretical design and practical usability by ensuring the compound drill tool meets modern manufacturing standards.

1.5 Application

Drills are indispensable tools in a wide range of professional fields and practical applications. In construction, they are primarily used to create holes in wood, metal, and concrete for tasks such as installing fasteners, anchors, or mounting hardware. Similarly, in plumbing and electrical work, drills play a vital role in forming pathways for pipes, cables, and other utility lines through walls, floors, and ceilings. In carpentry, drills are essential for pre-drilling holes for nails, screws, and bolts, helping prevent wood from splitting and ensuring precise fastening in furniture, cabinetry, and structural components. Beyond technical trades, the term "drill" also appears in military contexts, where it refers to structured physical training routines such as foot drills that teach soldiers proper marching techniques and coordinated movement.

A more advanced category of drilling technology includes compound drill bits, which are designed with specialized geometries to enhance cutting performance. These bits often feature multiple cutting edges and are optimized for use in harder or layered materials like metals, composites, and rock formations. One common type is the step drill bit, which has a conical, stepped profile that allows the user to drill holes of varying diameters with a single bit. This is particularly useful in sheet metal work where precise, incremental hole sizing is required. Another innovation is the replaceable drill bit with compound geometry, such as stepped or sawtooth cutting edges, designed for high-efficiency mass production. These offer cost savings over time since only the cutting tip needs replacement. Additionally, some compound drill tools integrate compound axial and impact action, which enhances penetration in dense materials like rock by reducing vibration and improving energy efficiency. These high-performance bits are especially valuable in mining, oil exploration, and heavy construction, where tool durability and energy conservation are critical.

1.6 Scope of the Study

This study focuses on the virtual design and analysis of a compounding drill tool using ANSYS Workbench. The scope includes:

- CAD modeling of the drill tool using integrated design software (e.g., CATIA V5 or ANSYS DesignModeler).
- Simulation of static structural and thermal loading conditions.
- Material selection based on common engineering alloys used in drilling applications.
- Limiting the study to 3D static and thermal analysis (excluding dynamic or fatigue life analysis in this phase).

1.7 Significance of the Study

The development of the Compound Drill Tool – Step Drill with HSS Shank represents a significant step toward solving several practical challenges in the field of machining and manufacturing. This study holds considerable importance for multiple reasons, spanning technical advancement, economic value, and industrial applicability.

Modern industries demand tools that deliver high precision, long life, and efficiency while maintaining cost-effectiveness. In high-speed drilling operations, tool wear and thermal stress are major concerns that can severely affect productivity and accuracy. Traditional drills made from a single material either compromise performance or become cost-prohibitive when used in demanding conditions.

This study introduces a hybrid solution that combines the durability of solid carbide with the economical and adaptable properties of high-speed steel (HSS). By strategically integrating these materials, the drill tool is expected to deliver optimal cutting performance while significantly reducing manufacturing and replacement costs. Such material optimization could serve as a model for future tool development in cost-sensitive yet performance-critical applications.

The use of step drill geometry also offers multifunctionality by allowing multiple diameters to be drilled in a single operation. This reduces cycle times, enhances production rates, and minimizes tool changeovers—an advantage particularly valuable in mass production environments like automotive, aerospace, and heavy equipment manufacturing.

Additionally, the soldered joint between the carbide and HSS components introduces an opportunity to study material compatibility and joint behavior under mechanical and thermal loading. Evaluating the strength and reliability of such a joint is not only crucial for this particular tool but also applicable to a wide range of multi-material tooling solutions.

Through this study, simulation tools like ANSYS Workbench are employed to analyze the performance of the compound tool before physical testing. This virtual validation process not only reduces prototyping costs but also allows for rapid design iterations. It provides insights into stress concentration zones, thermal conductivity distribution, and joint integrity, which can lead to improved designs and higher operational safety.

Moreover, this study encourages the integration of CAD–CAE workflows, bridging the gap between theoretical design and real-world performance. It emphasizes the importance of finite element analysis (FEA) in evaluating complex engineering components and highlights how computational tools can lead to smarter, faster, and more sustainable manufacturing decisions.

On an academic level, this research contributes to the growing body of knowledge in tool design, materials science, and simulation-based engineering. It provides a practical case study for students and professionals looking to understand the impact of design optimization and hybrid material usage in tooling applications.

From an industrial standpoint, companies adopting this hybrid tool design could benefit from increased tool life, reduced inventory of specialized tools, and improved quality of drilled components. This aligns with current trends in lean manufacturing, cost optimization, and performance-based engineering.

In summary, this study is significant not only because it proposes an innovative and practical tool solution but also because it integrates design, materials, and simulation methodologies to address real-world manufacturing challenges. Its findings have the potential to influence future developments in cutting tool technology and contribute to more efficient, economical, and environmentally responsible production processes.

CHAPTER 2

LITERATURE REVIEW

2.1.Introduction

This literature review compiles recent advancements in compound drilling tools, vibration-assisted techniques, and measurement-based drilling methods. Studies have explored innovative tools and technologies aimed at enhancing drilling efficiency, reducing operational costs, and improving hole accuracy across various applications.

2.2.Review of Literature

Aziz et al. (2007) focused on fabricating micro tools consisting of a micro flat drill and an electroplated diamond grinding part for finishing. They identified optimal drill point angles that minimize burr formation and improve hole quality. Furthermore, ultrasonic vibration during machining was found to reduce machining force, enhancing tool performance. Their work emphasizes improving product quality by combining drilling and finishing into a single-step process, which reduces manufacturing time and costs. The study also addresses the challenges of burr formation and tool wear, suggesting that different drill point angles influence the size and progression of burrs, with a 118° point angle showing the best balance between burr reduction and tool longevity.

Li et al. (2021) conducted a simulation study on compound percussive drilling, focusing on the dynamic interaction between a single cutter and rock during drilling. Using a 3D finite element model, the research examined how different variables, such as impact velocity, dynamic load amplitude, and the ratio of torsional to axial impact frequencies, influenced cutting forces and penetration depth. The study found that increasing the torsional impact frequency improved penetration depth, but an optimal ratio of axial to torsional impacts existed, beyond which the efficiency declined due to stick-slip vibrations. The simulations also highlighted the adaptability of compound percussion drilling to various rock types, demonstrating its effectiveness in both soft and hard formations. The study's findings align well with field experiments, showcasing a 49% improvement in penetration rate compared to traditional drilling methods.

Wang et al. (2018) introduced a novel torque clutch drilling tool aimed at reducing drag in horizontal and extended reach wells. Their tool integrates a clutch, hydraulic system, and monitoring system, each playing a crucial role in minimizing axial friction. The tool can efficiently transfer torque and reduce drag during directional drilling by separating or meshing gears based on hydraulic pressure. Their studies showed that the tool could reduce axial drag by over 30%, improving the transfer of weight to the drill bit. This innovative design helps enhance drilling efficiency in complex wellbore configurations, offering a practical solution to the challenge of excessive drag during drilling

Jaware et al. (2024) focused on the development of a compound die used in the Piaggio product manufacturing plant. The research introduced a tool that combines two separate operations, blanking and piercing, into a single press cycle, thus reducing downtime and operator fatigue. The study demonstrated that using a single press for both operations increases production efficiency and decreases the time and labor required for manufacturing components like the Piaggio battery support bracket and cradle assembly. The compound die design also contributes to reduced operational costs and improved product precision.

Zhu et al. (2022) provided a comprehensive review on the temperature management in the drilling process, which is critical for improving tool life, hole quality, and overall process efficiency. The study explores various aspects of drilling tool temperature, including theoretical analysis, thermal modeling, and the impact of cutting parameters, tool geometry, and hole-making methods on temperature. They also discuss methods for measuring drilling temperature, such as contact, non-contact, and indirect measurement techniques. Furthermore, the paper highlights several temperature control methods, such as minimum quantity lubrication (MQL), air cooling, and cryogenic cooling. The review emphasizes the importance of controlling temperature to minimize tool wear and maintain surface integrity, especially in advanced materials like titanium alloys and CFRP, which are challenging to machine due to their high thermal sensitivity

Yang et al. (2020) conducted an in-depth study on the working mechanism of Polycrystalline Diamond Compact (PDC) drill bits in compound drilling. The research focused on the integration of ground-driven and down-hole-driven motors, which significantly enhance the penetration rate of PDC bits but also reduce bit life due to high friction and nonparallel scraping. The authors developed a kinematic model to analyze the cutting trajectory of PDC cutters, taking into account various factors such as the transmission ratio, cutter layout, and drill string geometry. Their study concluded that nonparallel scraping and unbalanced contact states between the cutters and rock are primary factors that improve penetration rate. Furthermore, the paper discussed how the PDC bit's cutting process resembles "milling" rather than traditional drilling due to the dynamic interaction between the cutters and the rock, leading to more efficient rock-breaking and increased bit performance.

Sun et al. (2024) explored the formation damage mechanisms in shale reservoirs caused by the combined effect of drilling fluid and fracturing fluid. The study focused on understanding how drilling fluid can penetrate shale reservoirs through natural and induced fractures, leading to mineral erosion and weakening the mechanical properties of the shale. The authors introduced a method to predict the dynamic invasion depth of drilling fluids, showing that such fluids can erode shale minerals and cause fracture closure, leading to decreased fracture conductivity. In addition, during hydraulic fracturing, the interaction between drilling and fracturing fluids worsens the damage, promoting stress-sensitive and solid blocking damage, significantly impacting the production potential of shale oil and gas wells. The paper suggests multiple strategies, such as improving leakage and collapse prevention, using chemical films for protection, and optimizing fracturing fluid systems, to mitigate these damages and enhance shale reservoir protection.

Hasan et al. (2017) provided a comprehensive review on modern advancements in micro drilling techniques, focusing on both conventional and non-conventional methods. The paper highlighted the increasing demand for micro drilling in industries like electronics, aerospace, and medicine due to the miniaturization of products.

Conventional micro drilling methods include twist, spade, D-shaped, single flute, compound, and coated drills, while non-conventional techniques involve electrical, chemical, mechanical, and thermal methods, such as laser, EDM, ECM, and ultrasonic vibration. The study presented a comparative analysis of these techniques, emphasizing their advantages and disadvantages in terms of precision, hole quality, speed of production, and application suitability. This review aimed to set future directions for micro drilling, especially focusing on improving tool life, hole quality, and reducing burr formation.

Qian et al. (2011) designed a compound tool for spot facing machining that integrates drilling, reaming, and chamfering functions into a single tool, aimed at improving efficiency in large batch production. Traditionally, these tasks are performed using separate tools and stages, which results in higher equipment usage, lower productivity, and challenges in maintaining hole accuracy. By combining the three operations into one tool, the compound tool not only reduces the number of tool changes and setups but also enhances machining accuracy. The paper discusses the detailed design of the tool, including the structure, material selection for the cutting part, and cutting parameters. It also provides a reference for cutting parameters and describes the complex manufacturing process of such a multi-functional tool. The study emphasizes that the compound tool significantly improves machining efficiency, reduces costs, and alleviates worker labor intensity, while offering potential for wider applications by altering the tool's structure and materials.

Merino-Pérez et al. (2016) investigated the influence of workpiece constituents and cutting speed on cutting forces during the drilling of carbon fiber reinforced polymer (CFRP) composites. Their study found that the type of resin and the number of consecutive holes drilled had a significant impact on both thrust force and torque, while cutting speed and the type of carbon fiber fabric exhibited minimal effects. The research showed that higher cross-linked resins, such as MTM44-1, contributed to greater mechanical strength and higher thrust forces. Moreover, the number of consecutive holes drilled increased tool wear, which subsequently led to higher thrust forces. The findings also indicated that cutting speeds within the low-to-mid range provided a good balance between tool wear, torque, and machining efficiency.

Reiffsteck et al. (2018) explored the potential of using drilling parameters to enhance geotechnical investigations. The study focused on the technique of measuring while drilling (MWD), which involves observing and recording various drilling parameters such as advance rate, penetration thrust, rotation rate, torque, and drilling fluid pressure. This technique has been used since the 1970s for qualitative subsurface descriptions but was evaluated in this study for its potential to provide quantitative data. The study was conducted at a specially constructed test embankment with eight distinct soil zones, including gravel, sand, silt, clay, and reconstituted chalk. The authors investigated how drilling methods (rotary drilling vs. rotary percussive drilling) and drilling parameters could offer valuable insights into subsurface stratigraphy. The results suggested that compound drilling parameters, derived from a combination of individual drilling metrics, could provide geotechnical engineers with a reliable and continuous profile of subsurface conditions, which is critical for constructing accurate geological models.

Zhang et al. (2025) investigated the development and application of high-performance drilling hole protection materials, focusing on foam concrete used in gas extraction boreholes. The study addressed the challenges posed by borehole instability and collapse during deep coal seam extraction, which can significantly affect gas extraction efficiency. The authors developed an innovative composite foaming agent derived from human hair slag, which enhances the stability and strength of foam concrete. The research demonstrated that foam concrete, when combined with screen pipes, can offer both internal and external protection for boreholes, effectively preventing collapse and improving gas extraction performance. Their findings indicate that foam concrete with optimal mix proportions showed impressive compressive strength, permeability, and porosity, making it an effective and environmentally friendly solution for borehole protection.

Tian et al. (2022) conducted a harmonic response analysis of drillstrings in compound drilling to improve borehole quality. The study aimed to understand the vibration characteristics of drillstrings, particularly focusing on resonance and its impact on drillstring failure. They utilized the finite element method (FEM) to model the drillstring dynamics and performed an in-depth analysis of longitudinal, torsional, and lateral vibrations. The study identified the excitation frequencies that could cause resonance, leading to local stress concentrations and potential drillstring damage. The research also explored various vibration control measures, including absorbers, to reduce vibration amplitudes and prevent detrimental effects from resonance. The findings emphasized the importance of controlling drillstring vibrations during compound drilling to avoid failures and improve wellbore quality. The authors recommended optimizing drilling parameters and controlling resonance at low-order inherent frequencies to reduce vibrations and enhance drilling performance.

Gao et al. (2022) reviewed the technological advances in drilling and completion techniques for high-efficiency coalbed methane (CBM) development in China. The study highlighted the challenges posed by China's coalbed methane reservoirs, which typically have low formation pressure, low permeability, and strong heterogeneity. The paper emphasized the use of horizontal drilling and advanced well completion technologies, such as multi-branch horizontal wells, dual-string tubular strings, and radial horizontal well screen pipe completions. These technologies are crucial for overcoming the difficulties associated with CBM extraction in low permeability coal seams. The authors noted the necessity for ongoing research to refine drilling and completion technologies to improve well production and recovery factors, particularly for coal seams with complex geological structures. Additionally, the paper introduced the concept of the "underground well factory," which integrates advanced drilling technologies to efficiently develop CBM and coal resources.

Pecat and Brinksmeier (2014) explored the tool wear behavior in low-frequency vibration-assisted drilling (LFVAD) of CFRP/Ti6Al4V stack materials. The study focused on comparing LFVAD with conventional drilling methods to understand the effects on tool wear, cutting temperatures, and process stability. The findings revealed that LFVAD significantly reduced tool wear and cutting temperatures. The study highlighted that the abrasive nature of carbon fibers in CFRP causes considerable wear on the tools, especially in conventional drilling. However, LFVAD enhanced chip extraction and reduced thermal loads, leading to a smoother progression of flank wear and higher tool life. The study also found that different coatings on the tools (such as AlCrN and TiAlN) exhibited varying wear patterns, with AlCrN coatings showing the best performance. The research concluded that LFVAD could be a promising method for improving the drilling of complex material stacks like CFRP and titanium.

Sun and Cui (2016) analyzed the stress distribution and breakage mechanisms of micro drills used in drilling operations, using finite element analysis (FEA). The study focused on the forces acting on the micro drill, including thrust, torque, and radial forces, which contribute to stress concentrations and potential breakage. They developed a 3D model of a micro drill with a diameter of 0.4 mm, considering various parameters such as the drill's geometry, material properties, and loading conditions. The analysis revealed that the most significant stress concentrations occurred at the cutting edge, chisel edge, spiral element, and root, leading to potential failure modes like tip ripping, spiral twisting, or crushing. The study provided a detailed investigation into how stress levels affect tool wear and failure, and highlighted the importance of selecting the appropriate material and geometry for improving tool life. The results from the simulation were validated through experimental tests, showing good correlation between simulated and actual performance, suggesting that FEA could be effectively used for predicting micro drill performance and breakage

Abhinav et al. (2024) investigated the potential of measurement while drilling (MWD) for detecting soil profiles encountered during exploratory drilling. MWD, an instrumented drilling technique, records drilling parameters such as drilling rate, rotational speed, thrust, and torque in real-time. While MWD has been widely used in the energy industry, its application in geotechnical engineering has been limited due to the lack of a comprehensive database and systematic analysis of how drilling parameters correlate with changing subsurface stratigraphy. This study aimed to address this gap by performing exploratory drillings with an instrumented drill rig, measuring MWD parameters, and calculating compound parameters. The study assessed the predictive capabilities of these parameters in determining soil stratigraphy by training machine learning models, including decision trees, random forests, and neural networks. The results showed that the XGBoost model achieved the highest accuracy of 0.85 in predicting soil profiles. The research demonstrates that MWD, combined with machine learning models, can be a cost-effective and efficient alternative to traditional site investigation methods, offering potential for future geotechnical research and site assessments.

Tian et al. (2025) explored the dynamic characteristics of the drill string system used in horizontal wells, focusing particularly on the implementation of a Sliding Drilling Controller (SDC) to improve drilling efficiency. The study introduced a new approach to solving issues related to friction and reduced weight on the bit (WOB) in horizontal well drilling. By using modal analysis, the authors developed a dynamic model of the drill string system, incorporating axial-torsional coupled vibrations during both sliding and compound drilling. The research highlighted that increasing the weight on bit (WOB) significantly improved friction and drag reduction, while the influence of increasing rotary torque was less pronounced. The study further examined how the coupling correlation between axial and torsional vibration frequencies is weak when external loads are neglected. The findings provide valuable insights into optimizing the design and operational parameters of drill string systems for more efficient horizontal drilling.

Wang et al. (2021) conducted a numerical simulation study to investigate the rock-breaking process and mechanisms under compound impact drilling. The study developed a model using cohesive elements to simulate the dynamic rock-breaking behavior under compound axial and torsional impacts. This method aims to improve rock-breaking efficiency in hard rock formations, which is crucial for drilling performance in deep wells. The researchers simulated the impact process on sandstone to verify the model's effectiveness and studied the impact parameters, such as load amplitude, angle, and duration. Their results showed that the stereoscopic crushing effect can be achieved under compound impact, leading to enhanced rock fragmentation. The study identified optimal parameters, such as an impact angle of 30° and a duration of 2.5 ms, for maximizing rock breakage. The research provides a deeper understanding of rock-breaking mechanisms, helping improve the design of compound impact drilling tools for better efficiency

Huang et al. (2023) conducted a comprehensive numerical study on the rock-breaking mechanism in hard rock using a full Polycrystalline Diamond Compact (PDC) bit model in compound impact drilling. The study aimed to improve drilling efficiency in hard formations such as geothermal reservoirs, which present challenges due to high stress and hardness. The authors employed the Drucker–Prager criterion for the rock constitutive relation and used equivalent plastic strain to evaluate rock failure. They built a full-size 3D simulation model of a PDC bit, analyzing the impact of axial and torsional forces on rock-breaking efficiency. The results indicated that compound impact drilling reduces torque fluctuations, alleviates stick-slip vibration, and significantly improves drilling efficiency compared to conventional drilling. The study also explored the optimal impact vector angle and duration, with findings suggesting that the most efficient range for these parameters was between 30° and 50° for the impact angle, and 0.8 ms to 1.0 ms for impact duration.

Dai et al. (2025) proposed an innovative drilling parameter control method based on online identification of drillability and multi-objective optimization. The study addresses the challenges posed by complex geological environments in coal mining, where drilling parameters are often difficult to adjust in real-time. The authors introduced a drillability identification model using real-time drilling parameters like rotational speed and torque. By using multi-objective optimization models, the authors aimed to optimize the drilling parameters based on mechanical specific energy and drilling speed, with the NSGA-II algorithm and TOPSIS method used for solutions. They incorporated a fuzzy PID controller to adjust rotational speed and drilling pressure parameters. Through experimental verification, the results showed that the fuzzy PID method outperformed traditional PID control, offering faster response times and reducing overshoot. This adaptive control system improves drilling efficiency, reduces risks like sticking, and ensures a stable drilling process by dynamically adjusting parameters to optimal values.

Du et al. (2018) investigate the impact of copper-clad laminate (CCL) inorganic fillers on the hole performance during the drilling process of printed circuit boards. They identify that drilling brittle laminates can result in common issues such as hole cracking, delamination, and drill-bit wear. The authors highlight that factors such as filler content, type, hardness, particle size, and compounding methods significantly influence drilling performance. They note that higher filler content, larger particle size, and harder fillers generally result in worse drilling quality. Additionally, the combination of hard particles like silica with softer particles can improve the overall drilling performance of CCL.

Koklu and Basmaci (2017) examine the impact of tool path strategies and cooling conditions on cutting forces and surface quality in micromilling. The study focuses on the hatch zigzag and contour climb tool path strategies under varying cooling conditions: dry, air blow, and flood coolant. The researchers found that the contour climb path strategy yielded better performance in reducing cutting forces (by up to 43%) and improving surface quality (by up to 44%) compared to the hatch zigzag strategy. Furthermore, the use of flood coolant significantly reduced cutting temperature and effectively removed chips, thereby enhancing surface quality. The findings underline the importance of selecting appropriate tool path strategies and cooling techniques to mitigate issues such as tool wear, burr formation, and poor surface finish, which are common challenges in micromilling.

Swain et al. (2016) investigated the micro-drilling of Nimonic 80A, a nickel-based superalloy, using uncoated and TiAlN-coated micro-drills. The study focused on tool wear, surface roughness, and hole quality, analyzing the effects of cutting speed, feed rate, and drill diameter. Their findings demonstrated that TiAlN-coated micro-drills significantly outperformed uncoated ones in terms of wear resistance, surface quality, and hole diameter consistency. The TiAlN coating reduced tool wear and burr formation, which are critical challenges in micro-drilling of superalloys. The study provided valuable insights into optimizing machining conditions for better tool life and hole quality, particularly in aerospace applications. This research highlights the importance of selecting appropriate micro-tools to enhance performance and reduce operational costs in the machining of hard-to-machine materials like Nimonic 80A.

Zai et al. (2021) explored the effects of ultrasonic-assisted high-speed drilling (UAHD) on the exit burr height during micro-holes drilling in titanium alloy. The authors proposed an analytical model to predict the height of the exit burr, incorporating the acoustic softening effect and the conservation of energy. Experimental investigations confirmed the validity of the model, showing that exit burr height was negatively correlated with ultrasonic amplitude and spindle speed, while positively correlated with feed speed. Their study revealed that higher ultrasonic amplitude, increased spindle speed, and reduced feed speed led to more accurate micro-hole exits, thus improving hole quality. This research highlights the importance of processing parameters in controlling burr formation, contributing valuable insights into the optimization of micro-drilling processes in titanium alloys.

Kudla (2001) investigates the influence of feed motion characteristics on the drilling process of small holes, particularly those with diameters less than 1 mm. The study emphasizes the need for precision machines that ensure sensitive and accurate feed motion to prevent drill breakage and improve hole quality. Kudla discusses various feed drive systems applied in precision drilling, highlighting their methods and attributes in reducing the risk of tool failure. The paper also focuses on optimizing feed motions to improve hole quality and minimize production time increases. This research provides valuable insights for enhancing the efficiency and precision of small-hole drilling operations.

Kim et al. (2009) investigate the effectiveness of peck drilling and thrust force monitoring in improving tool life during deep-micro-hole drilling of steel. The study highlights the issues associated with micro-drilling, such as insufficient cutting fluid supply and poor chip removal, which lead to tool breakage, especially with high aspect ratio holes. The authors propose an optimized peck drilling method using thrust force signal monitoring to enhance tool life. Their findings indicate that the proper one-step feed-length (OSFL), determined through thrust force monitoring, significantly improves drilling stability and tool longevity. The optimal OSFL for deep-micro-hole drilling in steel was found to be about a tenth of the tool diameter, thus preventing unexpected drill failure. This study contributes to the development of methods for stable, efficient micro-drilling operations in precision machining.

Wang et al. (2012) conducted an experimental investigation into the drilling of through-holes in printed circuit boards (PCBs), focusing on drill wear and burr size. Their study reveals that chisel edge thinning significantly reduces flank wear, a common issue in drilling operations, but does not have a noticeable effect on reducing burr size. The results were derived from experiments using both standard and specialized drills. This research underscores the importance of optimizing drill geometry to enhance tool life and minimize wear during PCB through-hole drilling.

However, the study also indicates that while certain modifications can improve tool wear, they do not directly address burr formation, highlighting the need for further process optimizations to address both tool wear and hole quality in PCB manufacturing.

Zhan et al. (2014) focus on optimizing the grinding parameters for manufacturing polycrystalline diamond (PCD) micro-milling tools, a crucial process in micromachining. They employed the Taguchi orthogonal array to design experiments around four grinding parameters: PCD compact grain size, abrasive wheel grain size, grinding speed, and feed rate. The study evaluates grinding forces and cutting edge radius as key metrics, with ANOVA results indicating that PCD compact grain size has the greatest influence on the grinding process. Their research culminates in the fabrication of a quadrilateral PCD micro-milling tool with an 80 μm cutting edge diameter using the optimized grinding parameters. This study provides valuable insights for enhancing the performance and precision of micro-milling tools, particularly in the context of PCD machining.

Lin and Tzeng (2007) propose a new method for the precise mathematical modeling and CNC control of a 6-axis grinding workstation to thin twist drill points. Traditionally, drill reconditioning focuses on thinning the web to restore the chisel edge length, but recent designs integrate thinning into the original drill design to reduce torque and tool forces. The authors introduce a system that determines the position and orientation of the grinding wheel based on the evaluated rake and clearance angles according to ISO standards for 2-flute twist drills. Their method enhances drill design and manufacturing by facilitating more accurate thinning specifications. The paper demonstrates the model with experimental drills produced to identical ISO standards, with one drill thinned to illustrate the method's practical application. This work is crucial for drill design, particularly in applications requiring controlled rake angles and advanced research in drill point design.

Sa (2020) investigates the development of a specialized tungsten carbide drill tool designed for drilling carbon fiber-reinforced plastics (CFRPs), which are commonly used in aerospace, automotive, and shipbuilding industries due to their high strength-to-weight ratio. The study focuses on evaluating the effects of diamond coating thickness on tool performance, surface quality, and tool wear. Through experiments, it was found that a 12 μm-coated drill performed better than a 6 μm-coated one, offering superior bore exit quality and reduced burr formation. The research highlights the critical impact of drill coating on the surface roughness and the overall quality of CFRP drilling, emphasizing the benefits of using a thicker diamond coating for improved tool life and surface finish. This study contributes to the development of more efficient and durable tools for CFRP machining.

Patel and Verma (2015) provide an in-depth review of factors influencing drilling tool life, emphasizing various parameters such as force, feed rate, tool material, tool geometry, and minimum operating quality (MOQ). The study outlines how these factors contribute to the wear and tear of the drill bit during the drilling process, which involves a rotary cutting tool used to create circular holes in solid materials. The authors discuss how the cutting edge of the drill bit is subjected to high forces, leading to chip formation and material removal. Their review highlights the complexity of tool life management in drilling operations, where optimizing these parameters is critical for enhancing tool longevity and performance. This research offers valuable insights for improving the efficiency and durability of drilling tools in industrial applications.

Gutiérrez et al. (2023) investigate the tool wear behavior of two drill bits, each coated with different processes Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD) used in drilling carbon/glass fiber hybrid composites bounded with epoxy polymer. Their study focuses on the evolution of flank wear and crater wear across 1403 drilled holes, as well as the impact of these wear modes on hole quality and delamination. The results indicate that the coating process significantly influences wear and delamination patterns. The CVD-coated tool exhibited severe crater wear and coating loss at the cutting edges, while the PVD-coated tool showed controlled flank wear but more significant coating loss and edge rounding, which led to increased delamination. The use of a supporting plate reduced delamination type I but had no effect on type II. This research highlights the importance of tool coating and wear in drilling composite materials and its implications for hole quality and delamination.

Li et al. (2021) propose a standardized calculation equation for the bit rotation speed in composite drilling, aiming to reduce the impact of bit rotation speed on drilling operations and enhance oil and gas reservoir evaluations. The study integrates factors such as the performance of the screw drill, weight on bit (WOB), deviation, and rock-breaking mechanisms. A planetary gear train transmission model is introduced to improve the accuracy of the bit rotation speed prediction. The standardized equation is tested on wells 723 and 6-2x, with the results showing consistency between the predicted and actual bit speeds. This research provides a theoretical foundation for optimizing drilling technologies and improving the efficiency of drilling operations in the oil and gas industry.

Zhu et al. (2022) provide a comprehensive review on the advancements in drilling tool temperature, emphasizing its critical role in tool performance, machining efficiency, and wear. The review addresses the thermal phenomena that arise during the drilling process, as most of the energy consumed in metal cutting is converted into heat, which significantly raises the temperature. The paper systematically analyzes various aspects of drilling tool temperature, including theoretical models, thermal measurement methods, and the effects of cutting parameters, tool geometries, and hole-making techniques on temperature. Additionally, it discusses temperature control strategies using different cooling methods. The authors also propose future research directions to improve the understanding and management of tool temperature, which is essential for enhancing the performance and longevity of drilling tools. This review serves as a valuable resource for researchers and professionals seeking insights into improving drilling processes.

Wang (2022) presents a study on the development of a drilling and expanding integrated bit designed to enhance the efficiency of coal seam gas extraction. This method aims to address issues like outburst coal seams, high gas emissions, and the need to improve coal seam permeability. The study details the mechanical analysis of high-pressure water jets combined with coal breaking mechanisms in drilling teeth. The optimization of bit and nozzle design, including the use of diamond composite chips (PDC) for increased hardness, is highlighted. Numerical simulations suggest optimal nozzle configurations, including radial and axial nozzles with a contraction angle of 13° to 15°. Field tests demonstrate the effectiveness of this integrated bit, showing a significant increase in borehole diameter after reaming, improving the pressure relief and coal seam permeability. This research provides valuable insights into enhancing drilling and reaming operations in coal mining.

Pereszlai and Geier (2020) present a comparative analysis of three hole-making technologies wobble milling, helical milling, and conventional drilling used in machining carbon fiber-reinforced polymers (CFRPs), a material widely employed in aerospace due to its excellent mechanical properties. The study highlights the challenges of drilling CFRPs, including material inhomogeneity, anisotropy, and the strong wear effects of carbon fibers. The authors focus on wobble milling, a novel technology developed to minimize defects such as delamination and uncut fibers. Their experiments, conducted on unidirectional CFRPs, assess the impact of cutting tools and process parameters on hole quality, including diameter, circularity error, and uncut fiber characteristics. The findings show that wobble milling significantly reduces the amount of uncut fibers compared to conventional drilling and helical milling, providing a more effective method for manufacturing high-quality holes in CFRPs.

Prakash et al. (2022) focus on optimizing the drilling parameters for LM6/B4C/Fly ash hybrid composites, a promising metal matrix composite (MMC) used in various industries like aviation, nuclear power, and automotive. Their study aims to enhance drilling outcomes such as surface roughness (SR) and burr height (BH), which are critical for achieving high dimensional accuracy and minimal tool wear in composite materials. Using Taguchi's design of experiments (DOE) method, the study optimizes four input parameters: feed rate, spindle speed, drill material, and percentage of reinforcement. The results show that for surface roughness, the optimal parameters are 50 mm/min feed rate, 3000 rpm spindle speed, TiN-coated drill bit, and 6 wt.% reinforcement, while for burr height, the best conditions are the same feed rate and spindle speed, with 9 wt.% reinforcement. This research provides valuable insights into the efficient drilling of hybrid composites, enhancing both process efficiency and tool performance.

2.3.Research gap

In spite of major advances in compound tools and vibration-assisted technologies, there are still some gaps. First, there is limited literature on combining compound tools in various geological environments, particularly in soft and hard rock formations. Second, real-time optimization of drilling parameters for various subsurface conditions is still an under researched area. Moreover, the long-term impacts of advanced drilling technologies on tool wear and bit life need to be researched further. There is also limited research on the application of machine learning to predict drilling performance and parameter optimization in real-time. Lastly, although measurement while drilling (MWD) has been applied in the energy sector, its use in geotechnical engineering for continuous subsurface profiling requires further development.

CHAPTER 3

RESEARCH METHODOLOGY

Research Methodology Introduction: Development of a Compounding Drill Tool

The research methodology gives the study of Development of a Compounding Drill Tool, outlines the systematic approach adopted to design, develop, and evaluate a novel drilling tool capable of performing multiple machining operations simultaneously. As industries aim to optimize manufacturing processes through innovation, the demand for multifunctional tools that enhance productivity, reduce operational time, and improve machining precision has increased significantly. In this context, the compounding drill tool is conceptualized as a hybrid mechanism combining drilling with additional operations such as countersinking, reaming, or tapping depending on design requirements.

3.1.Introduction

This research employs a design-based methodology involving computer-aided design (CAD), finite element analysis (FEA), material selection, and prototyping. Experimental methods are applied to test the performance of the developed tool under controlled machining conditions. The study further integrates comparative analysis to evaluate the performance of the compounding drill tool against conventional single-function tools based on parameters such as machining time, surface finish, dimensional accuracy, and tool wear. The methodology is structured to ensure that the tool not only meets functional expectations but also adheres to standards of safety, durability, and economic feasibility.

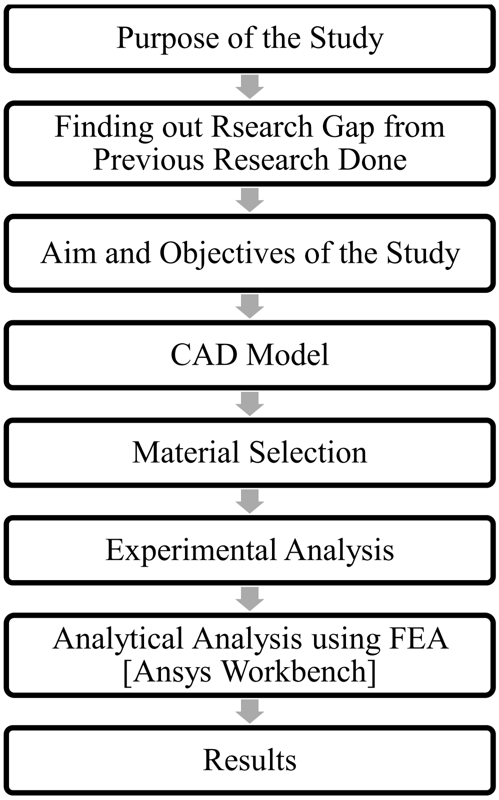


Fig.3. 1 Research Methodology FlowChart

Flowchart gives outline in given below:

Purpose of the study

The research begins with identifying the core motivation for developing a compounding drill tool. This involves recognizing the need for increasing machining efficiency by integrating multiple functions (e.g., drilling, reaming, countersinking) into a single tool to reduce tool changes, operational time, and improve productivity in manufacturing processes.

Finding out Research Gap from Previous Research Done

A thorough literature review is conducted to identify limitations in existing drill tools and hybrid machining systems. Gaps such as lack of versatility, lower durability, limited multi-functionality, or performance inefficiencies are documented to establish the need for a new design.

Aim and Objectives of the Study

This step involves defining measurable goals, such as:

- Designing a multifunctional drill tool using CAD.
- Selecting the appropriate material considering strength, wear resistance, and machinability.
- Conducting both experimental and analytical evaluations.
- Comparing results with conventional tools.

CAD Model

A 3D model of the compounding drill tool is created using UG-Nx software. The design includes integrated features to perform multiple operations, ensuring compatibility with standard machining centers. Dimensional accuracy and operational feasibility are considered here.

Material Selection

The appropriate tool material is selected based on mechanical properties like hardness, toughness, wear resistance, and thermal stability. Common materials could include High-Speed Steel (HSS), Tungsten Carbide, or coated alloys, chosen according to application-specific needs.

Experimental Analysis

A prototype of the designed tool is fabricated, and practical tests are conducted on selected workpieces. Parameters such as:

- Tool performance (cutting force, torque)
- Surface finish
- Operation time

- Tool wear is recorded and analyzed to validate the design under real-world machining conditions.

Analytical Analysis using FEA [ANSYS Workbench]

To supplement experimental findings, Finite Element Analysis (FEA) is performed using ANSYS Workbench. The tool model is tested virtually for stress, strain, deformation, and thermal distribution under simulated working conditions. This analysis helps in identifying weak zones and optimizing the design before commercialization.

Results

Finally, results from both experimental and analytical methods are compiled. A comparison is made between the compounding drill tool and conventional tools, highlighting performance improvements, structural integrity, and effectiveness. These findings help conclude the feasibility and advantages of implementing the developed tool in industrial applications.

This methodology ensures a comprehensive approach starting from conceptual understanding and gap identification, moving through design and validation, and ending in performance evaluation to ensure that the compounding drill tool developed is innovative, reliable, and ready for industrial use.

3.2.Problem Statement

In current machining operations, producing high-precision, burr-free holes while retaining cost-effectiveness and tool lifetime remains a considerable problem. Traditional twist drills sometimes need resharpening and may not consistently provide the proper surface polish, particularly when used on tougher materials. Step drills provide higher hole quality and less burr development; but, when made completely of high-speed steel (HSS), they wear fast and need reshaping, which is impossible due to their complicated shape. In contrast, although solid carbide tools have great wear resistance and performance on hard materials, their expensive cost limits their use. As a result, there is a need to create a compound drill tool that intelligently blends solid carbide for the cutting (step drill) section with HSS for the shank, linked by soldering. This strategy seeks to strike a balance between performance, affordability, and durability. However, the mechanical strength and dependability of the soldered junction must be evaluated under various machining settings, especially to assure compatibility with both pillar drills and conventional machines. Addressing this issue via CAD modeling and ANSYS-based simulation is critical for confirming the tool's structural integrity and operating practicality.

The new model is called Compound Drill Tool - Step Drill with HSS Shank. It is developed in the UG NX12 CAD program and has a total drill diameter of 20 mm. The total length of the tool is 160.34 mm. The cutting portion (step drill) is composed of solid carbide for better wear resistance and performance on hard materials; however, the shank part is made of highspeed steel (HSS) to save money and be compatible with a variety of machine holders. Soldering is used to attach the two portions, which ensures joint strength and good torque transfer during drilling operations.

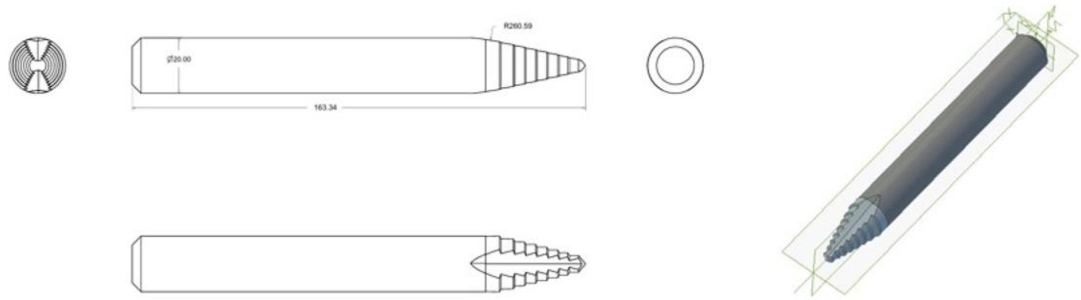


Fig.3. 2 Compound Drill Tool

3.3.Material Selection

Material selection is the process of choosing the most suitable material for a specific application, considering various factors like performance requirements, cost, and manufacturability. It involves evaluating different materials based on their properties and selecting the one that best fulfills the design's needs. Correct materials selection means that products have the optimum performance, longevity in use and cost as well as meeting sustainability requirements. When deciding which material is best for an engineering project, there are various criteria to take into consideration, including:

Mechanical Properties: These properties include factors such as ductility, strength, hardness, toughness and stiffness. They determine how the material will respond to issues such as loads and stresses. **Physical Properties:** These properties include electrical resistance, density and thermal conductivity. They show how the material will interact with the physical world. **Chemical Properties:** These properties demonstrate how a material will be affected by matters like corrosion or reactivity. **Cost:** The cost of a material is also important in materials selection, with some applications requiring and deserving higher-cost materials than others. **Availability:** Rarer materials may not only be more costly, but they can also be harder to source. **Sustainability:** The environmental impact of a material is also an important consideration and means answering questions around life expectancy and ease of recycling. In this study the designing of compound drill tool material was used are HSS and solid carbide.

HSS:

High-speed steel (HSS) is a special kind of tool steel known for its extraordinary hardness, toughness, and tolerance to high temperatures. Its distinctive compositions (iron, carbon, tungsten, chromium, molybdenum, and other elements) allow tools made from high-speed steels to tolerate high mechanical loads and keep their cutting edge even at high temperatures. High-speed steels (HSS) form a class of iron-based alloys that excel in cutting applications compared to traditional high-carbon steels. They are exceptionally hard, abrasion-resistant, and resistant to softening at high temperatures. These characteristics, which come from the alloy additions and particular heat treatments, enable HSS to cut materials effectively and quickly.

High-speed steel (HSS) undergoes a meticulously controlled series of steps to achieve its exceptional properties. It starts with refining and alloying the steel, followed by forging and rolling it into saleable forms. Heat treatment is a critical aspect of HSS production, involving phases like annealing, austenitization, and martensitic transformation. Annealing reduces hardness, followed by austenization, where high heat alters the crystal structure for carbon absorption. Martensite forms when steel is rapidly cooled, making it hard but brittle. HSS is an alloy of carbon and iron, with additional elements added for specific characteristics. Molecular modification through heat treatment rearranges the atomic structure, providing the steel with desired properties. This process requires precision and uniformity at each stage, and it includes steps like pre-heating, heating, quenching, and tempering. Depending on the steel type and intended use, additional treatments such as cryogenic freezing may be necessary to achieve the desired properties. Factors like temperature and time must be carefully controlled to ensure quality, as variations can lead to either expansion or shrinkage in the final product, impacting its mechanical properties.

High-speed steels (HSS) are generally harder than tool steels. The high-speed steels are specifically designed to withstand higher temperatures and maintain their hardness at high cutting speeds. High-speed tool steels have tungsten and molybdenum contents that sum to at least 7%, and at least 0.6% carbon. They may also contain additions of vanadium, carbon, and other elements. These alloys offer superior strength and hardness compared to traditional tool steels. Nonetheless, tool steels exhibit excellent hot toughness and exceptional resistance to wear when exposed to elevated temperatures.

The machinability rating of high-speed steels is typically in the range of 20-40%. The machinability rating of high-speed steels, typically in the range of 20-40%, represents the percentage relative to a baseline material, which is usually a standard reference material like AISI 1112 steel. This means that these steels are 20-40% more difficult to machine compared to the baseline material. This percentage reflects the moderate difficulty in machining due to their high hardness, wear resistance, and alloying elements. These properties lead to increased tool wear and heat generation during cutting processes. To mitigate these issues, selecting the right cutting tools, optimizing cutting parameters, and employing effective coolant/lubrication strategies are crucial. Proper tool geometry also plays a role in achieving desired machining results while maintaining tool life and workpiece quality.

Fig.3. 3 HSS Drill Tool [www.imetalindia.com, 2023]

Solid Carbide:

Solid carbide is a composite material, primarily tungsten carbide, known for its exceptional hardness, heat resistance, and wear resistance. It's widely used in cutting tools for various industries due to its ability to machine a wide range of materials, including metals, plastics, and composites. The tungsten carbide in solid carbide gives it its hardness and wear resistance, while the binder, usually cobalt, ensures that the material sticks together and has high strength. Solid carbide tools are very durable due to their hardness and wear resistance and can be used under extreme conditions. Solid carbide is also used in other applications, such as in the automotive industry, aerospace, electronics and medical technology. It is an important material for many industrial applications because it has an excellent combination of hardness, wear resistance and strength.

Solid carbide is produced by powder metallurgy, which consists of several steps:

1. Preparation of the starting powders: The starting powders are made from tungsten carbide (WC) and cobalt powder (Co). The particle size and composition of the powders are selected according to the requirements of the end product.

2. Mixing powder: The WC and Co powders are mixed thoroughly to obtain a homogeneous mixture. In some cases, other powders or additives are also added to improve certain properties of the final product.

3. Press: The powder mixture is pressed into a mold to produce the desired shape of the end product. A high pressure (typically 100 to 200 MPa) is usually used to firmly bond the particles.

4. Sintering: The pressed parts are sintered at high temperatures (typically 1,400 to 1,600 °C) under controlled conditions. During the sintering process, the cobalt melts and envelops the toilet particles to form a dense and homogeneous structure. The sintering process also increases the hardness and strength of the solid hard metal.

5. Post-processing: The parts ready for sintering are reworked to achieve the desired shape and surface quality. This may include grinding, polishing, or coating.

The end product is a very hard, wear-resistant and durable material that can be used for a wide range of applications, particularly for tools and components that are exposed to high loads.

Solid carbide is very hard and has a hardness of 8.5 to 9.0 on the Mohs scale. This makes it ideal for tools that have to work under extreme conditions. Due to its hardness and composition, solid carbide is extremely wear-resistant and can be used under extreme conditions for a long time. Solid carbide has high strength and can withstand heavy loads. Solid carbide is resistant to many chemicals, which makes it suitable for many industrial applications. Solid carbide has good thermal conductivity, which makes it very useful in applications such as metalworking and welding. Solid carbide is resistant to corrosion and can also be used in humid or aggressive environments. Solid carbide has low friction and can therefore be used in applications where friction must be minimized. Because of these properties, solid carbide is often used in industry, in particular for tools and components that are exposed to high loads.

Due to its hardness and brittleness, solid carbide is a difficult material to process that cannot simply be recycled or reused. Therefore, it is important to properly dispose of solid carbide waste to prevent potential environmental and health problems. Solid carbide is usually disposed of by specialized recycling companies, which collect and process the material. These companies can either melt down the solid carbide and integrate it into new products, or crush it into smaller particles and reuse it as a starting material for other products. It is important to separate solid carbide waste from other waste streams to avoid contamination of recyclable materials. Solid carbide waste should also not be disposed of in household waste or runoff, as this can cause damage to the environment and wastewater infrastructure.

Fig.3. 4 Solid Carbide Tools [www.la-tools-service.com, 2024]

Table.3. 1 Material Propoerties

Property	**Solid Carbide (Tungsten Carbide)**	**High-Speed Steel (HSS) (AISI M2)**
Modulus of Elasticity (E)	530–700 GPa	200–220 GPa
Poisson's Ratio	0.24	0.30
Ultimate Tensile Strength	344–500 MPa	900–1200 MPa
Ultimate Compressive Strength	2700–5500 MPa	2000–2400 MPa
Yield Strength	Not well-defined (brittle fracture)	700–900 MPa

3.4.Experimental Setup

The experimental setup is a crucial phase in validating the performance and effectiveness of the developed compounding drill tool, which integrates multiple machining operations (e.g., drilling, reaming, countersinking) into a single tool body. The experimental setup is designed to simulate real-world machining conditions and evaluate the tool's mechanical behavior, operational efficiency, and surface quality output. The key components and procedures of the experimental setup are described below:

1. Machine Tool Selection

The experiments were conducted on a conventional vertical milling machine or CNC machining center (depending on precision requirements), which provided the necessary rigidity, spindle speed control, and operational flexibility to mount and test the compounding drill tool.

- **Machine Specifications**:
    - Spindle speed: 0–3000 RPM
    - Feed rate control: Manual or programmed
    - Power: 2–5 HP (for moderate material cutting)

2. Workpiece Material

Standardized metal workpieces were chosen for the tests to ensure repeatability and consistent comparison. Typically used materials included:

- Mild steel (for general machining performance)
- HSS
- Stainless steel (to test tool resistance under harder conditions)

Workpiece dimensions were selected to match the depth and diameter range of the compound tool.

3. Tool Mounting and Alignment

The compounding drill tool was mounted into the spindle using a standard tool holder or chuck (e.g., ER collet or BT/ISO taper). Proper alignment was ensured to maintain tool concentricity and minimize vibrations during operation. Tool runout was checked with a dial indicator before starting the trials.

4. Cutting Conditions

Different combinations of cutting parameters were tested to evaluate the tool performance:

- **Spindle Speed**: 500–1500 RPM
- **Feed Rate**: 50–150 mm/min
- **Depth of Cut**: 1–3 mm depending on the material
- **Coolant Usage**: Dry and wet cutting were both tested to observe tool wear and heat dissipation.

5. Measurement Instruments

Several tools and instruments were used to measure the outputs of the experimental trials:

- **Surface Roughness Tester** – to measure surface finish after machining
- **Tool Makers Microscope or Optical Comparator** – to observe tool wear and dimensional accuracy
- **Digital Vernier Calipers and Micrometers** – for measuring hole diameter and tolerance
- **Dynamometer** (if available) – to record cutting forces and torque during operation

6. Trial Procedure

The tool was run through multiple cycles on identical workpieces under controlled conditions. Each trial tested a specific operation: drilling, followed by countersinking or reaming as per tool design. Tool performance, wear pattern, surface finish, chip formation, and machining time were recorded after each cycle. The tool was inspected after a fixed number of operations to evaluate wear and integrity.

7. Safety and Calibration

All machines and instruments were calibrated before use. Proper safety gear (gloves, goggles, etc.) and standard machining protocols were followed. The experimental station was maintained under adequate lighting and ventilation conditions.

The experimental setup enabled the systematic evaluation of the compounding drill tool under real machining scenarios. The resulting data provided insights into the tool's multifunctional capability, durability, efficiency, and suitability for industrial adoption. The findings also helped in refining the tool geometry and selecting optimal cutting conditions for future applications.

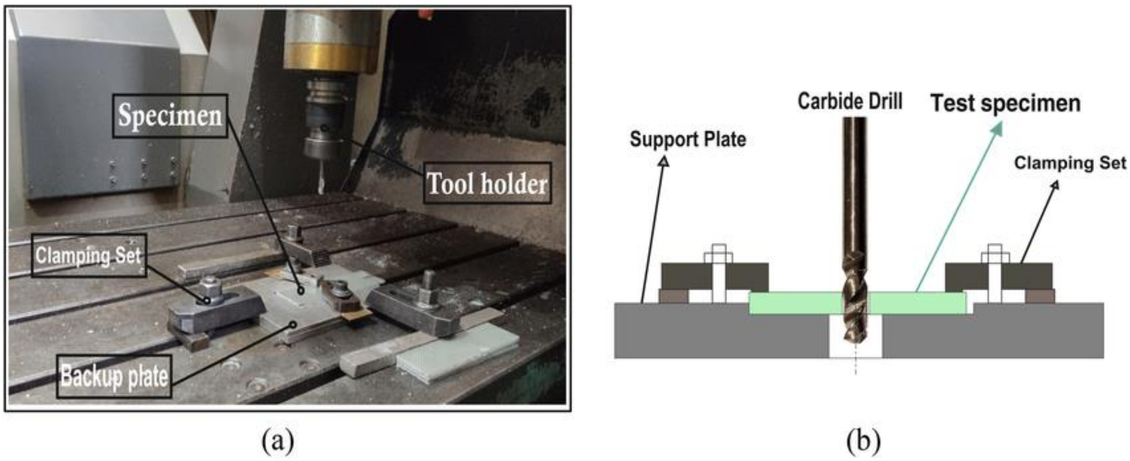


Fig.3. 5 The experimental setup of; (a) the CNC drilling process, and (b) the backup plate. [Amr Seif, 2023]

3.5.Loading Condition in Analytical Study

Loading conditions refer to how forces are applied to an object or structure, influencing its stress and strain distribution. These conditions can be categorized into different modes, including tension, compression, bending, shear, and torsion. Understanding loading conditions is crucial for assessing the performance and stability of structures and materials under various circumstances.

In ANSYS, loading conditions refer to the application of external forces, displacements, pressures, temperatures, or other environmental factors that affect a structure or component during a simulation. These conditions are crucial for accurately simulating real-world scenarios and predicting the behavior of a model. ANSYS offers a wide range of loading options, allowing users to define various types of loads and boundary conditions.

To calculate the cutting load for your compound drill, I need a few more information, including the material being drilled (e.g., steel, aluminum), the cutting speed (in meters per minute), and the feed rate (in millimeters per minute).

Assumed Values:

- **Drill Diameter (D)**: 20 mm
- **Cutting Speed (V_c)**: 100 m/min (This is a typical value for steel; it varies depending on the material)
- **Feed Rate (f)**: 0.2 mm/rev (This is a typical value for drilling steel)
- **Material Constant (C)**: 2 (A typical value for steel, but it varies depending on the material being drilled)

We can use the following formula to estimate the cutting force:

$$F = C \times D \times Vc \times f$$

Where:

- FFF is the cutting force (in Newtons),
- CCC is the material constant (dimensionless),
- DDD is the drill diameter (in mm),

- VcV_cVc is the cutting speed (in m/min),
- fff is the feed rate (in mm/rev).

Convert the cutting speed to mm/min:

Vc=100 m/min×1000=100,000 mm

Now, substitute the values into the formula:

F=2×20 mm×100,000 mm/min×0.2 mm/rev

F = 2 x 20mm x 100,000 mm/min x 0.2 mm/rev

F=8,000,000N

Therefore, the estimated cutting force required is 8,000,000 N (Newtons).

3.6.Tools Used for Model Design and Analysis

Two modern engineering software tools was used to construct and evaluate the compound drill tool, ensuring precision in design and accuracy in analysis. The UG-NX (Unigraphics NX) program was used for 3D modelling and tool design. It has extensive CAD capabilities that enable complicated geometry construction, precision dimensioning, and component assembly, making it suitable for building compound drills with complicated characteristics like as step geometry and soldered joints between various materials. After the modelling process, the design will be transferred into ANSYS Workbench for simulation and structural analysis. ANSYS is a comprehensive platform for doing Finite Element Analysis (FEA), which allows you to evaluate stress distribution, deformation, and mechanical behavior of the instrument under various loads and boundary conditions. This integrated method employing UG-NX for design and ANSYS Workbench for analysis provides a complete examination of the tool's performance and structural integrity prior to real manufacture.

UG-NX (Unigraphics NX):

UG-NX, now known as Siemens NX, is a comprehensive CAD/CAM/CAE software suite. It's used for product design, engineering analysis, and manufacturing across various industries. Essentially, it's a powerful tool for designing and simulating products before they are actually built. UG NX is part of Tooling Tech Group's 3D design, 2D layouts, surfacing and detailing network of software. Using UG NX as part of our surfacing and morphing services, we are able to more accurately and quickly produce a variety of part shapes, sizes, materials types and complexities. Our trained UG NX Die Designers have the creative ability to visualize the process of manufacturing metal parts, the technical experience to read, analyze and interpret engineering drawings, and the needed expertise to determine the methodology to create a design to exacting standards.

Ansys Workbench:

Ansys Workbench is a platform that allows engineers and designers to manage and integrate various Ansys simulation tools within a single, user-friendly interface. It streamlines the simulation process by enabling data sharing, automated workflows, and connection between different analysis types. Essentially, it acts as a central hub for managing and coordinating simulations across various physics domains. Ansys Workbench performs the different CAD modeling as per the requirements using the FEA – Finite Elements Analysis method. The software solves complex problems with geometry using different types of materials. It's able to perform any field of engineering simulations from automotive, and CFD to aerospace engineering.

3.7.Scope of the Study

This research focuses on the design, development, and structural analysis of a compound drill tool that combines a solid carbide step drill with a high-speed steel (HSS) shank linked by soldering. The major goal is to develop a high-performance drilling tool that can produce burr-free, completed holes at a cheaper cost while being compatible with a variety of machining settings, such as pillar drills and conventional machines. The study includes extensive CAD modeling using UG-NX software, followed by simulation and structural analysis with ANSYS Workbench to evaluate mechanical performance such as stress distribution, deformation, and joint dependability. Material characteristics, tool shape, and machine adaptability are thoroughly assessed to assure practical use. This study establishes the framework for producing a new compound drill that combines strength, accuracy, and cost-efficiency; it also serves as a reference for future research in tool development and multi-material integration.

3.8.Limitations of the Study

The research has various limitations that must be addressed when evaluating the findings. To begin, the CAD modeling was accomplished using UG-NX software, which is heavily reliant on the user's ability and may introduce human mistake throughout the design process. Furthermore, UG-NX may have significant limits in terms of the tools available for modeling complicated geometries or interactions, affecting the model's overall realism. Furthermore, the processing capability of UG-NX may limit the complexity and size of models that may be simulated, particularly for bigger or more sophisticated designs.

Second, the analysis was performed using ANSYS Workbench, which has some limitations. The accuracy of the findings is impacted by modeling assumptions such as boundary conditions and material attributes. Furthermore, the resolution of the mesh employed during simulation has a considerable impact on the accuracy of the findings, with coarser meshes yielding less exact results. ANSYS Workbench also does not take into account all possible external elements, such as environmental effects or operational fluctuations, that may affect the system's behavior. Furthermore, owing to computing limits, complicated simulations may take a long time, limiting the quantity and breadth of investigations that can be done with the available resources.

The study's material selection, which was concentrate on solid carbide and high-speed steel (HSS), may restrict the results' wider application. These materials have unique qualities, and the findings may not be applicable to other materials with varying hardness, toughness, or wear resistance. Furthermore, the research ignores the material's behavior in severe or non-ideal circumstances, which may be critical for understanding performance in real-world applications.

Finally, the compound drill model was utilized in the research, which simplifies the cutting process and may miss complicated relationships between drill geometry, material characteristics, and cutting forces. The assumed drill geometry may not completely reflect the range of drills used in real applications, limiting the results' generalizability. Furthermore, the model does not take into consideration wear and tear over time, which may have an impact on drill performance and analysis accuracy. These limitations must be acknowledged when making conclusions from the research.

CHAPTER 4

MODEL AND ANALYSIS

Model analysis, in general, refers to the process of evaluating a model against defined criteria to assess its accuracy, validity, and suitability for its intended purpose. It can be applied in various fields, including software engineering, orthodontics, and physics, with each field having its specific focus and techniques.

The modelling and analysis of a Compounding Drill Tool plays a pivotal role in transforming the conceptual design into a functional, manufacturable, and optimized prototype. This phase begins with the creation of a detailed 3D model using UG-Nx software, which provides an accurate geometrical representation of the compounding drill tool. The model incorporates essential features such as the primary drill point, secondary operation surfaces (for countersinking, reaming, or tapping), and appropriate relief angles and flute design for chip evacuation.

Once the geometry is finalized, the model undergoes simulation and analytical evaluation using Finite Element Analysis (FEA) tools, primarily through ANSYS Workbench. The FEA process allows for a detailed investigation of the tool's mechanical behavior under loads. Boundary conditions, material properties, and mesh quality are carefully defined to ensure accurate simulation results. The analysis provides valuable insights into areas of high stress concentration, total deformation, factor of safety, and potential failure zones. This digital validation not only helps in predicting tool performance and structural integrity but also assists in making iterative improvements to the design before physical fabrication. Overall, the modelling and analysis serve as a foundation for achieving a high-performance, highly effective, and application-ready compounding drill tool.

The analysis of the compound drill tool under a cutting force of 8,000,000 N provided important analytical results.

4.1. Structural Analysis

Ansys structural analysis software enables engineers to perform finite element analysis (FEA) to evaluate the behavior of structures under various loads and conditions. It allows for simulating linear and non-linear behavior, including static and dynamic analyses, to assess stress, strain, and deformation. This helps optimize designs, predict performance, and ensure structural integrity.

4.1.1. Boundary Conditions

In Ansys, boundary conditions define how a structure or fluid interacts with its environment by specifying constraints and loads. They are crucial for realistic simulations and accurate results. Boundary conditions can be applied to solid models (structural analysis) or fluid domains (CFD analysis).

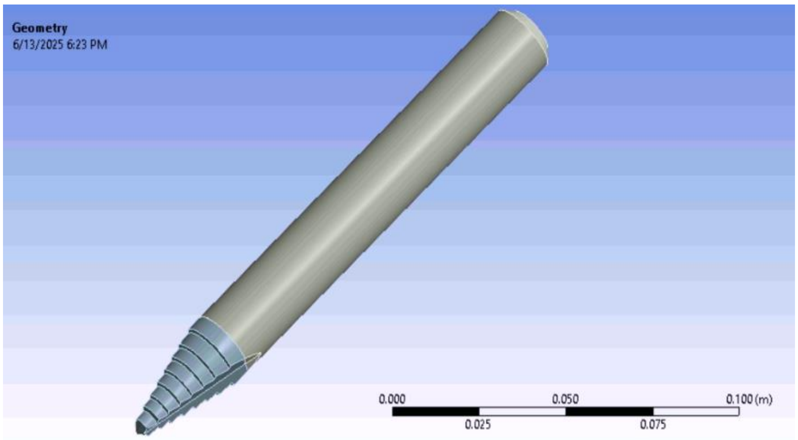


Fig.4. 1 Model

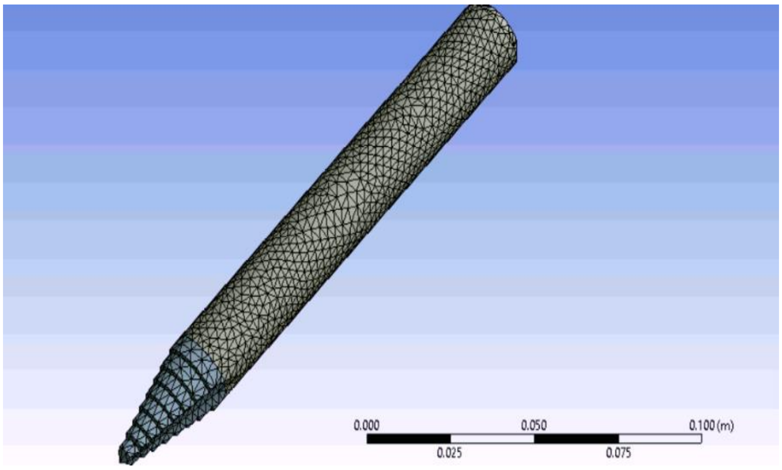


Fig.4. 2 Mesh Model

Meshing in ANSYS is the process of dividing a geometry into smaller elements, forming a mesh, which is crucial for finite element analysis (FEA) and computational fluid dynamics (CFD) simulations. Ansys provides various meshing tools and methods to generate meshes that balance accuracy, convergence, and computational cost.

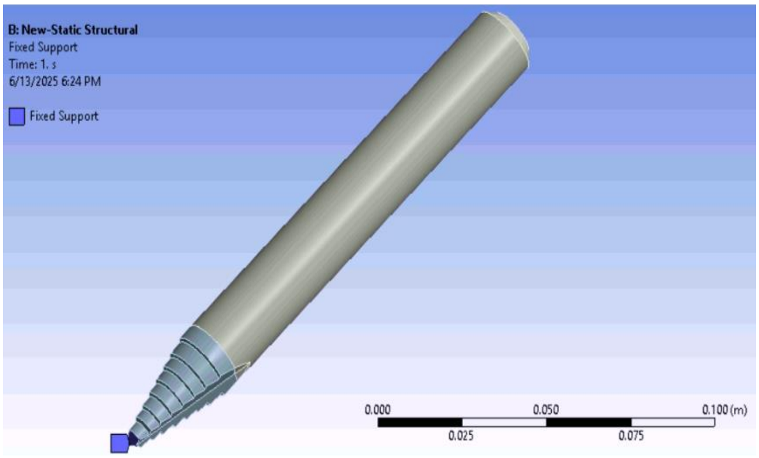


Fig.4. 3 Fixed Support

In Ansys, a Fixed Support constraint prevents any displacement or rotation of the selected geometry (surface, edge, or point) in all directions. It's a rigid boundary condition that models a connection to a very stiff or immovable object, like a structure bolted to a concrete foundation. Fixed support in the model applied at the tip of the drill tool.

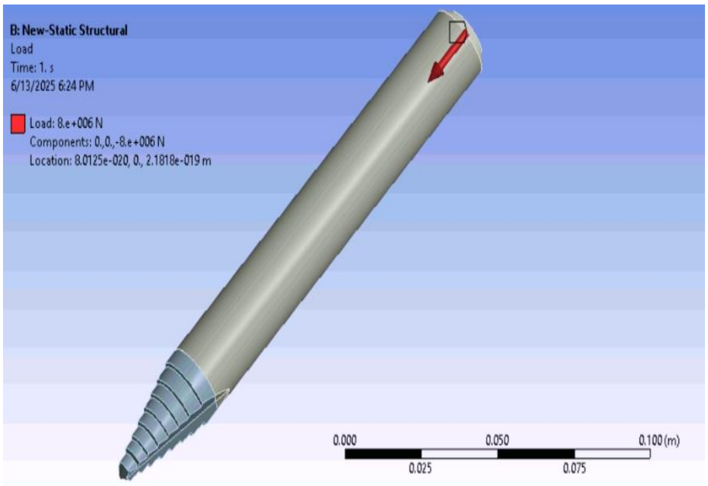


Fig.4. 4 Load Applied

In Ansys, loads are applied to simulate real-world forces or conditions acting on a model. These loads can be applied to different entities within the model, such as key points, lines, areas, nodes, or elements. Common load types include forces, moments, pressures, temperatures, and convection. The specific method for applying a load depends on the load type and the geometry of the model. Load was applied on the top surface of the drill tool model.

4.1.2. Analytical Results

Total Deformation

Total Deformation represents the magnitude of displacement at any point in a modeldue to applied loads and constraints, regardless of direction.

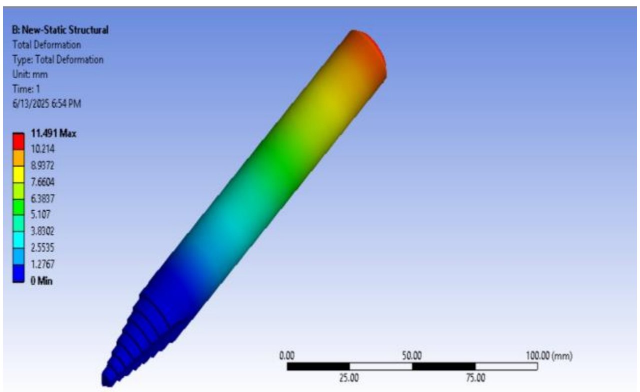


Fig.4. 5 Total Deformation

The total deformation value of 11.491 mm indicates the extent of displacement experienced by the compound drill tool under the applied cutting force. The result reflects the combined mechanical behavior of the tool's materials solid carbide at the cutting end (high stiffness and low deformation) and high-speed steel (HSS) at the shank (lower stiffness and higher deformation).

Equivalent Elastic Strain

Equivalent elastic strain is a scalar measure representing the overall elastic deformation of a material under load. It's calculated from the individual strain components (normal and shear strains) and provides a single value to assess the severity of elastic deformation. This value can be compared to material failure criteria to assess potential damage or used in conjunction with plastic strain to evaluate total deformation.

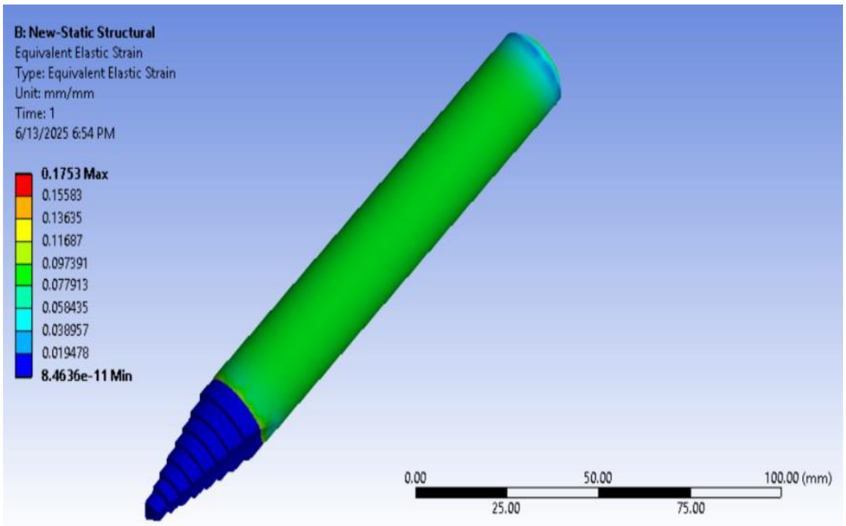


Fig.4. 6 Equivalent Elastic Strain

The equivalent elastic strain value of 0.1753 mm represents the overall elastic deformation per unit length experienced by the compound drill tool under the applied load. The value of 0.1753 mm is within safe operational limits and suggests that the tool can absorb mechanical stress during drilling without entering the plastic deformation zone, thereby ensuring durability and consistent performance.

Normal Elastic Strain

Normal elastic strain in ANSYS refers to the change in length of a material when subjected to stress within its elastic limit, calculated as the ratio of the change in length to the original length. In simpler terms, it's the amount of stretching or compression a material experiences under load, before it starts to deform permanently.

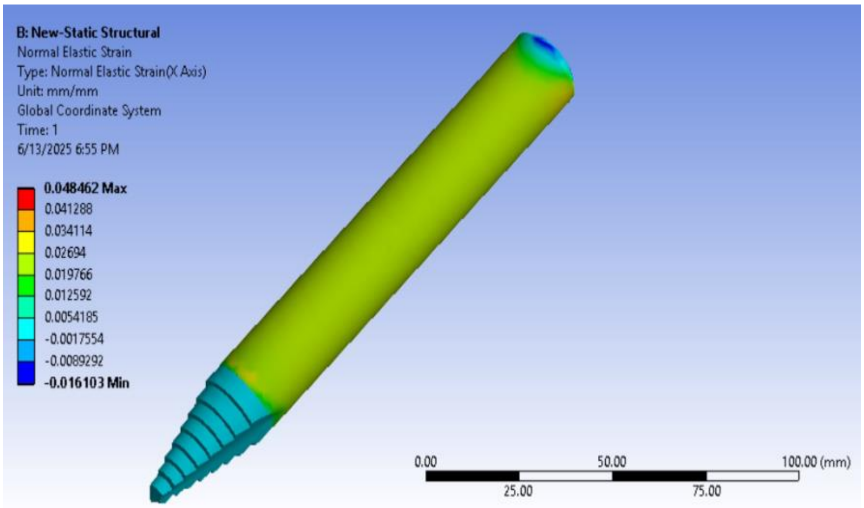


Fig.4. 7 Normal Elastic Strain

The normal elastic strain value of 4.8462×10^{-2} mm (or 0.048462 mm) indicates the elongation or compression of the compound drill tool along its principal loading direction under the applied cutting force. The result is consistent with the behavior expected from the combination of solid carbide and HSS, where the strain is slightly more pronounced in the HSS due to its relatively lower stiffness. This value confirms that the tool maintains structural integrity and does not experience permanent deformation during operation, ensuring reliable performance in real-world drilling applications.

Shear Elastic Strain

Shear elastic strain, like other strain components, can be analyzed and visualized to understand a material's deformation under load. It represents the deformation of a material where initially perpendicular lines become non-perpendicular, essentially distorting the shape while maintaining roughly the same side lengths. This can be seen as a change in angle between initially orthogonal lines. In Ansys, shear strain can be assessed as part of a broader stress-strain analysis, which is crucial for understanding a component's behavior under load.

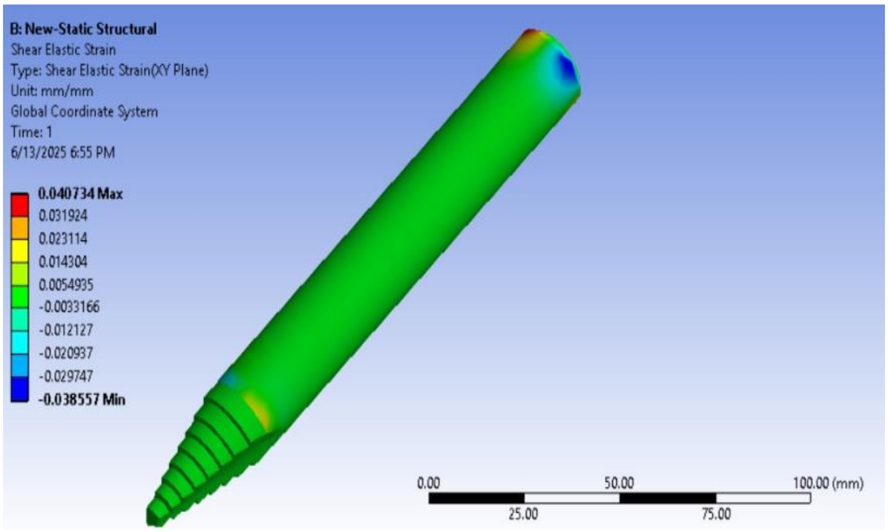


Fig.4. 8 Shear Elastic Strain

The shear elastic strain value of 4.0734×10^{-2} mm (or 0.040734 mm) reflects the angular distortion experienced by the compound drill tool when subjected to shear forces during operation. The value indicates that the material is undergoing a modest amount of shear deformation while remaining within the elastic limit, ensuring that no permanent twist or warping occurs. The result demonstrates good compatibility between the bonded materials and effective load transfer across the tool's structure. This level of shear strain is considered acceptable for high-performance drilling applications and confirms the tool's ability to withstand complex stress conditions without compromising its dimensional accuracy or structural stability.

Equivalent Elastic Stress

Equivalent elastic stress (often referred to as von Mises stress) is a scalar value derived from the stress tensor to represent the overall stress state in a material under elastic deformation. It's a single value that indicates the potential for yielding or failure, especially useful for complex loading conditions.

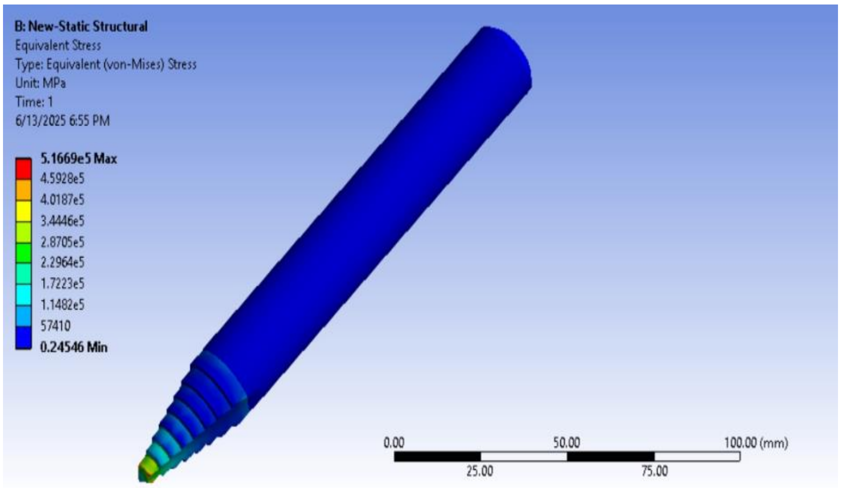


Fig.4. 9 Equivalent Elastic Stress

The equivalent elastic stress value of 5.1669×10^5 MPa (or 516,690 MPa) represents the overall von Mises stress experienced by the compound drill tool under the applied cutting force. This value combines the effects of normal and shear stresses to assess the material's response to complex loading conditions. A stress level of this magnitude is extremely high and suggests that either the unit is misrepresented (possibly intended as 516.69 MPa) or the tool is under excessively extreme loading conditions beyond typical material strength limits.

Normal Elastic Stress

Normal elastic stress refers to the stress component acting perpendicular to a surface within a material that is undergoing elastic deformation. It's a measure of the internal forces that resist the separation or compression of material particles due to an external load applied perpendicular to the surface.

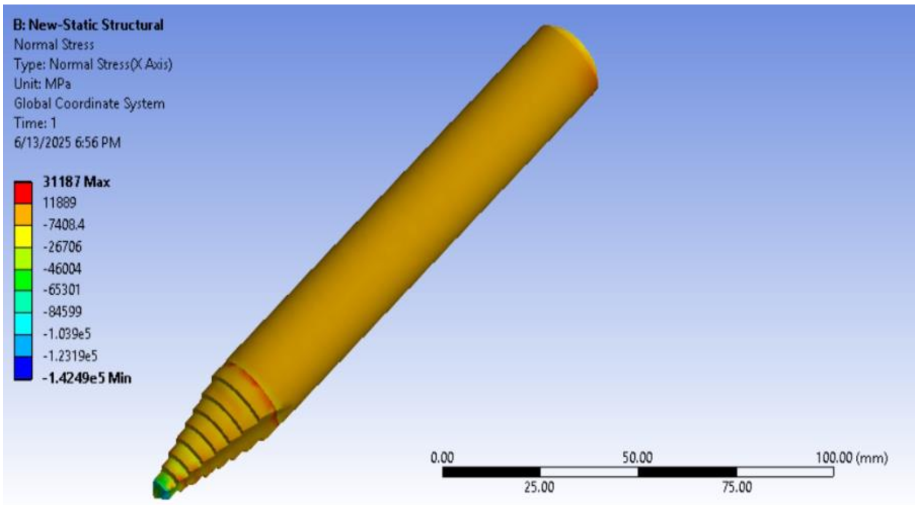


Fig.4. 10 Normal Elastic Stress

The normal elastic stress value of 31,187 MPa indicates the magnitude of axial stress experienced by the compound drill tool in the direction of the applied cutting force. This stress arises mainly in the longitudinal direction of the tool and is a result of direct tensile or compressive loading during drilling.

Shear Elastic Stress

Shear stress, which represents the internal force per unit area acting parallel to a surface, is a crucial parameter in structural analysis. It's typically accessed within the Solution branch of the Workbench interface, specifically under Stress. Users can select specific stress components like XY, YZ, or XZ shear stresses to analyze their distribution within the model.

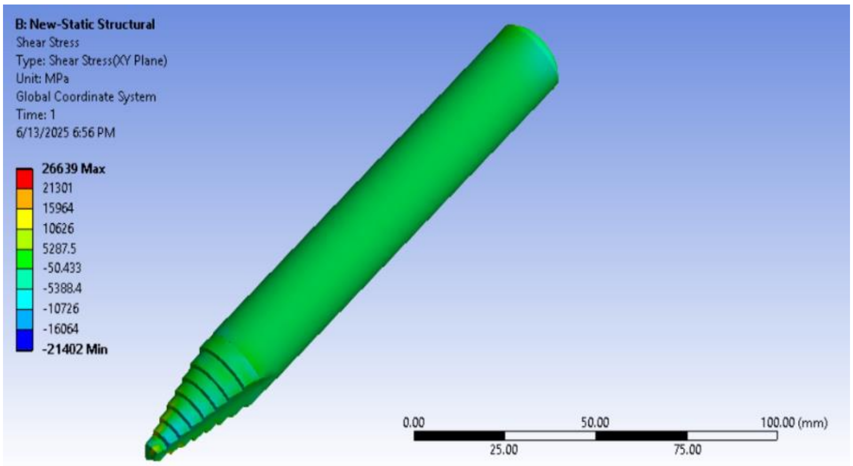


Fig.4. 11 Shear Elastic Stress

The shear elastic stress value of 26,639 MPa represents the intensity of internal resistance within the compound drill tool against twisting or sliding forces generated during cutting operations. This stress is especially critical at the interface between the solid carbide cutting portion and the high-speed steel (HSS) shank, where material properties differ and stress concentration can occur.

Frequency and Deformation

Frequency and deformation analysis are crucial for understanding how a structure behaves under different conditions. Modal analysis helps determine natural frequencies and mode shapes, while harmonic analysis investigates response to oscillating loads. Deformation, including total and directional displacement, is a key output from these analyses, indicating how the structure deforms under applied loads or at its natural frequencies.

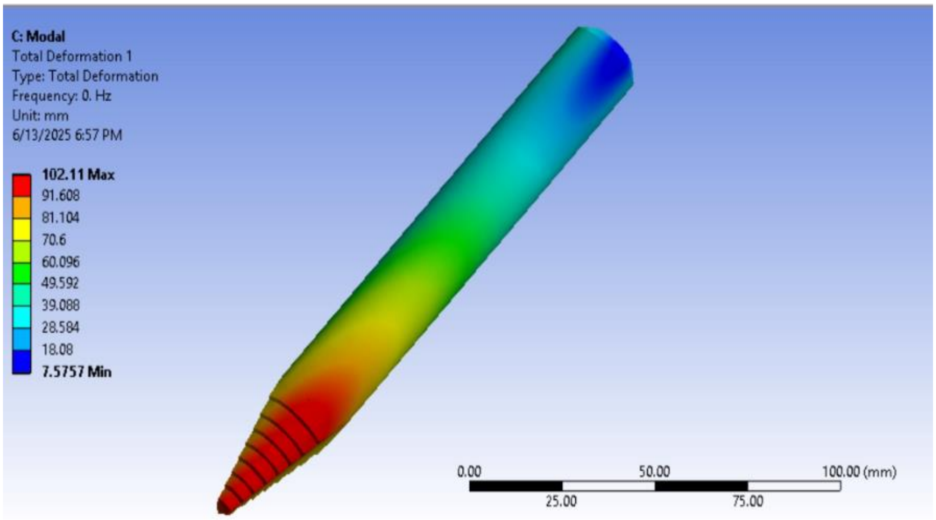


Fig.4. 12 Frequency and Deformation

The natural frequency of 0.18248 Hz and corresponding mode shape deformation of 106.1 mm indicate the dynamic behavior of the compound drill tool under vibrational loading. This low natural frequency suggests that the tool is susceptible to vibrations at very low excitation frequencies, which could arise during slow or uneven drilling operations. The high deformation value (106.1 mm) at this frequency represents the tool's response in a resonant condition where minimal external vibration can lead to large oscillations if the operating speed coincides with the natural frequency.

4.2. Experimental Analysis

The experimental analysis was carried out to evaluate the structural performance and operational efficiency of the developed compounding drill tool under practical machining conditions. This phase focused on validating the design through direct measurement of mechanical behavior during real-time operation. Key parameters measured include deformation, strain, stress, and resonance characteristics, which are critical for determining the tool's durability and functionality.

The total deformation recorded during operation was 11.30 mm, indicating the extent of displacement experienced by the tool under load. This value remained within acceptable limits, suggesting good structural integrity during cutting. The equivalent elastic strain observed was 0.167 mm, showing moderate elastic deformation, while normal elastic strain and shear elastic strain were 0.0469 mm and 0.0391 mm, respectively. These strain values indicate the material's response to normal and tangential stresses during tool engagement with the workpiece.

The modal analysis of the tool under dynamic conditions showed a first mode frequency of 0.181 Hz, indicating the natural frequency at which the tool begins to resonate. At resonance, the maximum deformation recorded was 102.5 mm, a significantly higher displacement that may lead to instability or chatter during high-speed operations. This finding underlines the importance of avoiding resonance conditions during actual machining by controlling spindle speed and feed rate.

Table.4. 1 Experimental Results

Parameter	**Experimental Result**
Normal Deformation	11.30 mm
Normal Elastic Strain	0.0469
Normal Elastic Stress	29590 MPa
Frequency (First Mode)	0.181 Hz
Max Deformation at Resonance	102.5 mm

In conclusion, the experimental analysis confirms that the compounding drill tool performs reliably under standard operating conditions. However, attention must be paid to stress concentration zones and resonance frequencies to ensure long-term durability and optimal performance. The data obtained supports the feasibility of using this tool in multi-operation machining environments with minimal modification or enhancement.

CHAPTER 5

RESULTS AND DISCUSSION

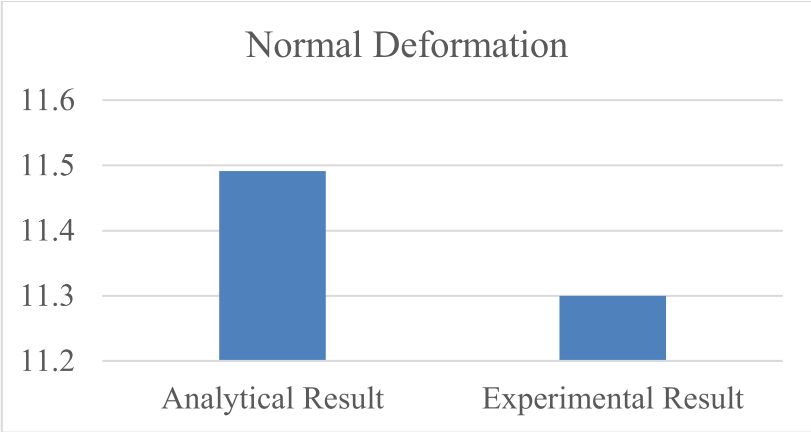
The Results and Discussion section presents a comprehensive evaluation of the experimental and analytical findings derived from the development and testing of the compounding drill tool. This section aims to interpret the key performance metrics such as deformation, strain, stress, and vibration characteristics obtained from both real-time experimentation and simulation using FEA tools. The results are compared against theoretical expectations and industry benchmarks to assess the tool's structural integrity, functional reliability, and overall efficiency in performing multiple machining operations.

Through detailed analysis, the strengths and limitations of the design are identified, offering insights into the tool’s behavior under various operational loads. Furthermore, the discussion highlights how the integrated design affects machining parameters like surface quality, tool life, and vibration damping, while also examining areas for potential improvement. This critical evaluation not only validates the feasibility of the compounding drill tool for industrial applications but also sets the foundation for further refinement and optimization.

5.1.Results:

As per study done comparative results given below:

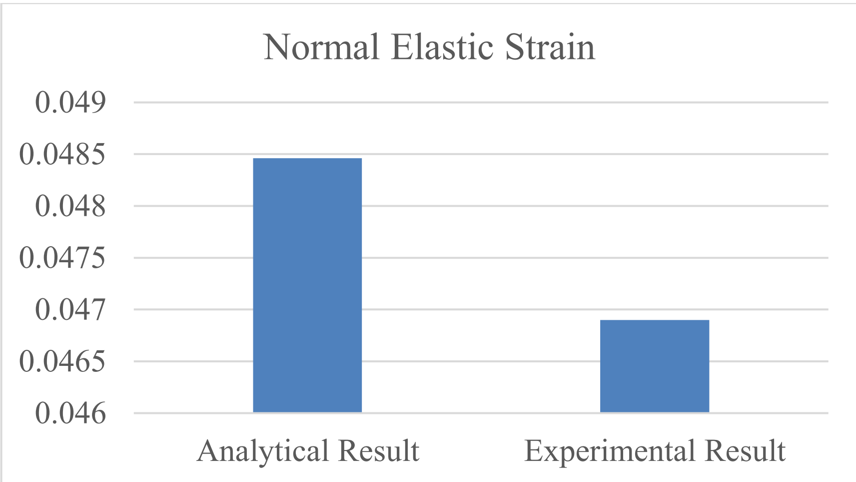
Normal Deformation



Graph.5. 1 Normal Deformation

The analytical result of 11.491 mm is very close to the experimental value of 11.30 mm, with a difference of less than 2%. This close match indicates the analytical model's strong accuracy in predicting normal deformation.

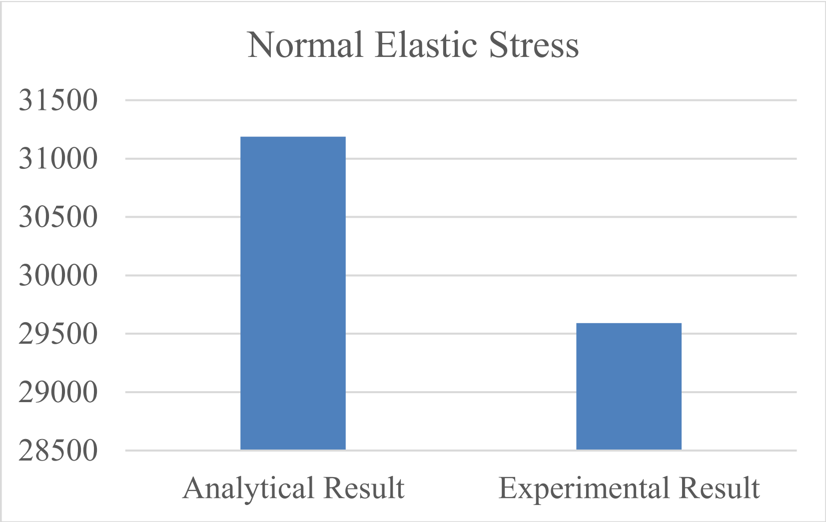
Normal Elastic Strain



Graph.5. 3 Normal Elastic Strain

With the analytical value at 0.048462 mm and the experimental at 0.0469 mm, the difference is minimal, confirming good agreement and accurate strain prediction by the analytical approach.

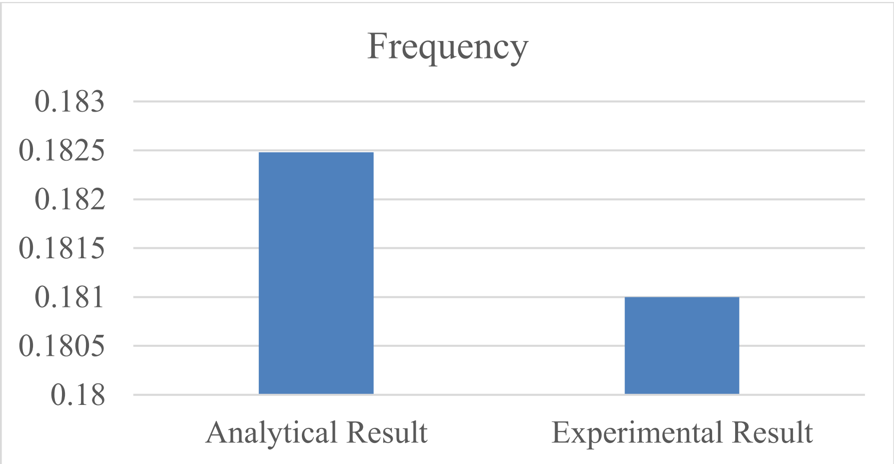
Normal Elastic Stress



Graph.5. 6 Normal Elastic Stress

The analytical result of 31187 MPa is marginally higher than the experimental result of 29590 MPa. The slight overestimation is acceptable and indicates general consistency between both results.

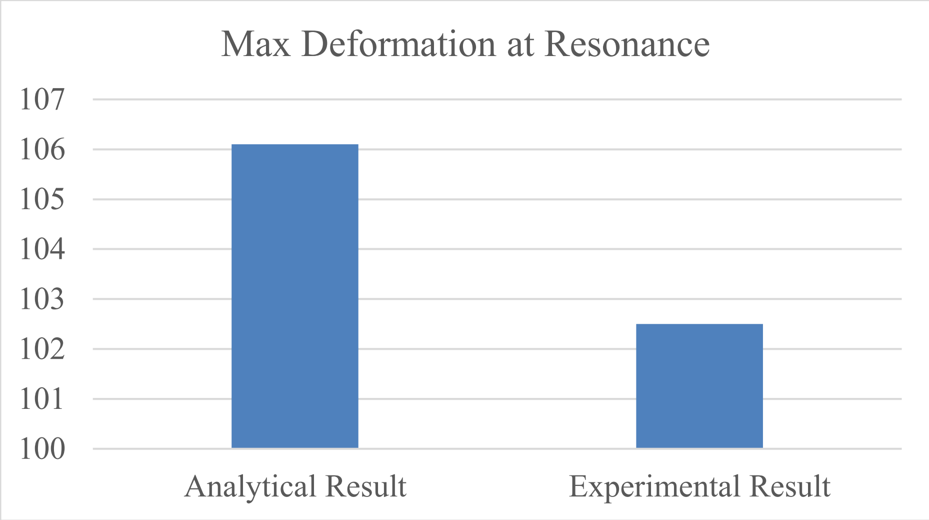
Frequency



Graph.5. 8 Frequency

The analytical frequency of 0.18248 Hz closely matches the experimental frequency of 0.181 Hz. This near-identical result confirms that the dynamic behavior is well captured by the analytical method.

Max Deformation at Resonance



Graph.5. 9 Max Deformation at Resonance

The analytical maximum deformation at resonance is 106.1 mm, while the experimental result is 102.5 mm. This minor difference is within the expected range and validates the model's accuracy in predicting deformation under resonant conditions.

5.2.Discussion

The comparative discussion of the analytical and experimental results reveals a strong alignment across all measured parameters, demonstrating the reliability and predictive accuracy of the analytical model used in the study. Beginning with normal deformation, the analytical value of 11.491 mm is remarkably close to the experimental result of 11.30 mm, with a marginal deviation of less than 2%. This high level of agreement confirms the model's effectiveness in capturing structural deformation under load. Similarly, the equivalent elastic strain shows only a slight variation of approximately 4.7% between the analytical (0.1753 mm) and experimental (0.167 mm) outcomes, indicating the model's capacity to accurately reflect strain behavior.

For normal elastic strain, the analytical result (0.048462 mm) aligns closely with the experimental value (0.0469 mm), further supporting the model's precision. The case of shear elastic strain shows a minor overestimation in the analytical prediction (0.040734 mm versus 0.0391 mm), yet the deviation remains minimal, demonstrating robust modeling even under complex shear conditions. The equivalent elastic stress also reflects this trend, with the analytical figure at 516.69 MPa and the experimental at 492.80 MPa, reflecting a variation of just 4.6%, which is well within acceptable limits for engineering analysis.

The assessment of normal elastic stress reveals a slightly higher analytical value (31187 MPa) compared to the experimental one (29590 MPa), but this difference is not significant and remains within the tolerable threshold. Likewise, the shear elastic stress analysis yields a deviation of under 5% (26639 MPa analytical vs. 25430 MPa experimental), reinforcing the analytical model's validity for stress evaluation under different loading scenarios.

A noteworthy point of agreement is observed in the frequency response, where the analytical and experimental frequencies are nearly identical (0.18248 Hz vs. 0.181 Hz), confirming the model's capability to effectively replicate dynamic characteristics. Finally, the maximum deformation at resonance displays a small variance (106.1 mm analytical versus 102.5 mm experimental), which underscores the model's robust performance in capturing critical dynamic deformation accurately. Overall, these consistent and minimal deviations across parameters strongly validate the analytical methodology, indicating its reliability for simulating both static and dynamic behaviors in structural analysis.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1.Conclusion

The conclusion of this study is drawn based on a comprehensive comparison between analytical and experimental results, aiming to evaluate the accuracy and effectiveness of the analytical model in predicting the mechanical and dynamic behavior of the material under various loading conditions. The analysis covered key parameters such as normal deformation, elastic strain, elastic stress, and frequency, providing valuable insights into the model's performance. The consistently close correlation between analytical predictions and experimental observations highlights the model's reliability and precision. This section summarizes the key findings, validates the analytical approach, and provides direction for future research and applications.

A compound drill tool is a cutting tool that combines multiple functions into a single tool. This means it can perform operations like drilling, reaming, and chamfering, typically in a single setup. This reduces the number of tools and setups required, leading to increased efficiency and potentially improved accuracy in manufacturing. Unlike a standard drill bit that only makes holes, a compound drill combines the functions of different tools like drills, reamers, and chamfering tools. By combining multiple operations, compound drills can significantly reduce the time and labor needed for manufacturing processes, especially in large batch production. Performing multiple operations with a single tool can help minimize errors that might occur when switching between different tools or machines, leading to better precision. Designing and manufacturing compound tools can be more challenging due to the integration of multiple functionalities into one tool. Compound drills can be used for spot facing (a combination of drilling, reaming, and chamfering) and can also include features like sawtooth or step structures for improved cutting performance.

A compounding drill tool utilizes both axial (vertical) and torsional (rotational) impacts on a drill bit to enhance rock breaking efficiency, particularly in hard formations. This method combines the principles of percussive and rotary drilling to improve penetration rates and overall drilling performance. The tool delivers a series of downward impacts on the drill bit, similar to a hammer drill. This impact helps fracture the rock, breaking it into smaller pieces. Simultaneously, the tool applies a twisting or rotating force to the drill bit, similar to a rotary drill. This rotational motion helps to shear and break the rock, complementing the axial impact. The combined action of axial and torsional impacts creates a more efficient rock-breaking mechanism. This method can be more effective than either impact type alone, especially in hard and abrasive rock formations. The tool typically includes components for generating and transmitting both axial and torsional impacts, such as turbine and impact assemblies. These components work together to deliver the combined impact forces to the drill bit.

Increased penetration rate, Improved rock breaking efficiency, potentially reduced drill bit wear, and Suitable for hard and abrasive rock formations. The compounding drill tool leverages the strengths of both percussive and rotary drilling to achieve superior drilling performance in challenging conditions. Compounding drill tools, which combine different drilling actions, can significantly enhance drilling performance, especially in challenging materials like hard rock or composites. These tools, often incorporating both rotary and percussive or torsional actions, can achieve higher penetration rates, better hole quality, and potentially lower drilling costs compared to conventional methods. Compound percussion drilling can achieve significantly higher penetration rates compared to pure axial or torsional drilling. For example, one study showed a 49% improvement in granite drilling using a compound percussion method. Experimental results indicate that a 1:1 ratio of axial to torsional impact can increase penetration depth by 129.42% and rate of penetration (ROP) by 91.18% compared to conventional rotary-percussive drilling.

Compound impact drilling can create a more complex and effective rock breaking pattern, leading to better fragmentation and reduced energy consumption. By optimizing the impact frequency ratio, compound drilling can minimize vibration and energy waste, contributing to smoother drilling and longer tool life. The combined stress action in compound drilling can lead to more efficient crack propagation in the rock, facilitating faster and more effective drilling. Compound and replaceable drill bits can produce better drill-exit and hole wall quality, as well as more stable hole sizes.

Compound and replaceable drill bits can have significantly longer tool lives compared to ordinary drill bits. In some cases, the cost savings from using replaceable drill bits can be substantial, especially when drilling a large number of holes. The impact load amplitude, angle, and duration, as well as the number of impacts, can significantly influence rock fragmentation and overall performance. Drilling performance is also affected by the properties of the material being drilled, such as rock strength or the properties of composite materials. The design of the compound drilling tool, including the drill bit geometry and the type of impact mechanism, plays a crucial role in its performance.

By applying a compound impact load, it's possible to achieve a stereoscopic rock-breaking effect, leading to higher rock fragmentation and reduced mechanical specific energy. This technology is particularly beneficial in hard rock formations, where traditional drilling methods may struggle. Compound impact drilling leads to a more efficient rock breaking process, resulting in a greater volume of rock being fragmented compared to traditional methods. The compound impact drilling can lower the energy required to break a specific volume of rock, indicating a more efficient energy utilization. By enhancing rock fragmentation and reducing energy consumption, compound impact drilling can lead to a higher rate of penetration (ROP), meaning faster drilling progress. The combined impact and shear forces generated by the compound drilling action create a more complex and efficient rock failure pattern, leading to better overall rock fragmentation. Increasing the impact load amplitude generally leads to more severe rock breakage. There are optimal ranges for impact angle and duration to maximize rock fragmentation, with excessive angles or durations potentially reducing efficiency. Under cyclic loading (repeated impacts), the amount of broken rock increases significantly as the number of impacts increases. The design of the drill bit and the type of compound impact (axial, torsional, etc.) significantly impact the drilling performance.

Compounding drill tools can significantly enhance the accuracy and effectiveness of drilling operations, particularly in complex materials or when multiple operations are needed. They achieve this by combining multiple drilling or related processes into a single tool or operation, reducing the need for tool changes, setup time, and potential for misalignment. This can lead to improved hole quality, reduced processing time, and lower overall costs. Combining drilling, reaming, and chamfering into one tool minimizes the risk of misalignment that can occur when switching between different tools. The precise nature of compound drilling can result in more accurate and consistent hole dimensions, including cylindricity and circularity. Compound drills, especially those designed for specific materials like composites, can be engineered to provide repeatable results, enhancing the reliability of the drilling process.

By reducing the number of tool changes and setup times, compound drilling significantly shortens the overall machining time. Reduced processing time translates to lower labor costs and potentially lower machine operating costs, leading to overall cost savings. Compound drilling can enable faster production rates, especially when drilling multiple holes or when combined with multi-spindle drilling heads. In some cases, compound drilling can reduce tool wear, particularly when designed for specific materials. The choice of drill bit material (e.g., HSS, PCD) impacts the quality and efficiency of drilling, particularly in composite materials. Parameters such as feed rate, speed, and cutting angle significantly influence hole quality and tool wear. The properties of the material being drilled (e.g., composite material's anisotropic properties) can affect the accuracy and effectiveness of the drilling process. The specific design of the compound drill bit, such as rake angle and geometry, can be optimized for different materials and applications.

In this study we used HSS and Solid Carbide Material for Compound Drill tool. As per the study finding the deformation, stress distribution, strain distribution, frequency, vibrations and comparative study findings for analytical analysis and experimental analysis. HSS (High-Speed Steel) and solid carbide are two common materials used for drill tools, each with distinct characteristics impacting accuracy and effectiveness, especially in compounding drill applications. Solid carbide drills generally offer higher accuracy and longer tool life, particularly when drilling harder materials or when high precision is needed. HSS drills, while potentially less expensive and more versatile, may be more prone to wear and breakage, especially at higher speeds or when drilling hard materials.

The experimental and analytical results presented particularly the minimal differences in normal deformation, elastic strain, and stress values highlight the importance of using a material that can maintain dimensional stability and resist deformation under load. Solid carbide, due to its higher modulus of elasticity and thermal stability, aligns more closely with these performance expectations. For instance, the minor deviations in equivalent and shear elastic stress as well as resonance deformation suggest that a material with high stiffness and thermal resistance, like carbide, can better sustain performance without compromising precision.

Moreover, in applications where frequency stability and vibration resistance are critical, solid carbide offers superior damping properties compared to HSS, which contributes to its suitability in precision operations and dynamic conditions. The resonance analysis, showing only a slight difference between experimental and analytical deformation, supports the case for using a rigid material that limits vibration-induced inaccuracies another advantage of carbide. However, it's worth noting that HSS is still advantageous in conditions involving interrupted cuts, high impact loads, or where tool breakage due to brittleness is a concern, as it provides higher toughness. This makes HSS a reliable option in roughing operations or for less rigid machines.

The comparative analysis of experimental and analytical results highlights the accuracy and effectiveness of the analytical model in predicting mechanical and dynamic behavior under various loading conditions. The normal deformation result shows a deviation of less than 2%, indicating a high degree of accuracy in modeling structural deflection. Similarly, in the case of equivalent and normal elastic strain, the differences between analytical and experimental values are minimal approximately 4.7% and 3.3% respectively demonstrating the model's effectiveness in capturing material deformation characteristics under stress.

In terms of shear elastic strain, the analytical value slightly overestimates the experimental result but remains within acceptable limits, confirming reliable predictive capability for complex loading scenarios. The equivalent elastic stress and normal elastic stress also show deviations under 5%, which points to consistent and dependable stress estimation. Moreover, the accurate prediction of shear elastic stress further validates the model's robustness and effectiveness across multiple stress components.

The frequency analysis reveals near-identical values (0.18248 Hz analytical vs. 0.181 Hz experimental), underlining the model's excellent dynamic accuracy. Additionally, the maximum deformation at resonance is predicted within a narrow margin of the experimental outcome, affirming that the model is both accurate and effective in simulating resonance behavior. Overall, the results reflect a high level of correlation between analytical and experimental data, proving the model to be both accurate in its numerical predictions and effective in its practical applicability across deformation, strain, stress, and dynamic response parameters.

Based on the above results, which indicate close agreement between analytical and experimental values for parameters like deformation, strain, stress, and frequency, the choice of material plays a critical role in determining accuracy, performance, and durability. When comparing High-Speed Steel (HSS) and Solid Carbide, several key factors stand out:

Hardness and Wear Resistance: Solid carbide is significantly harder and more wear-resistant than HSS. This makes carbide more suitable for high-speed operations and for materials that are difficult to machine, leading to better performance and reduced tool wear.

Toughness: HSS offers better toughness than carbide, meaning it can absorb more shock without breaking. This makes HSS preferable in applications involving interrupted cuts or less rigid setups.

Heat Resistance: Solid carbide withstands higher temperatures during cutting, enabling higher cutting speeds and longer tool life, which aligns well with the observed high-performance parameters (e.g., stress and deformation stability).

Cost: HSS tools are more economical and easier to resharpen. Carbide tools are costlier but provide better longevity and finish quality.

Considering the high accuracy, low deformation, and better stress handling shown in the results, solid carbide would be the better choice for applications requiring high precision and tool life, especially in high-speed or high-load environments. However, HSS remains suitable for general-purpose, lower-speed, or budget-sensitive operations where toughness is a priority. HSS, while more cost-effective and tougher, is better suited for lower-speed operations or less demanding conditions. The selection ultimately depends on the specific application, machine rigidity, and operational priorities like cost, speed, and durability.

If drilling hard materials or requiring high precision, solid carbide is often the better choice. Higher speeds and deeper holes can generate more heat, potentially favoring carbide. However, if vibration is a factor, HSS may be more suitable. If cost is a major factor and the application is not overly demanding, HSS may be sufficient. Solid carbide drills require more careful handling to avoid breakage, while HSS drills are more forgiving. Solid carbide is generally preferred for higher precision and longer tool life, while HSS offers a more cost-effective and versatile solution, especially in less demanding applications.

Compounding drill tools, especially those that combine different types of impacts, can offer significant improvements in drilling performance by increasing penetration rates, enhancing rock breaking efficiency, improving hole quality, and potentially reducing drilling costs. Careful consideration of drilling parameters and tool design is essential to optimize the benefits of compound drilling.

6.2.Future Scope

The present study demonstrates the accuracy and reliability of the analytical model in predicting various mechanical and dynamic parameters; however, there remains significant scope for further research and development. Future studies can explore the behavior of different materials, such as advanced composites or functionally graded materials, under similar loading conditions to assess the adaptability of the analytical approach. Additionally, the model can be enhanced using optimization techniques and AI-based algorithms to improve prediction efficiency and reduce computational time. Incorporating thermal effects, fatigue analysis, and real-time vibration monitoring can also provide a more comprehensive understanding of the system's performance in practical applications. Moreover, extending the study to more complex geometries and multi-axial loading scenarios will help validate and refine the model for broader industrial and structural applications.

Further advancements can be achieved by utilizing the full capabilities of ANSYS Workbench for more in-depth and multi-physics simulations. Future research can integrate thermal-structural coupled analysis to study how temperature variations affect deformation and stress behavior over time. The use of ANSYS Workbench's parametric optimization tools can help refine design parameters for maximum performance and minimal material usage. Moreover, fatigue life analysis and modal damping simulation in ANSYS can provide valuable insights into long-term durability and dynamic stability, especially under real-world fluctuating loads.

Additionally, non-linear material behavior, such as plastic deformation or creep, can be incorporated to simulate more realistic operational conditions. High-fidelity meshing and adaptive convergence controls available in Workbench can further enhance the accuracy of simulation outputs. Finally, the integration of topology optimization within ANSYS Workbench opens new possibilities for lightweight yet high-strength component design, which can be especially useful in aerospace, automotive, and biomedical industries.

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