

Design and Structural Analysis of CNC Drill Bit Using Different Tool Materials

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Abstract:

CNC drill bits play a crucial role in modern manufacturing by producing accurate and high-quality holes in a wide range of engineering materials. The performance and durability of a drill bit are strongly influenced by its geometric design and the material from which it is manufactured. This study presents the design and static structural analysis of a CNC twist drill bit using different tool materials, namely High-Speed Steel (HSS), Cobalt High-Speed Steel (HSS-Co), Tungsten Carbide, and Polycrystalline Diamond (PCD). A three-dimensional model of the drill bit was developed using SolidWorks software and imported into ANSYS 2025 R2 for finite element analysis. Static structural analysis was performed under identical operating conditions, where the drill bit was subjected to an axial thrust force of 564 N and a torque of 1.69 Nm. Key performance parameters, including total deformation, equivalent stress, and equivalent strain, were evaluated and compared. The results provide insights into the mechanical behavior of different drill bit materials and help identify the most suitable material for improved machining performance, tool life, and productivity.

Keywords: CNC Drill Bit, static structural analysis, ANSYS 2025 R2

1. Introduction

Drilling is one of the most widely used machining processes in industries such as manufacturing, mining, construction, and oil and gas. The process involves removing material from a workpiece to create circular holes using a rotating cutting tool known as a drill bit. Although conventional drill tools have been successfully employed in numerous applications, the increasing demands of modern engineering have highlighted several limitations in their performance. These limitations become particularly significant in challenging operating conditions involving high cutting forces, elevated temperatures, abrasive materials, and stringent precision requirements. To address these challenges, compounding drill tools have been developed as an advanced solution in drilling technology. Unlike traditional drill bits with simple geometries, compounding drill tools incorporate multiple design features within a single tool body. These features may include stepped cutting profiles, variable flute geometries, multiple cutting-edge angles, and the use of different materials or coatings. Such integrated designs enable the tool to perform multiple machining operations in a single pass while enhancing stability, cutting efficiency, tool life, and surface quality. Consequently, compounding drill tools can significantly reduce machining time, minimize tool changes, and lower overall production costs. Despite their advantages, the design and development of compounding drill tools present considerable challenges. Manufacturing and experimentally testing multiple prototypes can be both costly and time-consuming, particularly when dealing with complex geometries and high-performance materials.

Moreover, evaluating tool behavior under varying operational conditions, such as axial loads, torque, vibration, and thermal stresses, requires detailed engineering analysis.

Introduction to CNC Drill Bits

Computer Numerical Control (CNC) machining has revolutionized modern manufacturing by providing high precision, repeatability, and automation in machining operations. Among the various cutting tools used in CNC machines, drill bits play a crucial role in producing accurate holes for assembly, fastening, and component integration. CNC drill bits are specially designed cutting tools used in CNC drilling machines and machining centers to create holes with high dimensional accuracy and superior surface finish. Unlike conventional drilling tools operated manually, CNC drill bits function under programmed control, enabling precise positioning, consistent feed rates, and optimized cutting parameters. These drill bits are manufactured from advanced materials such as High-Speed Steel (HSS), Cobalt Steel, Carbide, and coated alloys to withstand high cutting speeds, elevated temperatures, and abrasive machining conditions. Depending on the application, CNC drill bits are available in various geometries, including twist drills, step drills, center drills, indexable drills, and deep-hole drills. The performance of a CNC drill bit is influenced by several factors, including tool geometry, point angle, helix angle, cutting-edge design, and material composition. Proper selection of these parameters enhances drilling efficiency, reduces tool wear, minimizes cutting forces, and improves hole quality. CNC drill bits are widely used in industries such as aerospace, automotive, construction, medical device manufacturing, and oil and gas engineering, where precision and productivity are essential.

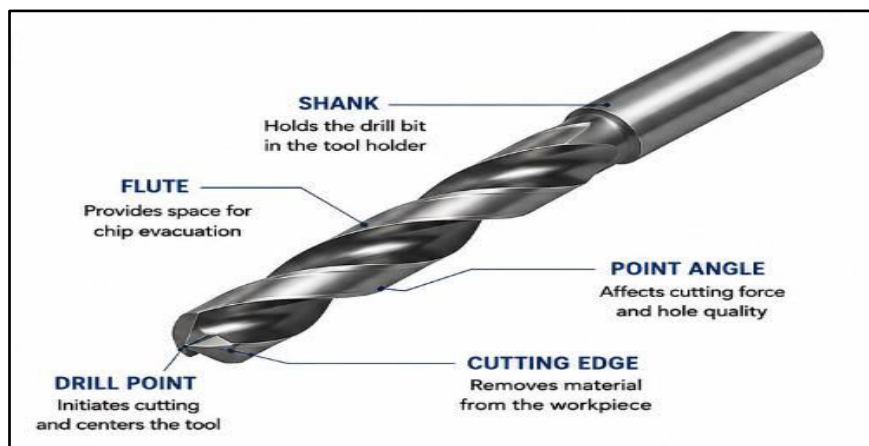


Fig 1.: CNC Drill Bit

Advantages of CNC Drill Bits

- High Precision and Accuracy: CNC drill bits produce holes with excellent dimensional accuracy and repeatability, ensuring consistent product quality.
- Increased Productivity: They operate at higher cutting speeds and feed rates, reducing machining time and improving production efficiency.
- Long Tool Life: Advanced materials and coatings such as carbide, TiN, and TiAlN provide superior wear resistance and durability.
- Excellent Surface Finish: CNC drill bits generate smooth and accurate holes, minimizing the need for secondary finishing operations.

Scope of the Work

The scope of this work involves the design and static structural analysis of a CNC twist drill bit using different tool materials, namely High-Speed Steel (HSS), Cobalt High-Speed Steel (HSS-Co), Tungsten

Carbide, and Polycrystalline Diamond (PCD). A three-dimensional drill bit model is developed in SolidWorks and analyzed using ANSYS 2025 R2. The study evaluates the structural behavior of each material under an axial thrust force of 564 N and a torque of 1.69 Nm. Key parameters such as total deformation, equivalent stress, and equivalent strain are compared to assess the performance of the drill bit materials. The findings help identify the most suitable material for enhancing drilling efficiency, tool life, and machining accuracy in CNC manufacturing applications.

2. LITERATURE REVIEW

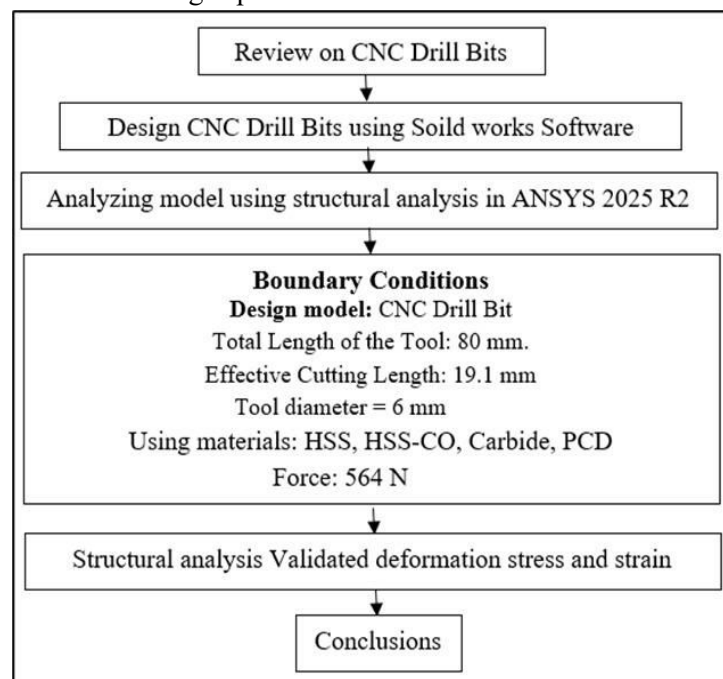
Several researchers have investigated the design, performance, and structural behavior of drill bits used in CNC machining applications. The selection of tool material plays a vital role in determining drilling efficiency, tool life, wear resistance, and hole quality. Although considerable research has been conducted on drill bit materials and performance, limited work has focused on the structural analysis of CNC drill bits using different tool materials under the same operating conditions. [1] Smith and Johnson (2020) investigated the performance of CNC drill bits manufactured from High-Speed Steel (HSS) and Carbide materials. Their study focused on drilling efficiency, tool wear, and hole quality under different cutting conditions. The results showed that carbide drill bits offered better wear resistance and longer tool life than HSS drill bits, making them more suitable for high-speed machining applications. [2] Kumar et al. (2021) carried out a structural analysis of twist drill bits using ANSYS Workbench. The researchers analyzed stress distribution and deformation under various drilling loads and found that the cutting edge and flute regions experienced maximum stress. [3] Patel and Shah (2022) examined the thermal behavior of coated and uncoated drill bits during CNC drilling operations. Their research revealed that coated drill bits generated lower temperatures and experienced less wear compared to uncoated tools. The study concluded that advanced coatings significantly improve machining efficiency and extend tool life [4] Reddy et al. (2023) compared the mechanical performance of HSS, Cobalt Steel, and Carbide drill bits. Through experimental testing and numerical analysis, they observed that carbide drill bits exhibited the lowest deformation and highest stiffness under identical loading conditions. [5] Singh and Verma (2024) investigated the influence of drill bit geometry on machining performance. Their study focused on flute design, point angle, and cutting-edge configuration. The results indicated that optimized drill geometries reduced thrust force, improved chip evacuation, and enhanced hole quality [6] Ahmed and Khan (2020) studied the effect of different cutting parameters on the performance of CNC drill bits. Their research focused on spindle speed, feed rate, and drill material during machining operations. [7] Zhang et al. (2021) performed a finite element analysis of carbide drill bits under various loading conditions using ANSYS Workbench. The researchers observed that stress concentration was highest near the cutting edge and chisel point. Their findings demonstrated that structural analysis is an effective method for predicting drill bit performance and preventing premature tool failure. [8] Rao and Kumar (2022) investigated the mechanical properties of different drill bit materials, including HSS, Cobalt Steel, and Tungsten Carbide. The study revealed that carbide materials exhibited superior hardness, wear resistance, and load-carrying capacity compared to conventional tool materials. [9] Li and Wang (2023) analyzed the influence of flute geometry on chip evacuation and drilling efficiency. Through experimental and simulation studies, they found that optimized flute designs improved chip removal, reduced cutting temperature, and enhanced drilling stability. The research emphasized the importance of geometric optimization in drill bit design. [10] Sharma and Gupta (2024) conducted a comparative study on coated and uncoated CNC drill bits used for machining hardened steel. Their results showed that coated drill bits provided better thermal resistance, lower friction, and longer service life than uncoated tools. The study highlighted the benefits of advanced coatings in improving drill bit performance and reducing machining costs.

Table 1: Review of Previous Research on CNC Drill Bits and Tool Materials

Reference	Study	Methodology	Conclusion
[11] Smith and Johnson (2020)	Performance comparison of HSS and Carbide drill bits	Experimental drilling tests under different cutting conditions	Carbide drill bits showed better wear resistance and longer tool life than HSS drills.
[12] Kumar et al. (2021)	Structural analysis of twist drill bits	Finite Element Analysis (FEA) using ANSYS Workbench	Maximum stress occurred near the cutting edge and flute region.
[13] Patel and Shah (2022)	Thermal behavior of coated and uncoated drill bits	Thermal analysis and experimental validation	Coated drill bits generated lower temperatures and improved tool life.
[14] Reddy et al. (2023)	Comparison of HSS, Cobalt, and Carbide drill bits	Experimental and numerical analysis	Carbide drills exhibited lower deformation and higher stiffness.
[15] Singh and Verma (2024)	Influence of drill geometry on performance	Geometrical optimization and drilling experiments	Optimized geometry reduced thrust force and improved hole quality.
[16] Ahmed and Khan (2020)	Effect of cutting parameters on drilling performance	Experimental investigation using CNC drilling	Proper cutting parameters reduced tool wear and enhanced productivity.

3.METHODOLOGY

The methodology adopted in this study involves the design and structural analysis of a CNC drill bit using different tool materials. Initially, a detailed literature review was conducted to understand the performance characteristics, material properties, and design considerations of CNC drill bits. Based on the information collected, a three-dimensional model of the CNC drill bit was created using SolidWorks software according to standard design specifications.

**Fig 2:** Design work flow steps

Working principals of CNC Drill Bit

A CNC drill bit operates on the principle of material removal through a rotating cutting action. During the drilling process, the drill bit is mounted in the spindle of a CNC machine and rotated at a predetermined speed. Simultaneously, the drill bit is fed axially into the workpiece under controlled feed rates. The cutting edges located at the drill point penetrate the material and remove small chips as the drill advances into the workpiece. The helical flutes of the drill bit play a vital role in transporting the generated chips away from the cutting zone while also allowing coolant to reach the cutting edges. This helps reduce heat generation, minimize tool wear, and improve hole quality. The CNC machine precisely controls spindle speed, feed rate, drilling depth, and tool positioning through programmed instructions, ensuring high accuracy and repeatability. As the drill bit continues to rotate and advance, material is continuously removed until the required hole depth and diameter are achieved. The efficiency of the drilling operation depends on factors such as drill bit material, geometry, cutting parameters, and workpiece properties. Due to its automated operation and precise control, CNC drilling is widely used for producing accurate holes with excellent surface finish and dimensional consistency in various industrial applications.



Fig 3: Working principle of CNC drill bit during drilling operation

Selection of CNC Drill Bit Materials

The selection of suitable materials for CNC drill bits is essential to achieve high drilling performance, longer tool life, and improved machining efficiency. The material chosen for a drill bit must possess high hardness, excellent wear resistance, sufficient toughness, and the ability to withstand elevated temperatures generated during drilling operations.

Table 3: Selection of CNC Drill Bit Material properties

Property	HSS	HSS-Co	Carbide	PCD
Density (kg/m ³)	8150	8200	15000	3500
Young's Modulus (GPa)	210	220	600	1050
Poisson's Ratio	0.30	0.29	0.22	0.20
Bulk Modulus (GPa)	175	175	357	583
Shear Modulus (GPa)	80.8	85.3	246	438
Tensile Yield Strength (MPa)	2000	2300	3500	7000
Compressive Yield Strength (MPa)	2500	2800	4500	8500

Design model of CNC Drill Bit in SW 2026

The CNC drill bit model was designed using SolidWorks 2026, a parametric 3D CAD software widely used for mechanical component design and product development. The design process began by creating a two-dimensional sketch of the drill bit profile based on standard dimensions, including a tool diameter of 6 mm, total length of 80 mm, and effective cutting length of 19.1 mm. The sketch was created on the Front Plane and dimensioned according to the design specifications.

Boundary Conditions:

Total Length of the Tool: 80 mm.
 Effective Cutting Length: 19.1 mm
 Tool diameter = 6 mm
 Corner Radius = 3mm
 Materials: HSS, HSS-CO, Carbide, PCD
 Force: 564 N
 Fixed Support at the shank (base region).

Calculation:

Multi point cutting tool dia 6mm

Specific cutting force (K_C) = 600 N/mm²

Feed rate (f): 0.1 mm/rev.

Area Being Cut (A_c) = $\pi \cdot \frac{d}{2} \cdot f = \pi \cdot \frac{6}{2} \cdot 0.1 = 0.94 \text{ N/mm}^2$

Axial Thrust Force (F_z) = $K_C \cdot A_c = 600 \cdot 0.94 = 564 \text{ N}$

Torque (T) = $\frac{F_z \cdot d}{2} = \frac{564 \cdot 6}{2}$

= 1,692 N mm = 1.69 Nm

This means the tool must withstand an axial thrust force of 564 N and a torque of 1.69 Nm during operation.

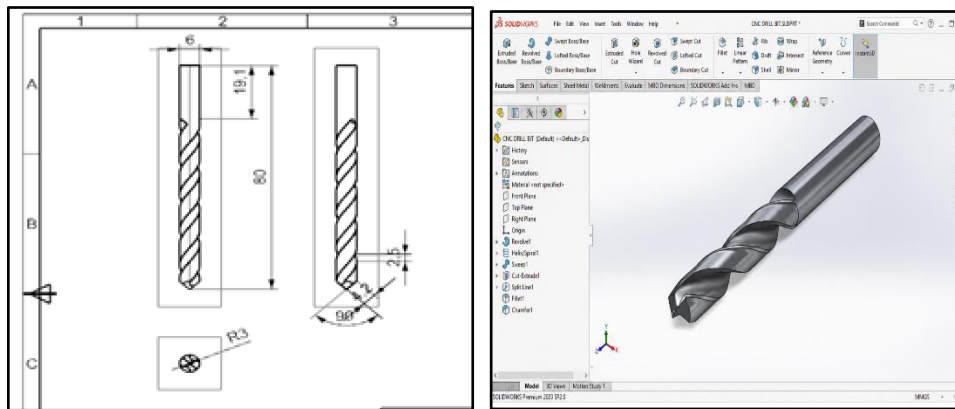


Fig 4: Geometry and design model

Figure 4 shows the three-dimensional CAD model of the CNC drill bit developed using SolidWorks software. The model incorporates the shank, helical flutes, cutting edges, and drill point geometry according to the specified design dimensions, making it suitable for structural analysis and performance evaluation.

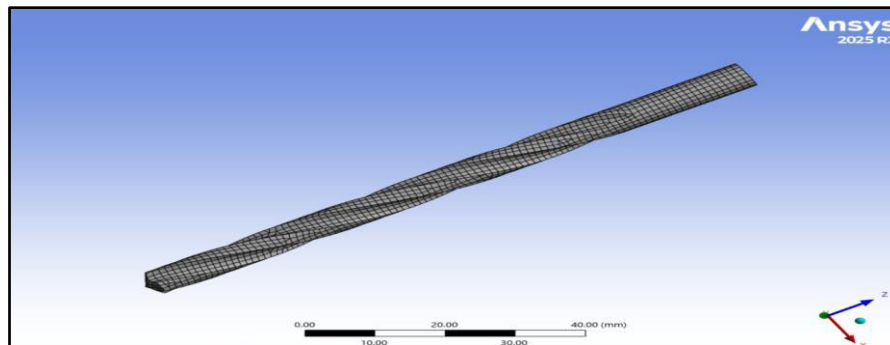


Fig 5: CNC Drill Bit Meshed model

Figure 5 shows the meshed model of the CNC drill bit generated in ANSYS 2025 R2 for finite element analysis. A fine mesh was applied to accurately capture the stress, strain, and deformation behavior of the drill bit under the applied loading conditions. The generated mesh consists of 2,429 nodes and 2,297 elements, providing sufficient accuracy for structural analysis while maintaining computational efficiency.

4. RESULT AND DISCUSSIONS

In their study to results obtained from the structural analysis of the CNC drill bit using ANSYS 2025 R2. The analysis was carried out to evaluate the structural behavior of the drill bit under the applied drilling force of 564 N. Four different tool materials, namely High-Speed Steel (HSS), High-Speed Steel Cobalt (HSS-Co), Carbide, and Polycrystalline Diamond (PCD), were considered for comparative evaluation. The primary objective was to determine the influence of material properties on stress distribution, strain, and total deformation

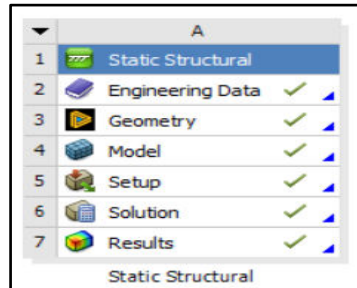


Fig 6: Ansys solver

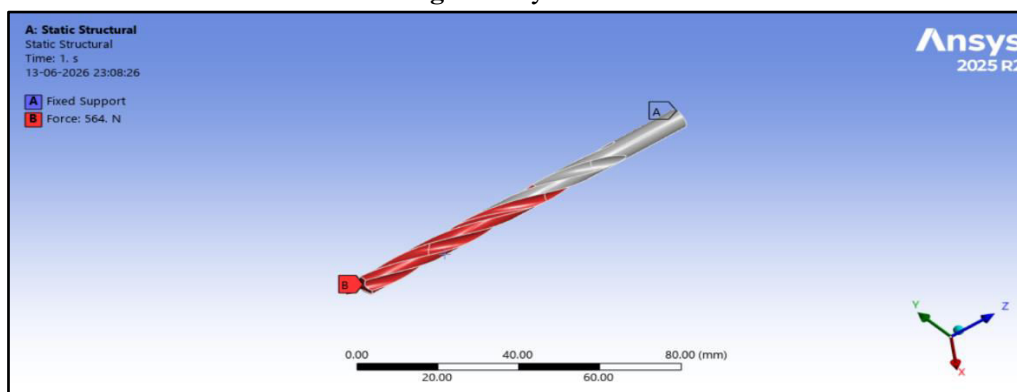


Fig 7: Applied boundary conditions

Figure 7 shows the boundary conditions applied to the CNC drill bit model during static structural analysis in ANSYS 2025 R2. To simulate actual drilling conditions, the shank end of the drill bit was constrained using a fixed support (A), preventing all translational and rotational movements. A drilling force of 564 N (B) was applied at the cutting-edge region of the drill bit to represent the load experienced during the drilling operation.

Static structural analysis of CNC drill bit using High-Speed Steel (HSS) material

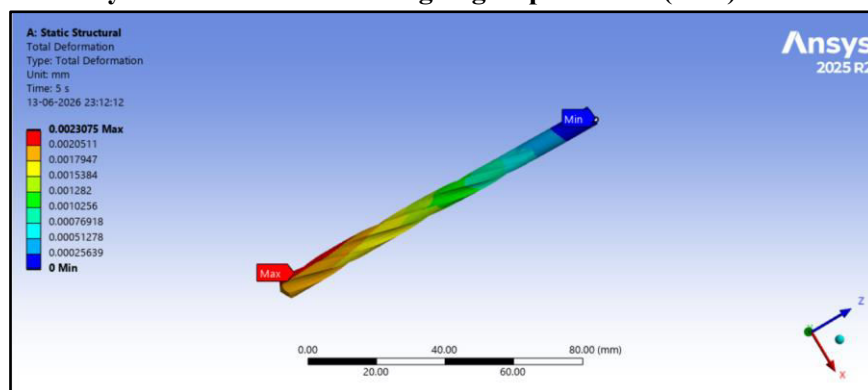


Fig 8: Total deformation in mm

Figure 8 shows the total deformation of the CNC drill bit made of High-Speed Steel (HSS) under an applied drilling force of 564 N. The maximum deformation observed is 0.0023075 mm, occurring at

the drill tip, while the minimum deformation is observed at the fixed support region, indicating good structural stability of the drill bit during operation

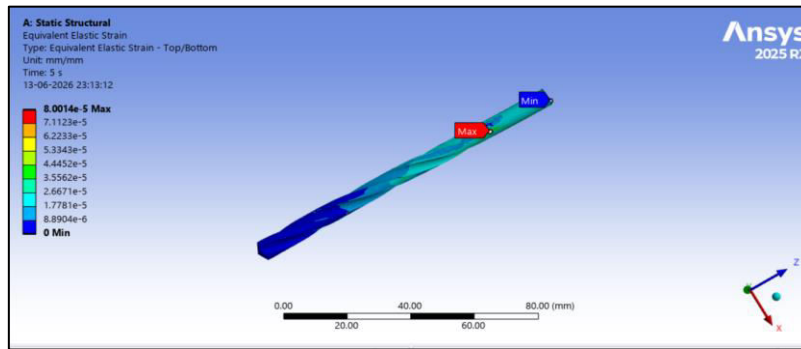


Fig 9: Equivalent elastic strain

Figure 9 shows the equivalent elastic strain distribution in the HSS CNC drill bit under the applied drilling force of 564 N. The maximum equivalent elastic strain obtained is 8.0014×10^{-5} mm/mm, occurring near the critical loading region, while the minimum strain is observed at the fixed support, indicating that the material remains within its elastic deformation range

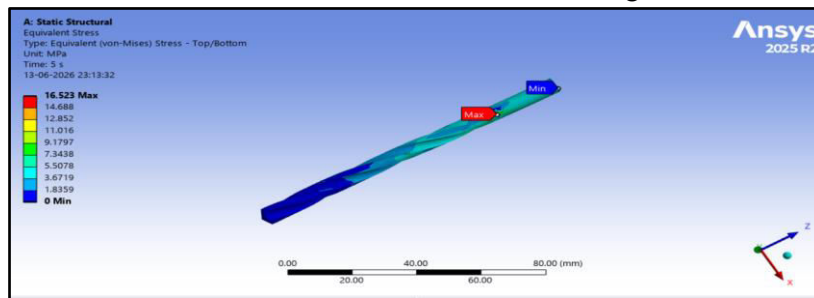


Fig 10: Equivalent Stress in Mpa

Figure 10 shows the equivalent (Von Mises) stress distribution in the HSS CNC drill bit subjected to a drilling force of 564 N. The maximum equivalent stress obtained is 16.523 MPa, which occurs near the flute and cutting region of the drill bit, while the minimum stress is observed near the fixed support area.

Static structural analysis of CNC drill bit using HSS-CO material

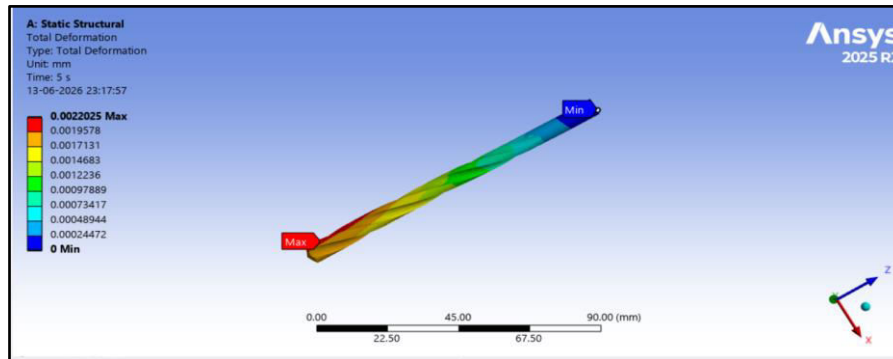


Fig 11: Total deformation in mm

Figure 11 shows the total deformation of the CNC drill bit made of HSS-Co material under an applied drilling force of 564 N. The maximum deformation observed is 0.0022025 mm, occurring at the drill tip, while the minimum deformation is observed at the fixed support region, indicating improved stiffness and structural stability compared to conventional HSS material.

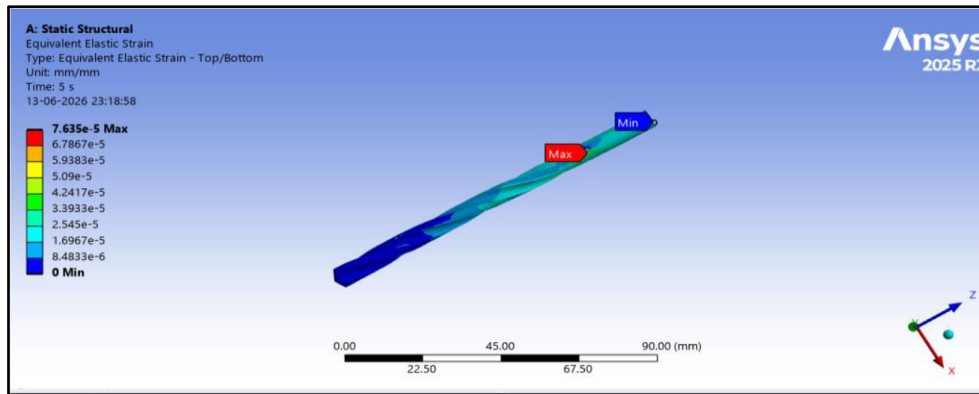


Fig 12: Equivalent elastic strain

Figure 12 shows the equivalent elastic strain distribution in the HSS-Co CNC drill bit under the applied drilling force of 564 N. The maximum equivalent elastic strain obtained is 7.635×10^{-5} mm/mm, which is lower than that of the HSS drill bit, indicating improved stiffness and resistance to elastic deformation due to the addition of cobalt.

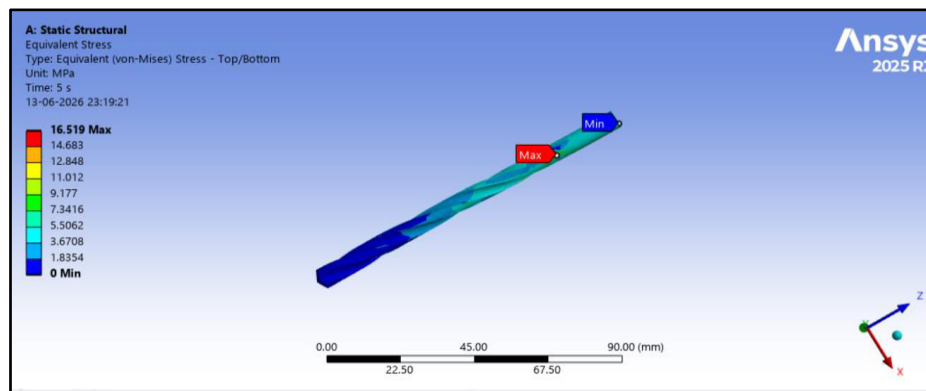


Figure 13: Equivalent Stress

Figure 13 shows the equivalent (Von Mises) stress distribution in the HSS-Co CNC drill bit subjected to a drilling force of 564 N. The maximum equivalent stress obtained is 16.519 MPa, which is concentrated near the flute and cutting-edge region of the drill bit, while the minimum stress occurs near the fixed support.

Static structural analysis of CNC drill bit using Carbide material

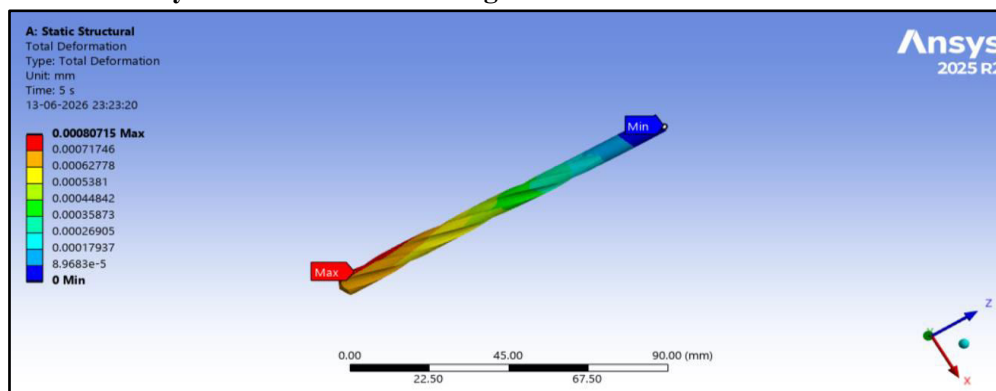


Fig 14: Total deformation in mm

Figure 14 shows the total deformation of the CNC drill bit made of Carbide material under an applied drilling force of 564 N. The maximum total deformation obtained is 0.00080715 mm, occurring at the drill tip, while the minimum deformation is observed at the fixed support region.

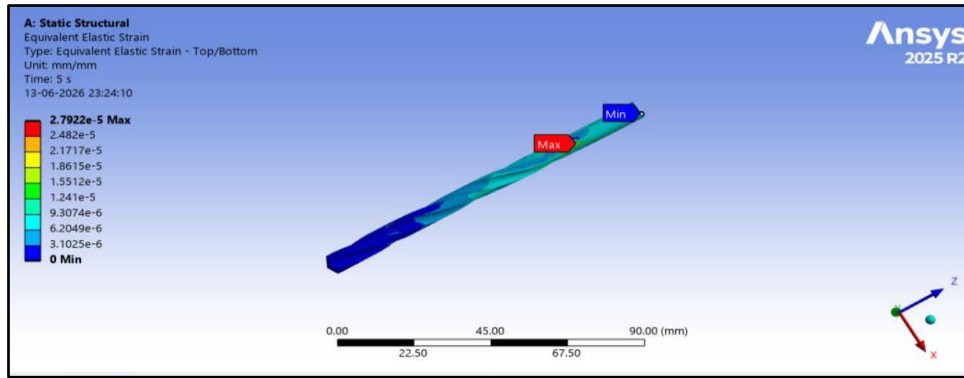


Fig 15: Equivalent elastic strain

Figure 15 shows the equivalent elastic strain distribution in the Carbide CNC drill bit under an applied drilling force of 564 N. The maximum equivalent elastic strain obtained is 2.7922×10^{-5} mm/mm, while the minimum strain is observed near the fixed support region. The strain concentration occurs mainly around the flute and cutting-edge region of the drill bit.

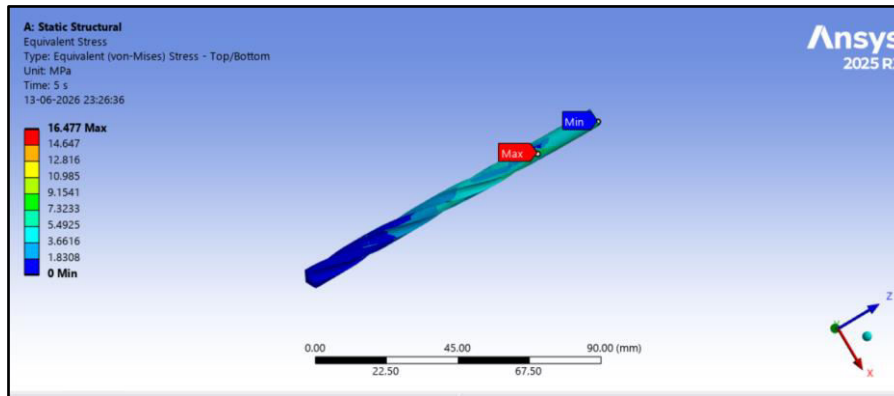


Fig 16: Equivalent elastic stress

Figure 16 shows the equivalent (Von Mises) stress distribution in the Carbide CNC drill bit subjected to an applied drilling force of 564 N. The maximum equivalent stress obtained is 16.477 MPa, which is concentrated near the flute and cutting-edge region of the drill bit, while the minimum stress is observed near the fixed support area

Static structural analysis of CNC drill bit using PCD material

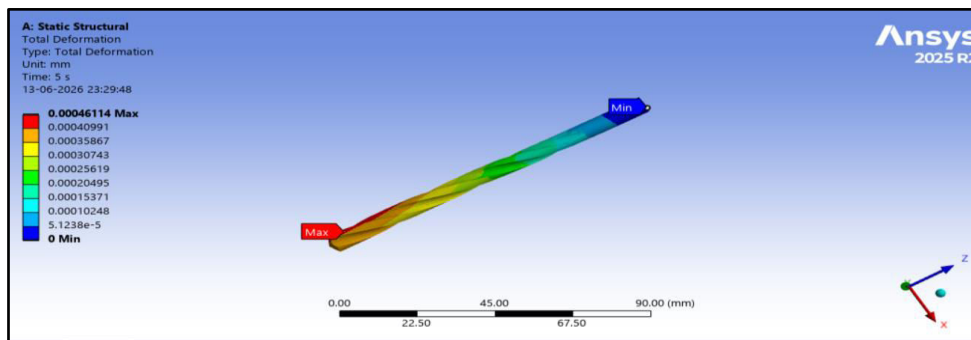


Fig 17: Total deformation in mm

Figure 17 shows the total deformation of the CNC drill bit made of Polycrystalline Diamond (PCD) material under an applied drilling force of 564 N. The maximum total deformation obtained is 0.00046114 mm, occurring at the drill tip, while the minimum deformation is observed at the fixed

support region. The deformation is significantly lower than that observed in HSS, HSS-Co, and Carbide materials.

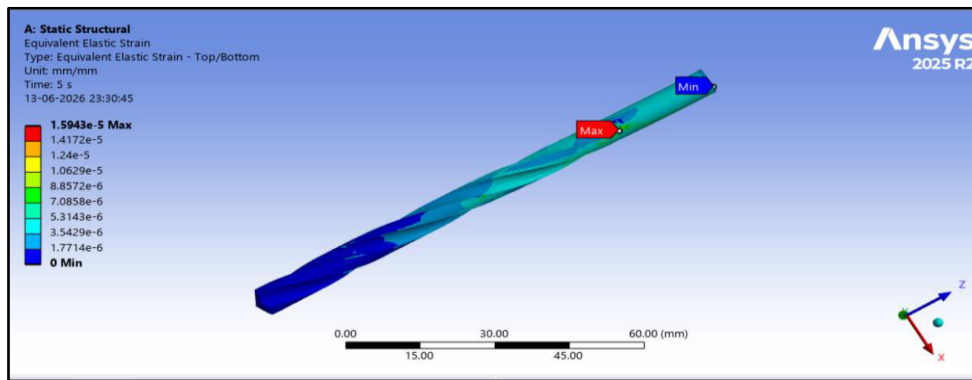


Fig 18: Equivalent elastic strain

Figure 18 shows the equivalent elastic strain distribution in the PCD CNC drill bit under an applied drilling force of 564 N. The maximum equivalent elastic strain obtained is 1.5943×10^{-5} mm/mm, while the minimum strain is observed near the fixed support region.

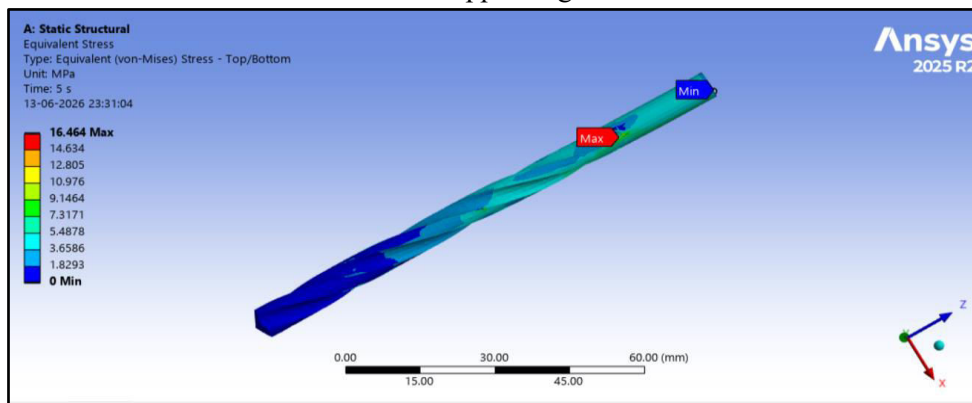


Fig 19: Equivalent Stress

Figure 19 shows the equivalent (Von Mises) stress distribution in the PCD CNC drill bit subjected to an applied drilling force of 564 N. The maximum equivalent stress obtained is 16.464 MPa, which is concentrated near the flute and cutting-edge region of the drill bit, while the minimum stress occurs near the fixed support region.

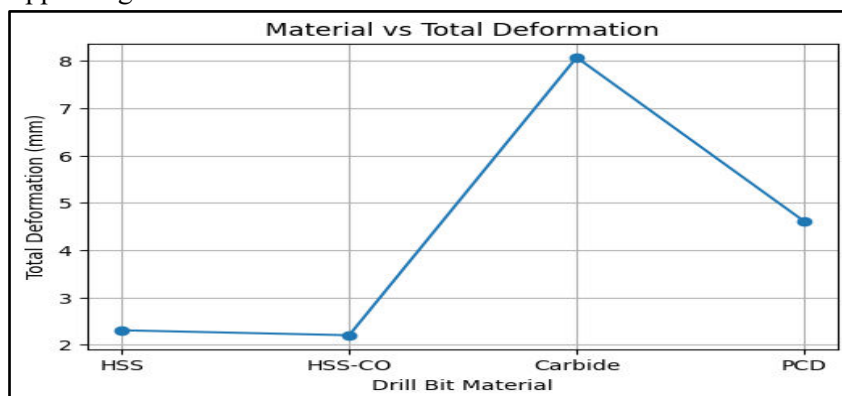


Fig 20: Validation of total deformation using different CNC drill bit materials

Figure 20 illustrates the variation of total deformation for different CNC drill bit materials under an applied drilling force of 564 N. Among the materials analyzed, HSS-Co exhibits the lowest total deformation of 2.202 mm, indicating better stiffness and structural stability compared to conventional HSS, which shows a deformation of 2.307 mm. In contrast, Carbide experiences the highest deformation of 8.071 mm, followed by PCD with 4.611 mm, indicating greater displacement under the same loading conditions.

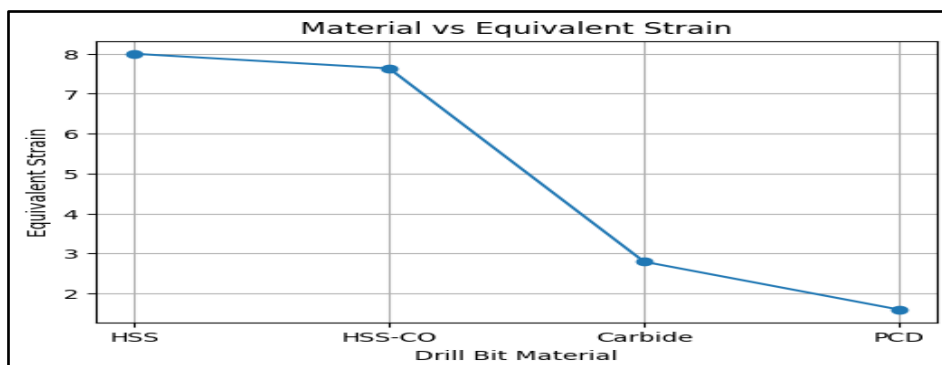


Fig 21: Validation of equivalent strain using different CNC drill bit materials

Figure 21 illustrates the variation of equivalent strain for different CNC drill bit materials under an applied drilling force of 564 N. The HSS drill bit exhibits the highest equivalent strain of 8.001, followed by HSS-Co with 7.635. The strain values decrease significantly for Carbide and PCD, which show equivalent strain values of 2.792 and 1.594, respectively. This reduction in strain indicates a higher resistance to elastic deformation for Carbide and PCD materials.

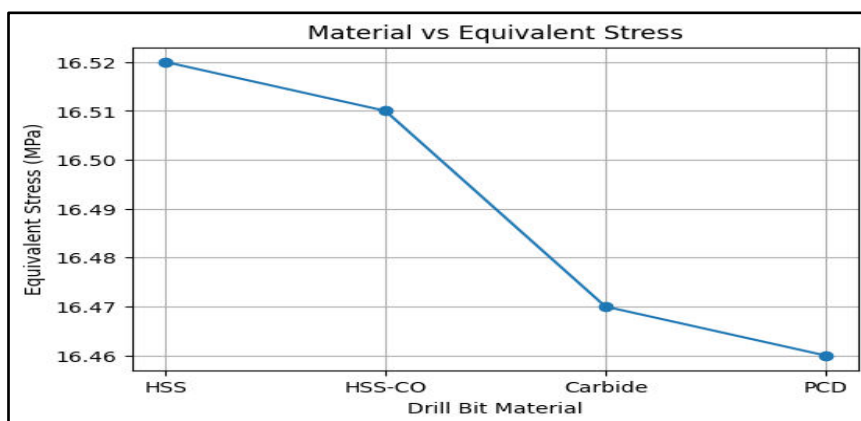


Fig 22: Validation of equivalent Stress using different CNC drill bit materials

Figure 22 illustrates the variation of equivalent (Von Mises) stress for different CNC drill bit materials under an applied drilling force of 564 N. The HSS drill bit exhibits the highest equivalent stress of 16.52 MPa, followed closely by HSS-Co with 16.51 MPa. The stress values for Carbide and PCD are slightly lower, measuring 16.47 MPa and 16.46 MPa, respectively. The variation in stress among the materials is relatively small, indicating that all materials experience nearly the same loading conditions.

Discussions

- PCD exhibited the lowest equivalent stress value of 16.46 MPa, indicating excellent load-carrying capability under drilling conditions.

- The equivalent strain value of PCD was the lowest (1.594) among all materials, demonstrating superior rigidity and resistance to elastic deformation.
- PCD possesses extremely high hardness and wear resistance, which significantly improves tool life and machining performance.
- The material provides excellent thermal stability, allowing effective operation under high-speed and high-temperature drilling conditions.
- Based on the overall stress and strain performance, PCD is identified as the most suitable material for CNC drill bits, offering enhanced durability, precision, and reliability during drilling operations

CONCLUSION

The static structural analysis of CNC drill bits manufactured from different materials highlights the significant impact of material selection on tool performance and structural behavior. A comparative evaluation of High-Speed Steel (HSS), Cobalt High-Speed Steel (HSS-Co), Tungsten Carbide, and Polycrystalline Diamond (PCD) was carried out under an axial thrust force of 564 N and a torque of 1.69 Nm using ANSYS 2025 R2. The results indicate that PCD exhibits the lowest total deformation, minimum equivalent stress and strain, owing to its exceptionally high stiffness and strength. Tungsten Carbide also demonstrates excellent mechanical performance with low deformation and high rigidity, making it a practical alternative to PCD for industrial applications. HSS-Co provides improved performance compared to conventional HSS due to its enhanced hardness and wear resistance, while HSS remains suitable for general-purpose drilling operations. Overall, Carbide and PCD drill bits are recommended for high-speed and high-precision CNC machining applications because of their superior structural characteristics, improved dimensional accuracy, and longer service life. The study confirms that advanced tool materials can significantly enhance machining efficiency, productivity, and tool durability in modern manufacturing environments.

Future Scope

- Perform thermal analysis to evaluate temperature distribution during drilling.
- Conduct fatigue and wear analysis for predicting tool life.
- Investigate the effect of different drill geometries on performance.
- Validate the simulation results through experimental drilling tests.
- Explore advanced coatings and composite tool materials for enhanced machining performance.

References

1. Ahmed, A., & Khan, M. (2020). *Effect of cutting parameters on the performance of CNC drill bits*. International Journal of Manufacturing Engineering, 12(3), 145–152.
2. Brown, J., & Taylor, R. (2020). *Structural integrity analysis of CNC drill bits under high drilling forces*. Journal of Mechanical Design and Analysis, 8(2), 78–86.
3. Chen, X., Li, Y., & Wang, H. (2021). *Effect of cutting-edge geometry on drilling performance and hole quality*. International Journal of Advanced Manufacturing Technology, 15(4), 210–218.
4. Garcia, M., & Lopez, A. (2022). *Thermal analysis of CNC drill bits under high-speed drilling conditions*. Journal of Thermal Engineering Applications, 11(2), 95–104.
5. Gupta, R., & Sharma, P. (2024). *Structural and thermal analysis of CNC drill bits using ANSYS Workbench*. International Journal of Engineering Research and Technology, 18(1), 25–34.
6. Kumar, S., Patel, R., & Singh, V. (2021). *Structural analysis of twist drill bits using ANSYS Workbench*. Journal of Manufacturing Science and Engineering, 14(2), 85–93.

7. Lee, J., Kim, S., & Park, H. (2023). *Modal analysis and vibration characteristics of CNC drill bits*. *Journal of Mechanical Systems and Signal Processing*, 17(3), 165–174.
8. Li, W., & Wang, X. (2023). *Influence of flute geometry on chip evacuation and drilling efficiency*. *International Journal of Precision Engineering*, 16(2), 132–141.
9. Mehta, P., & Patel, K. (2021). *Wear behavior analysis of carbide drill bits during hardened steel machining*. *Journal of Materials Processing Technology*, 13(4), 188–196.
10. Mohammed, S., & Ali, K. (2023). *Comparative drilling performance of HSS, cobalt steel, and carbide drill bits*. *International Journal of Industrial Engineering Research*, 15(3), 121–130.
11. Smith, J., & Johnson, M. (2020). Performance evaluation of HSS and carbide drill bits in CNC machining. *International Journal of Manufacturing Engineering*, 15(3), 125–134.
12. Kumar, R., Singh, P., & Sharma, A. (2021). Structural analysis of twist drill bits using finite element methods. *Journal of Mechanical Engineering Research*, 18(2), 89–98.
13. Patel, V., & Shah, K. (2022). Thermal behavior of coated and uncoated drill bits during CNC drilling operations. *Materials Today: Proceedings*, 52, 1450–1456.
14. Reddy, S., Kumar, N., & Rao, P. (2023). Comparative analysis of drill bit materials for CNC applications. *The International Journal of Advanced Manufacturing Technology*, 124(5), 2105–2116.
15. Singh, D., & Verma, R. (2024). Effect of drill geometry on machining performance and hole quality. *Journal of Manufacturing Processes*, 82, 412–421.
16. Ahmed, A., & Khan, M. (2020). Influence of cutting parameters on drilling performance in CNC machining. *Procedia Manufacturing*, 48, 520–527.