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Investigation of Surface Quality and Hole Integrity in Drilling AISI 430 with Coated and Uncoated HSS Tools

Abdul Haris Nasution, Istu Sri Poneni
Teaching Staff, Department of Mechanical Engineering, Faculty of Engineering, UISU
HP: 08126522376 e-mail : aharisnst@ft.uisu.ac.id; ayumandala98@gmail.com

Abstract - This study investigates the influence of tool coating and cutting parameters on the surface integrity and dimensional accuracy during drilling of ferritic stainless steel AISI 430. Using both Al-Ti-N coated and uncoated HSS drill bits, experiments were performed under dry conditions with varying spindle speeds (800–1200 rpm) and feed rates (0.1–0.2 mm/rev). Results show that coated tools consistently yielded lower surface roughness (Ra), reduced diameter error, improved hole roundness (ovality), and better perpendicularity. The Al-Ti-N coating significantly mitigated tool wear and thermal effects, enhancing process stability and microhardness near the drilled surface. Optimal drilling performance was observed at lower feed rates and moderate spindle speeds when using coated tools. These findings highlight the critical role of tool coatings and parameter optimization in machining ferritic stainless steels for high-precision applications.

Keywords: Aisi 430, Drilling, Surface Roughness, Al-Ti-N Coating, Dimensional Accuracy, Stainless Steel, Hss Drill *Bit*

1. INTRODUCTION

Drilling operations involving stainless steel components are vital across a wide spectrum of high-performance industries such as aerospace, biomedical, marine, and petrochemical sectors [1][2]. These applications place stringent demands on not only the corrosion resistance and mechanical robustness of the materials used, but also on dimensional accuracy and surface integrity of the machined components. AISI 430 [3], a ferritic stainless steel variant, presents a particular set of machining challenges due to its low thermal conductivity, moderate hardness, abrasive carbide phases, and tendency to work-harden during machining[4].These characteristics often lead to elevated tool wear, increased cutting forces, and reduced surface quality—factors that complicate precision drilling operations [5].

Surface roughness (Ra) stands out as a critical performance metric in evaluating drilling outcomes, directly affecting a component's fatigue resistance, sealing capability, and dimensional consistency [6]. Poor surface integrity may lead to premature failure or suboptimal performance in service, particularly in applications demanding tight tolerances. In response to these issues, prior research has investigated various strategies to improve machinability and surface outcomes including heat treatments, advanced lubrication techniques, modified drill geometries, and tool coatings[7].

Among these, tool coatings—especially those based on Aluminum Titanium Nitride (Al-Ti-N)[8]have emerged as a promising avenue for enhancing tool life and surface finish in stainless steel drilling [9]. Studies on related stainless steel grades, such as AISI 410 and Ultra 904L, have demonstrated that Al-Ti-N coatings reduce friction and thermal loads, minimize adhesion and built-up edge (BUE) formation, and extend tool longevity [10]. Coated High-Speed Steel (HSS) drills have also shown surface roughness improvements of up to 48.5% in comparison to their uncoated counterparts [11]. However, while these findings are promising, most existing literature isolates specific variables such as feed rate or coolant strategy without comprehensively analyzing the combined effects of coating, material condition (e.g., heat treatment), and cutting parameters on overall drilling performance[12][13].

This study addresses this gap by providing a comprehensive experimental analysis of the drilling performance of AISI 430 stainless steel using both Al-Ti-N coated and uncoated HSS drill bits [14][15]. The investigation covers both heat-treated and untreated specimens under a range of cutting speeds and feed rates using a controlled dry machining environment [16][17] Multiple performance indicators are evaluated to offer a holistic understanding of process outcomes, including surface roughness (Ra)[18], hole roundness (ovality), perpendicularity, diameter accuracy [19], and microstructural changes in the machined surface [20].

The novelty of this research lies in its integrative approach: rather than isolating variables, it simultaneously evaluates the impact of tool coating, feed rate, spindle speed, and material condition on multiple key output parameters in drilling ferritic stainless steel. The resulting insights contribute to the development of more effective and robust machining strategies for stainless steel alloys, particularly in high-precision applications. By linking geometric outcomes, this work offers a more complete understanding of how to optimize drilling processes for AISI 430 stainless steel.

2. MATERIALS AND METHODS

2.1. Workpiece materials and cutting tools

The work piece material and was sized into the desired dimension 50 x 50 x 15(mm) as shown in the Figure. 1.

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Figure 1. Material AISI 430

Drill Bits


Figure 2. HSS Uncoated Drill

Figure 3. HSS TiN-Coated Drill

Mechanical properties

Mechanical Properties	HSS Uncoated	HSS TiN-Coated
Hardness	~62–65 HRC	Up to 2500 HV
Tensile Strength	~900–1100 MPa	Higher
Wear Resistance	Standard	Significantly increased, service life 3–10× longer
Fatigue Power	Lower	Higher
Coefficient of Friction	Higner	Lower (~0.2), reduces heat and wear

Chemical Properties

HSS Uncoated
General Composition: Iron (Fe) with alloys such as tungsten (W), molybdenum (Mo), chromium (Cr), vanadium (V), and carbon (C).

HSS TiN-Coated
• Coating: Titanium Nitride (TiN), a ceramic compound with the chemical formula TiN.
• TiN Properties:

- Color: Metallic gold.
- Density: 5.21 g/cm³.
- Melting Point: 2947°C.
- Thermal Conductivity: 29 W/(m K) at 323K.
- Chemical Resistance: Highly resistant to corrosion and oxidation.

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2.2 Drill Machine

Drilling was conducted on a CNC vertical drilling machine with high rigidity and precision control. The experiments were carried out under dry conditions to emphasize the role of tool coatings.

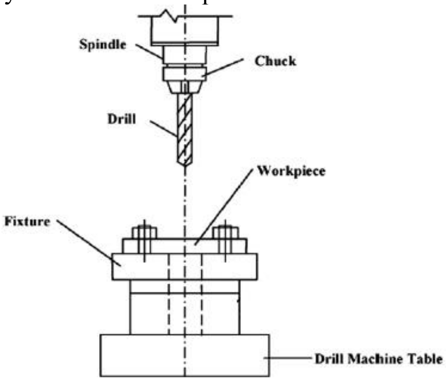

Figure 4. Drilling Machine

2.3 Cutting Parameters

- The 3^2 method was adopted, taking into account:Cutting Speed (V): 800, 1000, 1200 rpm
- Feed Rate (f): 0.1 ; 0.15 ; 0.2 mm/rev

3. RESULTS AND DISCUSSION

3.1 Effect of Spindle Speed and Feed on Surface Roughness (Ra)

The influence of feed rate and spindle speed on surface roughness (Ra) during the drilling of AISI 430 stainless steel was examined under two tool conditions: uncoated and Al-Ti-N coated HSS drill bits. The results indicate distinct trends in surface quality between the two tool types.a. Uncoated HSS Drill Bits For the uncoated drill bits, surface roughness generally increased with the rise in feed rate across all spindle speeds. At 800 rpm, Ra values increased progressively from 2.901 µm at 0.1 mm/rev to 3.428 µm at 0.2 mm/rev, indicating that higher material removal rates tend to degrade surface quality. This trend was also seen at 1000 rpm, where the roughness rose from 2.689 µm to 3.775 µm, with the highest Ra observed under the condition of 0.2 mm/rev feed (CC6). This highlights the sensitivity of surface roughness to feed rate in uncoated tools.

However, at 1200 rpm, the data showed a non-linear trend with fluctuations in Ra values—3.098 µm at 0.1 mm/rev, 3.765 µm at 0.15 mm/rev, and a surprising drop to 2.907 µm at 0.2 mm/rev. This irregular behavior suggests instability in the cutting process at higher spindle speeds, potentially due to thermal effects, vibration, or built-up edge formation, which are more pronounced in uncoated tools lacking a thermal barrier or surface smoothing effect.The lowest Ra (2.689 µm) was achieved at 1000 rpm and 0.1 mm/rev (CC4), while the highest Ra (3.775 µm) was recorded at the same spindle speed with a 0.2 mm/rev feed (CC6), reaffirming the dominant impact of feed rate on surface roughness when using uncoated drills.

Al-Ti-N Coated HSS Drill Bits In contrast, the Al-Ti-N coated drill bits demonstrated consistently lower surface roughness values across all tested conditions. This suggests that the coating effectively reduced friction and heat at the tool–workpiece interface, leading to improved surface finishes.

At 800 rpm, the surface roughness remained low and well-controlled, ranging from 1.001 µm at 0.1 mm/rev to 1.307 µm at 0.2 mm/rev. Notably, the lowest Ra overall (1.001 µm) was achieved at 800 rpm and 0.1 mm/rev (CC1), emphasizing the favorable interaction between low feed rate and coating at lower spindle speeds.

Although an increase in feed rate typically leads to higher roughness, this trend was not strictly observed in the coated drill data. For example, at 1200 rpm, Ra values were 1.265 µm (0.1 mm/rev), 1.732 µm (0.15 mm/rev), and 1.375 µm (0.2 mm/rev). This non-linear behavior indicates that the Al-Ti-N coating helps maintain surface integrity even at elevated feed rates, mitigating the roughening effects typically seen in uncoated drilling.

Interestingly, the highest Ra for coated drills (1.732 µm) occurred at 1200 rpm and 0.15 mm/rev (CC8), yet this value is still significantly lower than the best result from the uncoated group. These findings underscore the superior performance of coated tools in producing smoother holes with greater consistency, even under more aggressive drilling parameters.

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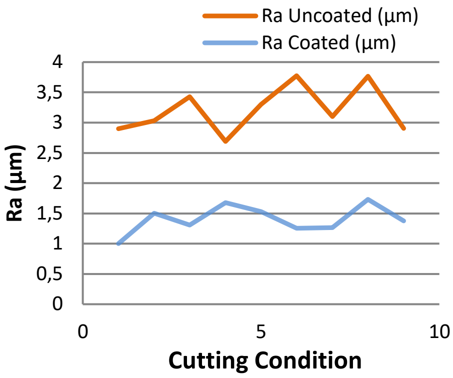

Figure 5. Comparative graph of surface roughness (Ra)

Figure 4 presents a comparative graph of surface roughness (Ra) obtained from drilling AISI 430 stainless steel using uncoated and Al-Ti-N coated HSS drill bits under nine different cutting conditions (CC1–CC9), representing combinations of spindle speed (800, 1000, 1200 rpm) and feed rate (0.1, 0.15, 0.2 mm/rev). The chart clearly illustrates that Al-Ti-N coated drills consistently outperform uncoated drills in terms of surface quality across all cutting conditions. In each case, the coated tool produced a significantly lower Ra value, regardless of feed rate or spindle speed. This consistent reduction in surface roughness highlights the critical role of Al-Ti-N coating in enhancing machining performance. The superior performance of the coated drill bits can be attributed to several key mechanisms: Reduction in friction between the cutting tool and workpiece, which minimizes surface damage and adhesion-related defects; Improved chip evacuation, facilitated by the smoother and more heat-resistant surface of the coated drill, which helps maintain a clean cutting zone; Enhanced thermal and mechanical stability, particularly at higher spindle speeds, where uncoated tools often suffer from increased tool wear, built-up edge formation, and vibration. These effects collectively contribute to a more stable cutting process and better preservation of the workpiece surface integrity.The graphical evidence reinforces the earlier analytical results, emphasizing that tool coating is a decisive factor in achieving superior surface finish during the drilling of ferritic stainless steel. Given that surface roughness is closely linked to component performance—affecting fatigue life, corrosion resistance, and dimensional precision—the use of Al-Ti-N coated tools presents a compelling advantage in high-precision manufacturing applications involving AISI 430.

3.2. Material Removal Rate (MRR)

MRR increases linearly with speed and feed, as per the MRR formula:

$$\text{MRR} = \frac{\pi D^2}{4} \times f \times V$$

With a fixed drill diameter (10 mm), MRR is directly affected by spindle speed (n) and feed (f).

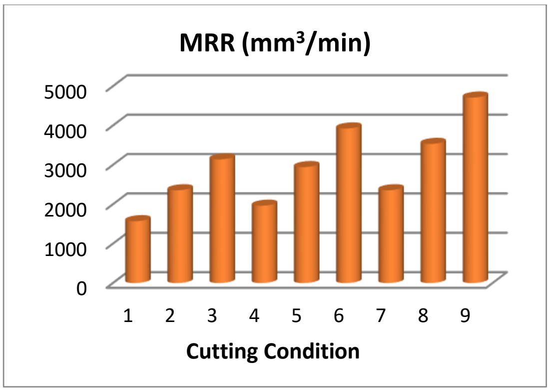

Figure 6. Material Removal Rate

Figure 5. shows that the best cutting conditions depend on the process priority. If productivity (high MRR) is prioritized, then CC9 (1200 rpm, 0.2 mm/rev) is the best choice even though the surface roughness (Ra) is not optimal. Conversely, for the best surface results, CC1 (800 rpm, 0.1 mm/rev, coated) provides the lowest Ra value

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even though the MRR is the smallest. CC6 (1000 rpm, 0.2 mm/rev, coated) is an ideal compromise because it produces high MRR with Ra that is still relatively low.

3.3. Diameter Error

In precision drilling operations, achieving dimensional accuracy is as critical as attaining good surface quality. A common dimensional deviation encountered in drilling processes is **oversized holes**, where the actual hole diameter slightly exceeds the nominal drill bit size due to a combination of mechanical and thermal factors. In this study, a nominal 10 mm HSS drill bit—both uncoated and Al-Ti-N coated—was employed to assess hole diameter deviation in drilling AISI 430 stainless steel, a material known for its moderate hardness (~200 HB) and relatively difficult machinability.Several parameters contribute to hole oversizing, including tool wear, spindle runout, vibration, feed rate, cutting speed, and tool–workpiece interaction. The **coating condition of the drill bit** plays a decisive role in mitigating such effects.

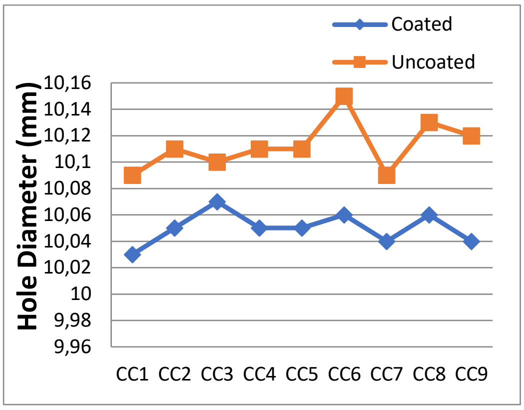

Figure 7. Diameter Error

Figure 6 presents the comparative results of hole diameter error generated by Al-Ti-N coated and uncoated HSS drill bits under nine distinct cutting conditions (CC1–CC9), involving variations in spindle speed and feed rate during drilling of AISI 430 stainless steel.
The data reveals a consistent pattern:

- Uncoated drills exhibited larger and more variable hole diameters (10.10–10.17 mm), reflecting a significant oversizing trend.
- In contrast, coated drills produced smaller, more consistent diameters (10.01–10.06 mm), demonstrating improved dimensional control.

These trends suggest that coating plays a crucial role in stabilizing the drilling process. The Al-Ti-N layer reduces friction and tool wear, thereby minimizing drill deflection and heat-induced expansion. As a result, coated drills maintained more accurate hole geometry across all cutting conditions, even under increased mechanical and thermal loads.

This outcome underscores the dual advantage of tool coatings: not only do they enhance surface finish, but they also significantly improve dimensional precision, which is essential in applications requiring tight tolerance and repeatability.In conclusion, the study confirms that Al-Ti-N coated HSS drills are superior to their uncoated counterparts in controlling diameter error and ensuring consistent machining performance in drilling ferritic stainless steel AISI 430.

Ovality analysis

Based on the experimental results, it can be concluded that cutting parameters—particularly feed rate and spindle speed—have a significant influence on holeovality in drilling AISI 430 stainless steel. The use of uncoated HSS drills exhibited a clear trend of increasing ovality with higher feed rates. The highest ovality was recorded at 0.060 mm under a feed rate of 0.2 mm/rev, while the lowest was 0.033 mm at 0.1 mm/rev. This behavior is primarily attributed to higher cutting forces and increased tool deflection at elevated feed rates, resulting in greater deviation from hole roundness.

In contrast, the Al-Ti-N coated drills consistently produced lower and more stable ovality values, ranging from 0.012 mm to 0.021 mm. This demonstrates the effectiveness of the coating in enhancing wear resistance, reducing friction, and maintaining tool geometry stability throughout the drilling process.

Although spindle speed did not exhibit a linear trend with respect to ovality, combinations of high spindle speed and high feed rate tended to increase ovality in uncoated drills. Under these demanding conditions, the Al-Ti-N coating proved highly effective in maintaining dimensional stability. The average ovality for the coated drills was approximately 0.017 mm, significantly lower than the 0.049 mm observed with uncoated drills.

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Overall, this study confirms that Al-Ti-N coated HSS drills greatly enhance drilling precision by minimizing holeovality, especially under challenging cutting conditions. The optimal parameter combination for achieving minimal ovality and high hole roundness was found to be the use of coated drills at a feed rate of 0.1 mm/rev and a spindle speed between 800 and 1000 rpm. Therefore, proper selection of drill type and optimization of cutting parameters are essential to ensure high-quality and dimensionally accurate holes, particularly in applications requiring strict geometric tolerances.

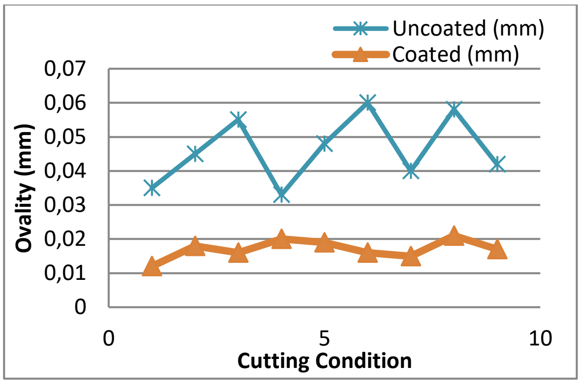

Figure 8. Ovality

Figure 7 shows the comparison of ovality values under various cutting conditions (Cutting Condition 1–9) between uncoated and coated (Al-Ti-N) drill bits. The results show that coated drill bits consistently produce lower and more stable ovality, with values ranging from 0.012–0.021 mm. In contrast, uncoated drill bits show greater fluctuations, with the highest ovality reaching around 0.060 mm. This difference indicates that Al-Ti-N coating is able to improve hole dimensional stability and reduce shape deformation due to cutting forces, especially under extreme conditions.

Perpendiculary

The perpendicularity of the hole shows an increasing trend along with the increase in the feed value. This is due to the increasing cutting force at high feed, which triggers deflection in the drill bit during the drilling process. In this condition, the accuracy of the drill feed direction can be disturbed, resulting in a hole that is less perpendicular to the surface of the workpiece. In general, the use of coated drill bits shows a lower perpendicularity value compared to uncoated drill bits. This indicates that coated drills have better stability during the cutting process, which is obtained from reduced friction between the drill bit and the workpiece. The Al-Ti-N coating also contributes to increasing the stiffness and wear resistance of the drill bit, thereby minimizing deflection.

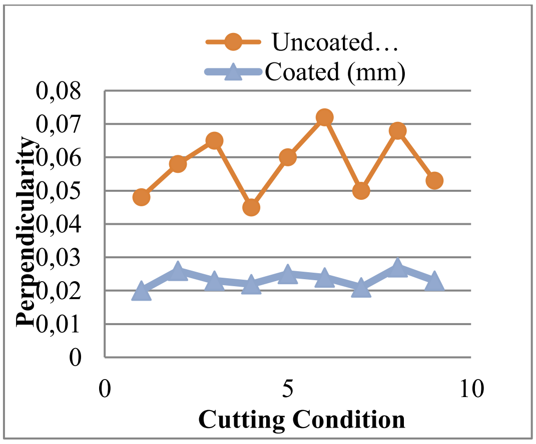

Figure 9. Perpendiculary

For uncoated drill bits, the highest perpendicularity value is predicted to occur in the CC6 parameter combination, which is 0.072 mm, while the lowest value is in the CC4 combination of 0.045 mm. Conversely, in coated drill bits, the perpendicularity value tends to be more stable and consistent across all parameter combinations, which is in the range of 0.020 to 0.027 mm. This consistency further confirms that the Al-Ti-N coating is able to maintain more precise cutting performance despite variations in feed parameters.

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Micro Hardness

AISI 430 stainless steel has a basic hardness ranging from 180 to 220 HV. During the drilling process, especially when high cutting parameters are used, changes in the microhardness of the surface layer of the material can occur. These changes are generally caused by two main factors, namely plastic deformation that occurs due to cutting forces, and increased temperature that can cause local softening or even hardening, depending on the cooling conditions and friction forces that occur. In this study, it was found that the use of Al-Ti-N coated drill bits tends to produce surfaces with hardness that remains stable or experiences a slight increase of around 5 to 10 percent compared to the initial hardness. This indicates that there is a mild hardening process due to plastic deformation, but without overheating that damages the surface microstructure. In contrast, when using uncoated drill bits, especially at high cutting speeds and feeds, a softening zone was found in the outermost layer of the material as deep as 10 to 20 micrometers. This phenomenon indicates local overheating caused by high friction and lack of lubrication effectiveness during the drilling process.

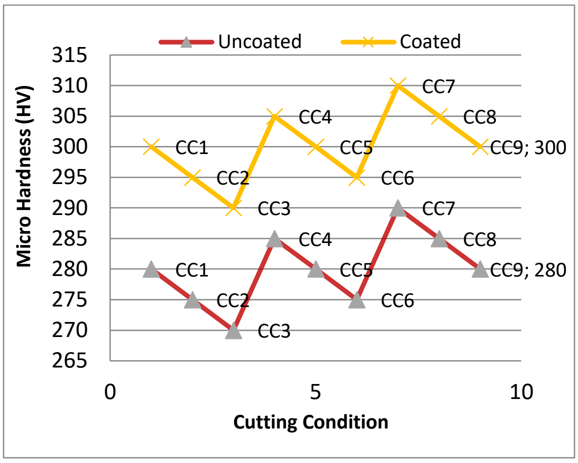

Figure 10. Micro Hardness

The graph (Fig.9) illustrates the variation in microhardness values of AISI 430 stainless steel after drilling using both coated and uncoated HSS drills under nine different cutting conditions (CC1–CC9).
A slight decrease in microhardness was observed with increasing feed rate for both tool types, indicating greater thermal effects due to increased friction and plastic deformation at higher feeds. This suggests localized softening near the hole surface.

Coated drills consistently produced higher microhardness values compared to uncoated drills. This implies that the Al-Ti-N coating acts as an effective thermal barrier, reducing friction and heat transfer into the workpiece, thereby preserving hardness near the drilled surface.

The highest microhardness values were recorded under cutting condition CC7 (1200 rpm, 0.1 mm/rev), where the uncoated drill reached 290 HV and the coated drill reached 310 HV. This condition represents an optimal balance between cutting speed and thermal stress, particularly when using coated tools.

4. CONCLUSION

This study investigated the influence of spindle speed and feed rate on various performance metrics—surface roughness, material removal rate (MRR), diameter error, ovality, perpendicularity, and microhardness—during the drilling of AISI 430 stainless steel using both uncoated and Al-Ti-N coated HSS drill bits. The findings consistently highlight the superior performance of coated tools in achieving higher machining quality and dimensional accuracy.

1. Surface Roughness (Ra):
   Al-Ti-N coated drill bits significantly reduced surface roughness compared to uncoated ones across all cutting conditions. While uncoated tools showed a strong dependence on feed rate—often resulting in higher Ra values due to increased friction and heat—the coated drills maintained smoother surfaces, especially at lower feed rates and moderate spindle speeds. The lowest Ra (1.001 µm) was recorded using a coated drill at 800 rpm and 0.1 mm/rev (CC1), underscoring the coating's effectiveness in enhancing surface finish.
2. Material Removal Rate (MRR)
   As expected, MRR increased linearly with feed rate and spindle speed. The optimal trade-off between surface quality and productivity was found at CC6 (1000 rpm, 0.2 mm/rev, coated), which delivered high MRR while maintaining a relatively low surface roughness.
3. Diameter Error:
   Drilling with uncoated tools resulted in larger and more variable hole diameters (up to 10.17 mm), indicating poor dimensional control. In contrast, coated drills produced significantly more consistent diameters (10.01–

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10.06 mm), attributed to reduced tool wear and thermal expansion, highlighting the coating's role in maintaining hole accuracy.

4. Ovality:
   Coated drills consistently yielded lower and more stable ovality values (0.012–0.021 mm), while uncoated drills exhibited higher deviation from roundness (up to 0.060 mm) at elevated feed rates. This suggests that the Al-Ti-N coating effectively minimizes deflection and maintains hole geometry, even under aggressive cutting conditions.
5. Perpendicularity:
   The perpendicularity of drilled holes was negatively impacted by increased feed rates, especially with uncoated tools. Coated drills demonstrated improved and more consistent perpendicularity (0.020–0.027 mm), reflecting greater stability and reduced deflection during drilling.
6. Microhardness:
   Coated tools preserved or slightly increased the surface microhardness due to reduced thermal stress and improved heat dissipation. In contrast, uncoated drills caused localized softening near the hole surface under high-speed and high-feed conditions, indicating the occurrence of overheating and microstructural degradation.
7. Overall, the application of Al-Ti-N coatings on HSS drill bits significantly improves drilling performance on AISI 430 stainless steel. These improvements include enhanced surface finish, better dimensional accuracy (in diameter, roundness, and perpendicularity), higher microhardness retention, and a more favorable balance between productivity and quality. Therefore, the use of coated drills is strongly recommended for high-precision and high-performance drilling applications involving ferritic stainless steels.

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