Reports in Mechanical Engineering
Vol. 6, No. 1, 2025, pp. 1-11
ISSN: 2683-5894, DOI: https://doi.org/10.31181/rme407

A New Mathematical Model to Predict Hole Surface Roughness in Drilling Operations

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Article Info

Article history:

Received December 13, 2024
Revised March 9, 2025
Accepted May 12, 2025

Keywords:

Drilling,
Drill Bit Geometry,
Surface Roughness,
Hardness,
Circularity.

ABSTRACT

In this study, a geometric approach is proposed to estimate the surface roughness of holes in the drilling process. This recommended model can be used to predict the hole surface quality based on the tip angle of the twist drill bit. This proposed, original approach has not been previously reported in the literature. The proposed theoretical approach aligns well with the experimental results. Depending on the results, surface roughness of hole calculated by using the new analytical method were quite compatible with the experiments. Although the point angle varies depending on the hardness of the material to be drilled, for steel workpieces, the standard point angle of 118° is the most common. However, according to the relevant standard, the tolerance of the point angle of 118° for twist drills up to 12 mm diameter can be ±5°. This means that for a 118°-point angle drill bit, the point angle can be between 113° and 123°. In order to support the proposed theory, experiments were carried out with drill bits with point angles of 113°-123°. In addition, the effects of these angular tolerances on hole surface roughness, hole hardness and circularity were also revealed. In this study, the effects of drilling parameters such as different point angles, presence and absence of cutting fluid on surface roughness, Vickers hardness and circularity of holes were investigated in drilling.

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1. Introduction

Amongst the traditional machining processes, drilling is one of the most important machining operations, comprising ~33% of all metal cutting operations (Chen & Tsao, 1999). In general, standard high-speed steel (HSS) twist drills are sufficient for drilling unalloyed steel materials. It can be stated that as the strength of metals increases, drillability problems also increase. When the correct drilling parameters are selected, economical machining without cutting fluid is already possible in most cases (Galal et al., 2024). Even mild steels can sometimes present a disadvantage in dry drilling. With drilling operations performed under appropriate conditions, the need for reaming and/or grinding operations is minimized. In recent years, many researchers are investigated the tool geometries and coatings to perform in dry drilling. The effects of cutting fluid application in drilling operations have been investigated in many studies. In case of dry drilling or cutting fluid application, the surface quality is affected (Ankalagi et al., 2017; Haan et al., 1997; Kalidas et al., 2001; Kelly & Cotterell, 2002). Cutting fluid significantly affects hole quality (Brandao et al., 2011). Although dry drilling is widely preferred today, it has been shown that the heat generated during the drilling process can lead to thermal expansion of the drill and workpiece, which affects the size of the holes and the surface quality (Haan et al., 1997). Better tolerances in holes are achieved when using cutting fluid compared to dry drilling (Kelly & Cotterell, 2002). The absence of cutting fluid causes an increase in surface roughness and tensile residual stresses, which in turn leads to a decrease in fatigue strength (Solis et al., 2024). In particular, the absence of cutting fluid can cause an increase in crack initiation. In addition, surface roughness and residual stresses increase due to thermal and mechanical effects during drilling (Solis et al., 2024). Drill geometry has an effect on cutting performance and hole quality in drilling operations (Yavuz et al., 2020). The effects of point geometry on the cutting performance of twist drills have been investigated (Satoshi, 2012). It is stated that torque increases significantly with web thickness and decreases conversely with helix angle (Satoshi, 2012). There is an optimum point angle to minimize torque. Thrust force increases significantly with web thickness and relief angle and decreases conversely with point angle and helix angle (Satoshi, 2012). There are some model studies to predict the effects on diameter and cylindricity of dry drilled holes (Bono & Ni, 2001). The model reveals that thermal expansions are effective and lead to holes with diameters that increase with depth (Bono & Ni, 2001). Since lower quality drilled holes can be obtained due to excessive heat generation as a result of the intense contact of the chips with the drill bit, it is necessary to remove the chips properly (Sedlak et al., 2023). It is observed that the thrust force, tool wear and surface roughness decrease linearly with increasing point angles (Demir, 2018). It is observed that as the cutting speed increases, the circularity error increases (Ankalagi et al., 2017). It is stated that this is due to the increase in cutting temperature caused by friction, leading to larger hole size and therefore larger circularity error. It is observed that circularity error decreases as the drill point angle increases (Ankalagi et al., 2017; Satoshi, 2012). Hole quality is usually evaluated by surface roughness (Ra), circularity and cylindricity error (Brandao et al., 2011). Dry drilling produces poor surface quality. Also, the use of cutting fluid is seen to affect cylindricity (Brandao et al., 2011). In this study, surface roughness, Vickers hardness (Hv), circularity of holes was measured using different parameters such as point angle of HSS twist drills, presence and absence of cutting fluid applications and different workpiece materials. Additionally, in this study, a model was proposed to predict the arithmetic average roughness of drilled holes and the theoretical results were compared with experimental results.

2. Geometry and Standard of Twist Drills

Drills are defined as rotary end cutting tools having generally two cutting libs and helical or straight flutes for the passage of chips and admission of a cutting fluid. The standard terms used to describe elements of twist drills are shown in Figure 1 and tolerances of the twist drills given in Table 1 as an ANSI B94.11M-1993standard (Ankalagi et al., 2017)

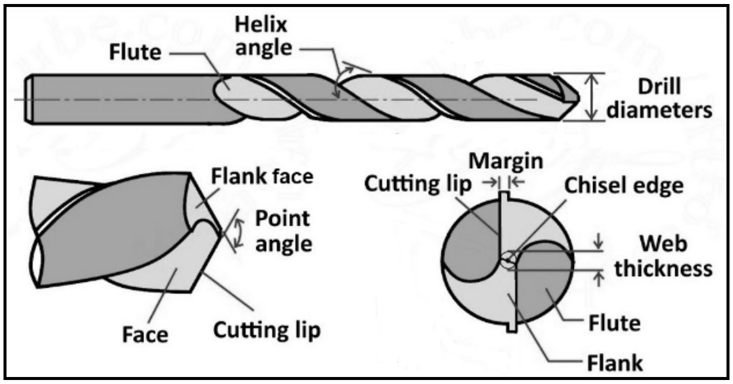


Figure 1: Drill Geometry and Nomenclature of the Standard Twist Drill

Twist drills can be classified according to the material from which they are made, kind of shank, number of flutes, hand of cut, length, diameter, and point geometry. The point (inclusive) angle of twist drills is standardized in ASME/ANSI B94.11M-1993.

Table 1: Point Angle Tolerances Relative to Diameter for Twist Drills

Included Angle of Point			
Diameter of Drill			
Inches	Milimeters	Point Angle	Tolerance
From 1/16 thru ½	From 1.59 thru 12.70	118°	±5°
Over ½ thru 1 ½	Over 12.70 thru 38.10	118°	±3°
Over 1 ½ thru 3 ½	Over 38.10 thru 88,90	118°	±2°

This means that, depending on the relevant standards, the 118° point angle drill bit, which is widely used in the manufacturing industry and especially in drilling steel workpieces up to 12 mm diameter, can actually be between 113° and 123°. The study was carried out theoretically and experimentally, taking into account the tolerance values specified in the relevant standard.

3. Suggested Model to Surface Roughness

As is well known, in turning operations, the nose radius geometry of the insert creates theoretical surface roughness. This geometric approach is given in Figure 2.

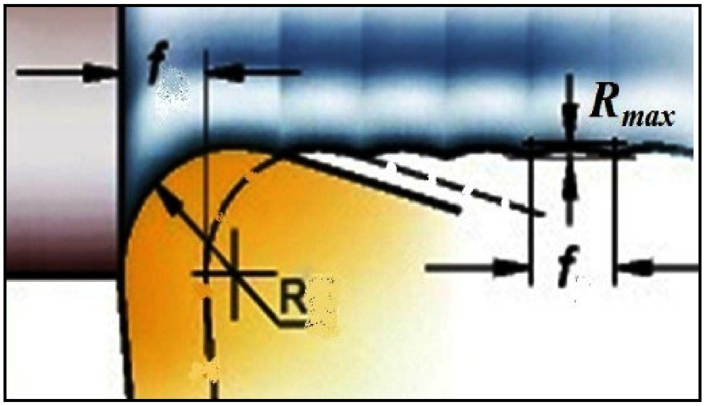
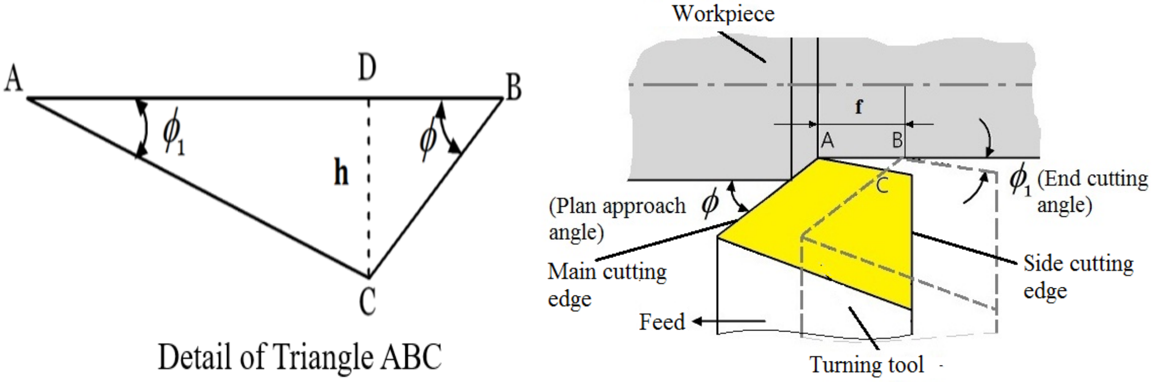


Figure 2: Geometric Approach to Workpiece Surface Roughness in Turning Process

As seen in Figure 2, the theoretical approach to the workpiece surface roughness (R_{max}) that may occur in the turning process can be obtained by the following Equation (1) using the tool nose radius and feed per revolution.

$$R_{max} = \frac{f^2}{8.r} \tag{1}$$

where r is the tool nose radius and f is the feed. In case of using a zero-nose radius cutting tool in the turning process, the possible surface roughness of the workpiece is given in Figure 3 as modelled in the literature (Abdellaoui et al., 2020; Christianto et al., 2023; Li et al., 2023).



Detail of Triangle ABC

Figure 3: Zero Nose Radius Cutting Tool Modelling in Turning

The theoretical approach to the workpiece surface roughness that can be achieved if a zero nose radius cutting tool is used in the turning process can be formulated as follows (Abdellaoui et al., 2020; Christianto et al., 2023; Li et al., 2023). As is known, feed is defined as the distance the cutting tool advances during one revolution of the spindle. In Figure 3, the feed per revolution (f) is shown as the distance AB. Feed per revolution (f-mm/rev);

$$f = AB \text{ or, } AD + DB \tag{2}$$

According to the rules of trigonometry, when a cutting tool with a zero nose radius advances by a distance f, triangle ABC is formed on the workpiece surface. In this triangle, the maximum height (h) is the DC distance and this distance allows the maximum surface roughness to be determined. To determine this height, the trigonometric approaches given in Equation (3) and Equation (4) below were used. From triangle BDC; According to the rules of trigonometry;

$$AD = DC.\cot \varphi 1 \quad \text{and} \quad DB = DC.\cot \varphi \tag{3}$$

In this case, the feed (f) is;

$$F = (DC.\ \mathrm{Cot}\ \varphi 1) + (DC.\ \mathrm{Cot}\ \varphi)\ \text{or}\ f = DC\ (\cot \varphi 1 + \cot \varphi \tag{4}$$

DC is equal to the maximum height h, and the value of h is also the maximum surface roughness (R_{max}). If Equation (4) is rearranged by replacing DC with the maximum height h expression, Equation (5) is obtained.

$$f = h.\ (\cot \varphi_1 + \cot \varphi) \tag{5}$$

If equation (5) is arranged, the maximum surface roughness (R_{max}) can be determined by the formula (6) given below;

$$R_{max} = \frac{f}{(\cot\varphi_1 + \cot\varphi)} \tag{6}$$

In drilling operations, the point angle in combination with feed rate affect the hole surface texture and accuracy. The theoretical profile height of the hole surface can be calculated with the proposed model given below (Figure 4).

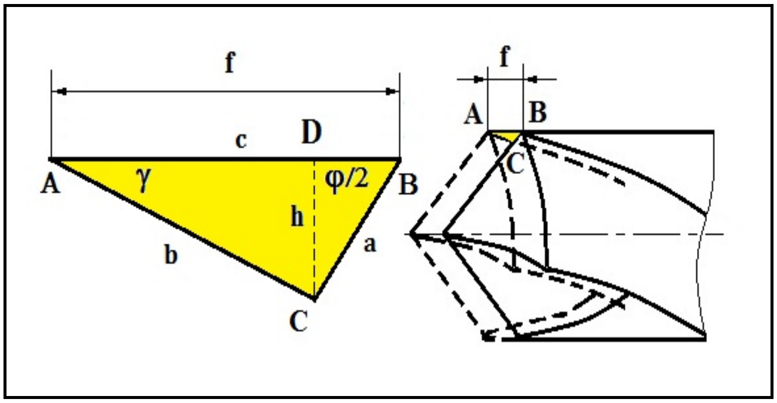


Figure 4: Modelling the Surface Roughness of the Hole Using a Geometric Approach

The approach proposed here is similar to the surface roughness approach that occurs in the turning process with a zero nose radius tool, stated in the literature (Abdellaoui et al., 2020; Christianto et al., 2023; Li et al., 2023) and given in Equation (6). In trigonometry, the law of sines (or sine rule) is an equation that relates the lengths of the sides of any triangle to the sines of its angles. The law of sines can be used to compute the remaining sides of a triangle when two angles and a side are known. This rule defines the ratio of sides of a triangle and their respective sine angles are equivalent to each other. By applying the sine rule to the proposed geometric approach, the Equation (7) given below was obtained. According to the proposed geometric approach, the AB distance of triangle ABC is the feed per revolution (f).

$$\frac{b}{\sin(\gamma)} = \frac{a}{\sin\left(\frac{\varphi}{2}\right)} = \frac{f}{\sin\left[\pi - \left(\frac{\varphi}{2}\right) + \gamma\right]} \tag{7}$$

where, φ/2 is equal to half the tip angle of the drill bit. γ is the helix angle of the twist drill. The distances "a" and "b" can be obtained from Equation (8) and Equation (9).

$$a = \frac{f}{\sin\left[\pi - \left(\frac{\varphi}{2} + \gamma\right)\right]} . \sin\left(\frac{\varphi}{2}\right) \tag{8}$$

$$b = \frac{f}{\sin\left[\pi - \left(\frac{\varphi}{2} + \gamma\right)\right]} . \sin\gamma \tag{9}$$

CD = h is the height of the triangle. “h” separates the triangle ABC into two right angled triangles as CDA and CDB. The maximum surface roughness (R_{max}) is equal to the height of the triangle (h). Here, the distance AB (feed per revolution (f)) and the angles are known. Based on these parameters and the rules of trigonometry, the height of the triangle can be calculated according to Equation (10). As a result, Equation (10) can be used to determine (or predict) the hole surface roughness in drilling, as proposed in this study.

$$h\ (\text{or}\ R_{max}) = \frac{1}{2} . a . b . \sin\left[\pi - \left(\frac{\varphi}{2} + \gamma\right)\right] \tag{10}$$

The helix angle provides optimum chip ejection and the strength of the drill cross section. Higher helix angles can result in reduced tool pressure, better finishes, and less heat build-up. A higher helix can also help with chip control by ejecting the chips at a steeper angle. However, the larger the helix, the less reinforced strength each cutting edge has. Lower helix angles provide better edge strength, which is helpful in harder steels and cast irons. N type drill bits are commonly used in drilling steel workpieces, and the helix angle in these types of drills is generally 28-32 degrees. In this study, the helix angle was 32°, which is commonly used. In the approach presented in this study, the helix angle is at least as effective and important as the tool point angle. Where; R_{max}: surface roughness, f: feed per rev, φ: drill bit point angle, γ: helix angle, D: drill diameter. Depending on the proposed geometric approach and modelling, the hole surface roughness formula is obtained as given in Equation (10). Using Equation (10) obtained as a result of the theoretical approach presented in the study, the predicted hole surface roughness for drill bits with 113°, 118° and 123° point angles are given in Figure 5.

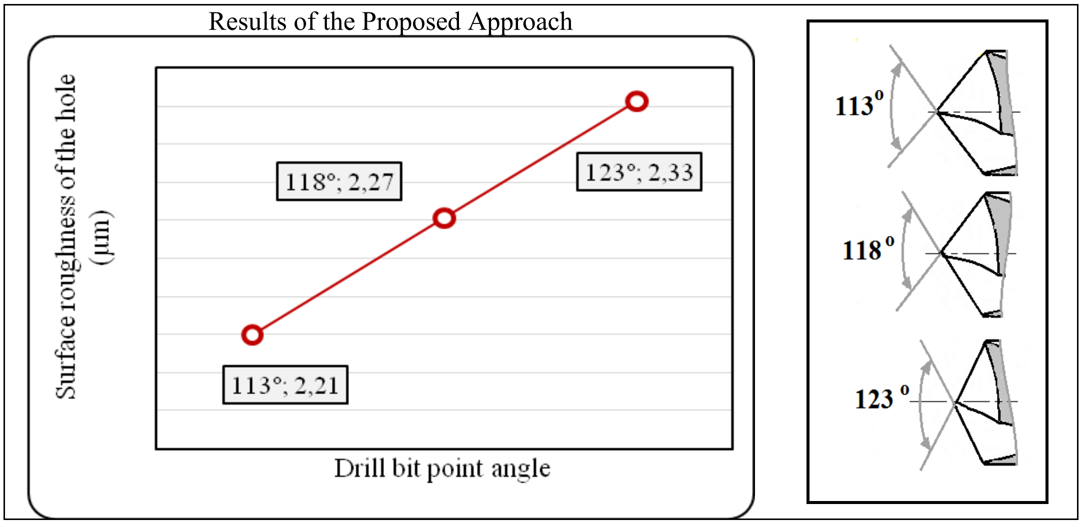


Figure 5: Hole Surface Roughness Estimation Depending on the Point Angles of Drill Bits

4. Experimental Setup

The purpose of this study is to investigate the effects of point angle change of HSS twist drills on hole surface roughness, hardness and circularity. Experiments were carried out at three different drill point angles (113^0, 118^0 and 123^0) and their effects on the surface roughness of the hole, the change in hardness (H_V) of the holes, and the change of the hole diameter along the depth were examined. In the experiments, mild and tempered steels were drilled using dry and cutting fluid and the results were compared. The chemical composition and original hardness of the workpiece materials are given in Table 2.

Table 2: The Chemical Composition and the Hardness of the Workpiece Materials

	Chemical Compositions (%)				Hardness
	C	Mn	P	S	(Hv)
Mild Steel	0.36	0.90	0.040	0.050	126
Tempered Steel	0.47-0.55	0.60-0.90	0.040	0.050	223

The cutting tools used were HSS twist drills. The tolerances of the point angles were ± 5° as stated in the standard, and the point angles of the drills were ground as 113°, 118° and 123°. The points of the drills were ground on the Precision brand TB20N model High Precision Tool Grinding machine. After the grinding processes, the point angle of each drill was checked on a BATY R14XL type profile projector machine. Angular deviations in point angles measured on drill bits were obtained between maximum (+)1.2° and minimum (-) 1.4°. Drilling experiments were carried out on a First brand VMC model CNC milling machine. In the experiments, the spindle speed was selected as 1000 rpm and the feed rate was 0.16 mm/rev. The selected cutting speed is 31.41 m/min, which is suitable for HSS cutting tools. The samples were prepared in cylindrical form with a diameter of 35 mm and a length of 40 mm. The experiments were carried out under dry and wet conditions. In drilling experiments performed under wet conditions, 8% emulsion was used as cutting fluid. In the experimental design, two different workpiece materials and three different drill point angles were selected as variables. The design matrix used in the experiments is presented in the Table 3.

Table 3: Experimental Design Matrix

Test No	Point Angle of Drill Bits	Material	Presence or Absence of Cutting Fluid
1	113°	Mild Steel	Wet
2	118°	Mild Steel	Wet
3	123°	Mild Steel	Wet
4	113°	Mild Steel	Dry
5	118°	Mild Steel	Dry
6	123°	Mild Steel	Dry
7	113°	Tempered Steel	Wet
8	118°	Tempered Steel	Wet
9	123°	Tempered Steel	Wet
10	113°	Tempered Steel	Dry
11	118°	Tempered Steel	Dry
12	123°	Tempered Steel	Dry

After drilling, each sample was cut along the hole and the workpiece surface roughness and hardness (Fig.8) were measured at a distance of 2.5 mm from the drill entrance and drill exit. The arithmetic mean surface roughness values of the holes were measured with a Taylor Hobson surface roughness measuring machine. The hardness values of the holes were measured as Vickers Hardness at the top and bottom of the holes using the Microhardness Testing System. The dimensional accuracies of the drilled holes were measured using the EOS544 Coord3 brand coordinate measuring machine (CMM). In order to determine the circularity of the holes, all samples were measured at the hole entrance and hole exit, and the obtained radius values are given in Table 5. It was determined that characteristic circularity differences occur in the holes in the case of wet drilling or dry drilling.

5. Experimental Results

In this study, the effects of drill geometry on hole surface roughness, circularity and hardness were investigated under the machining conditions given above. The values obtained as a result of the experiments are given and discussed below.

5.1 Surface Roughness of the Holes

As a result of the experiments, the surface roughness measured from the hole surface is shown in Figure 6. It has been observed that cutting fluid has a significant effect on surface quality. Better surface quality was obtained when using cutting fluid compared to dry cutting. Additionally, the point angle of the drills also appears to affect the surface roughness. Deviation values are also shown in Figure 6 and it is seen that very small deviation values occur.

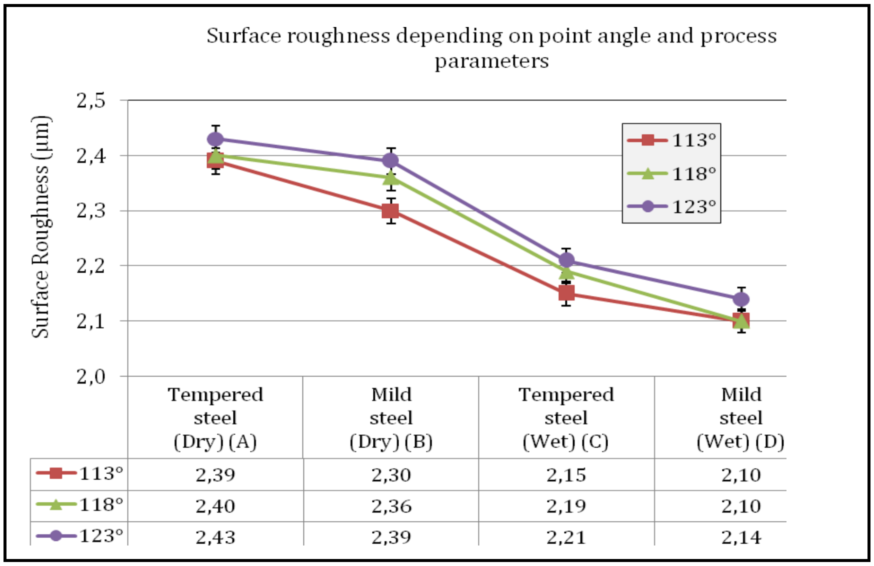


Figure 6: Variation of Surface Roughness Obtained in Wet and Dry Drilling Depending on the Drill Point Angle and Workpiece Material

Analysis of Variance (ANOVA) was used to check the adequacy of the results obtained (Groups A, B, C, D) for modelling. In this study, the adequacy of the model was tested with a confidence interval of more than 95% using the variance analysis method and was found to be sufficient, and the results are given in Table 4.

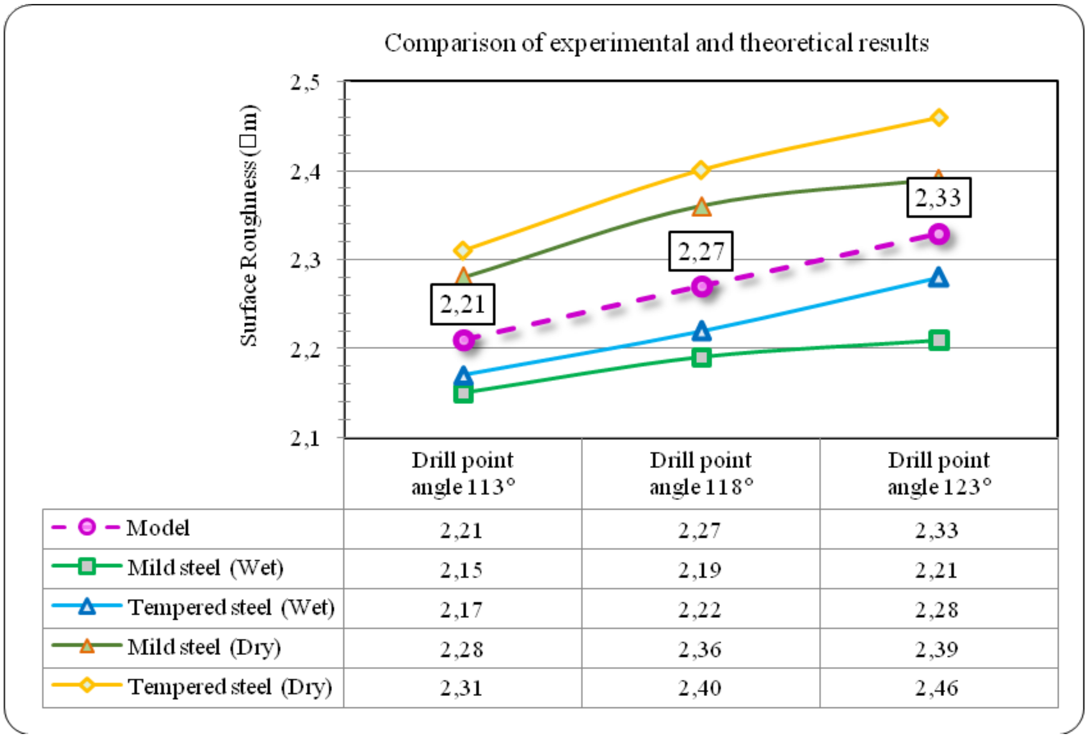
Table 4(a): Analysis of Variance to Hole Surface Roughness

Groups	Count	Sum	Average	Variance
A	3	7.22	2.406	0,0003
B	3	7.05	2.350	0,0021
C	3	6.55	2.183	0,0009
D	3	6.34	2.113	0,0005

Table 4(b): Analysis of Variance to Hole Surface Roughness

Source of Variation	SS	Df	MS	F	P-Value	F Crit
Between Groups	0.1708	3	0.056	56.955	0.0000	4.0661
Within Groups	0.0080	8	0.001			
Total	0.1788	11				

According to ANOVA, the point angle of drill affects hole roughness. Although the point tip angle of drill has an effect, dry or wet drilling applications have a greater effect. The comparison of the experimental data and the suggested model is given in Figure 7.



	Drill point angle 113°	Drill point angle 118°	Drill point angle 123°
Model	2,21	2,27	2,33
Mild steel (Wet)	2,15	2,19	2,21
Tempered steel (Wet)	2,17	2,22	2,28
Mild steel (Dry)	2,28	2,36	2,39
Tempered steel (Dry)	2,31	2,40	2,46

Figure 7: Comparison between the Experimental Data and the Suggested Model

The results seen in Figure 5 were generated using Equation 10 obtained from the proposed model. The results obtained from the experiments are given in Figure 6. The theoretical results given in Figure 5 and the experimental results given in Figure 6 are given comparatively in Figure 7.

5.2 Hardness and Circularity of the Holes

After drilling the holes, the workpiece was cut from the hole axis (Fig. 8-a) and then the microhardness values (Fig. 8-b) were measured on the hole surfaces at a distance of 2.5 mm from the entrance and 2.5 mm from the exit.

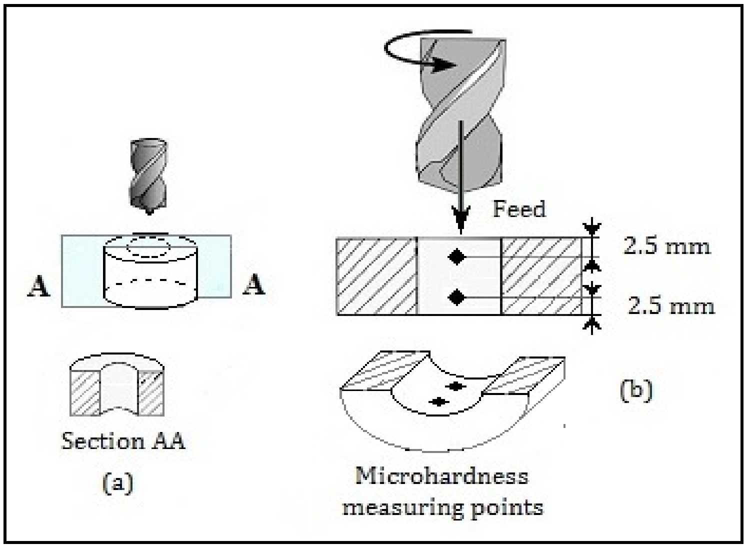
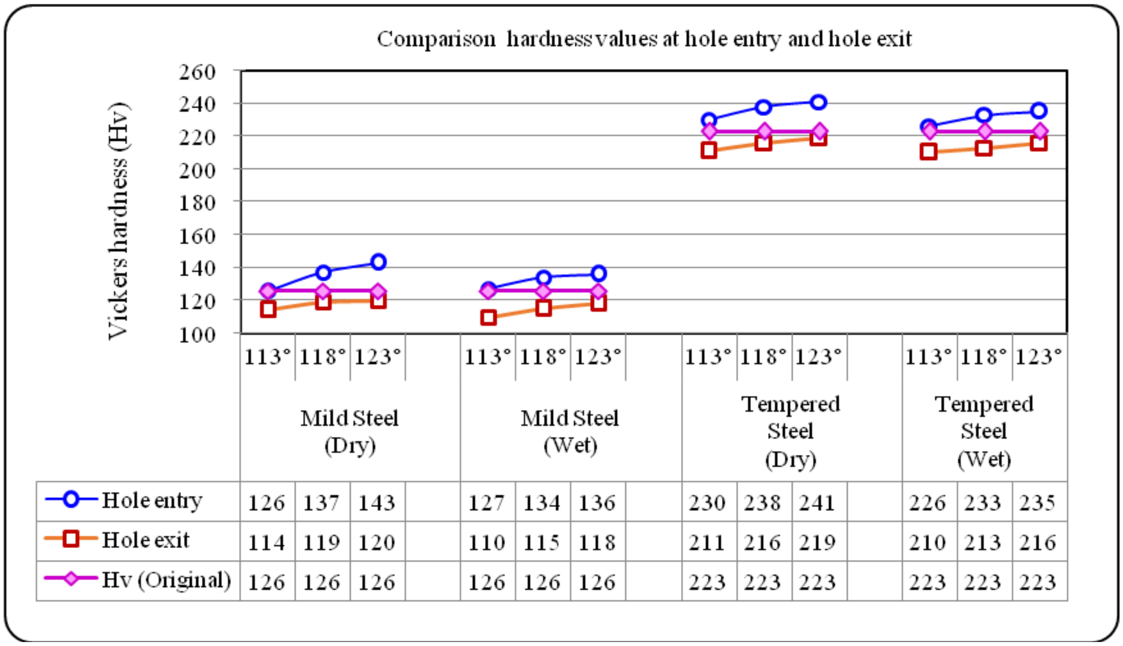


Figure 8: Schematic View of Micro Hardness Measurement from Hole Surfaces.

The hardness of the holes was measured as Vickers Hardness (Hv). In addition, the original micro hardness value of the workpiece was determined by measuring it before drilling. The original micro hardness was determined as 126 Hv for mild steel and 223 Hv for tempered steel. According to these original micro hardness values, it was checked whether there was a hardness change due to the drilling process at the hole entrance and hole exit, as shown in Figure 8. In all experiments, lower hardness values were measured at the hole exits, which is thought to be due to thermal effects. The original hardness of the workpiece and the hardness values measured at the hole entrance and hole exit are given comparatively in Figure 9.



	Mild Steel (Dry)			Mild Steel (Wet)			Tempered Steel (Dry)			Tempered Steel (Wet)		
	113°	118°	123°	113°	118°	123°	113°	118°	123°	113°	118°	123°
Hole entry	126	137	143	127	134	136	230	238	241	226	233	235
Hole exit	114	119	120	110	115	118	211	216	219	210	213	216
Hv (Original)	126	126	126	126	126	126	223	223	223	223	223	223

Figure 9: Hardness Values Measured at the Hole Entry and Hole Exit.

The circularity (and hence cylindricity) of the holes at the drill bit entry and exit were measured using a coordinate measuring machine (CMM). As is known, holes drilled with drill bits are not in ideal cylindrical form (Fig. 10), and deviations from cylindricality occur for various reasons. As schematically shown in Figure 10, the circularity was determined by measuring at four points 2.5 mm from the hole entrance and 2.5 mm from the hole exit using a coordinate measuring machine. Considering all experiments, the hole diameter at the bottom of the samples was always larger than the hole diameter at the top of the samples.

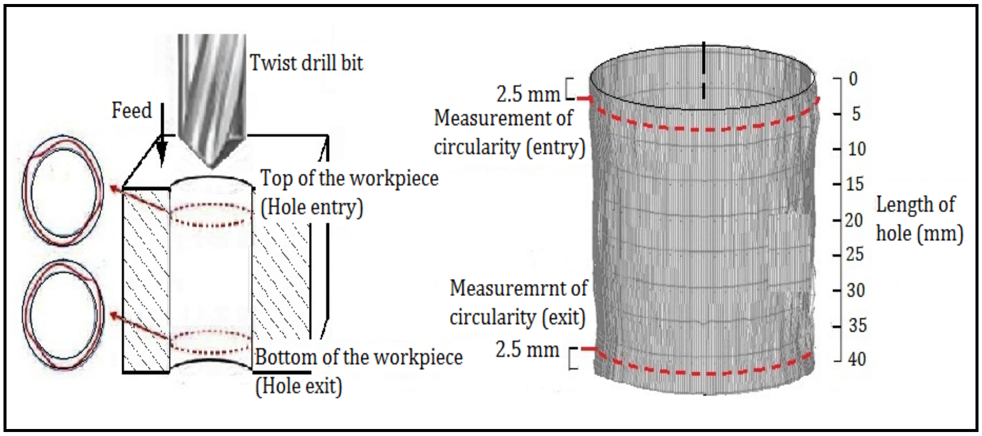


Figure 10: Schematic View of Circularity Measurements

The variations of the hole roundness are normally caused by deflection, vibration, thermal effect, wear etc. The results of the measured hole circularities are given in Table 5. Circularity was measured at four points in the same plane, from the top and bottom of each sample. It is observed that the average circularity values increase with the increase in the point angle of the drill bits in the absence of cutting fluid. On the other hand, it is observed that the average circularity values decrease with the increase in the point angle of the drill bits in the presence of cutting fluid. When cutting fluid was applied, the maximum difference between the hole entrance and the hole exit was 0.005 mm (5 µm). In the case of dry drilling, the maximum difference between the hole entrance and the hole exit was 0.003 mm (3 µm).

Table 5: Measured Hole Circularity Depending on Experimental Conditions

Material	Cutting Fluid	Point Angle	Top of Hole	Bottom of Hole	Difference (± mm)	Average Radii (mm)	Difference of Diameter
Mild Steel	Wet	113°	5.080	5.087	0.007	5.084	10.167
Mild Steel	Wet	118°	5.058	5.068	0.010	5.063	10.126
Mild Steel	Wet	123°	5.057	5,062	0.005	5.060	10.119
Tempered Steel	Wet	113°	5.087	5.095	0.008	5,091	10.182
Tempered Steel	Wet	118°	5.083	5,090	0.007	5.087	10,173
Tempered Steel	Wet	123°	5.074	5.083	0.009	5,079	10.157
Mild Steel	Dry	113°	5.085	5,098	0.013	5.092	10.183
Mild Steel	Dry	118°	5.095	5.106	0.011	5.101	10.201
Mild Steel	Dry	123°	5.102	5.109	0.007	5.106	10.211
Tempered Steel	Dry	113°	5.092	5.100	0.008	5.096	10.192
Tempered Steel	Dry	118°	5.110	5.113	0.003	5.112	10.223
Tempered Steel	Dry	123°	5.113	5.116	0.003	5.115	10.229

However, the hole diameter was measured slightly larger than that of wet drilling. The hole circularity of the lower part of the samples was always determined at higher values compared to the circularity of the upper part of the workpiece.

6. Discussion and Conclusions

In this study, a theoretical approach model has been proposed to predict the surface roughness of the hole in the drilling process, which has not been previously included in the literature. With the proposed approach, the cutting performance of different point angles of twist drills has been investigated. The effects of point angle and drilling conditions (wet or dry) on the surface roughness, hardness and circularity of the hole have also been discussed. The promising results obtained during the course of this research suggest that the feature of drilling optimization of the drills according to drilling parameters. Based on the results of this investigation the following conclusions can be drawn.

- A model has been developed to predict the surface roughness of the drilled holes. The measured surface roughness and the result of suggested model are compared. The theoretical surface roughness approximation model obtained as a result of the geometric approach has not been previously included in the literature and has been experimentally proven to be a sufficiently accurate approximation.

- The experimental results are slightly lower than simulation results in wet drilling. The experimental results are slightly bigger than simulation results in dry drilling. This deviation is easily explained that, during the drilling process, chips rub to the drilled holes surface, consequently the surface roughness become slightly higher than the suggested model. Also, in wet drilling, the experimental results are slightly lower than the model results due to the lubricating effect of the cutting fluid. This also depends on the chip mass. In the case of using cutting fluid, it was determined that the chip size did not adversely affect the hole surface quality when relatively small chips were produced. Application of cutting fluid provided relatively better surface roughness.
- It has been observed that when the point angle of twist drills increases, the hole surface roughness increases. The hardness of the holes was generally measured slightly lower in wet drilling than in dry drilling. Relatively lower hardness values were measured in the regions close to the hole exit compared to the hole entrance. This observation is the results of the thermal effects.
- In dry drilling conditions, slightly larger circularity values were measured compared to wet drilling. It was observed that the circularity measured at the bottom of the samples was generally slightly larger than the circularity measured at the top of the samples. This is decided effect of the thermal effect also.
- In drilling, as in turning, the cutting speed affects the hole quality and the best results can be achieved using higher speeds. However, increasing the feed rate in any case negatively affects the hole surface quality. In addition, the ductility or brittleness of the material affects the surface quality. In this study, two different steel materials were used in the experiments and their hardness values determine whether they are brittle or not. Undoubtedly, in the drilling process, better surface quality is obtained in ductile materials than in brittle materials.
- In the study, drill bits with helix angles between 28^0-32^0 were used and the theoretical approach was proven with drill bits at these values. However, there are also drill bits with larger or smaller angles than these helix angles. The study may be valid for the helix angles mentioned above.
- This study was carried out using HSS drill bits. It can also be carried out with TiN coated and/or coated and uncoated hard metal drill bits.

References

Abdellaoui, L., Khlifi, H., Bouzid Sai, W., & Hamdi, H. (2020). Tool nose radius effects in turning process. *Machining Science and Technology*, *25*(1), 1-30. https://doi.org/10.1080/10910344.2020.1815038

Ankalagi, S., Gaitonde, V., & Petkar, P. (2017). Experimental studies on hole quality in drilling of SA182 steel. *Materials today: proceedings*, *4*(10), 11201-11209. https://doi.org/10.1016/j.matpr.2017.09.041

Bono, M., & Ni, J. (2001). The effects of thermal distortions on the diameter and cylindricity of dry drilled holes. *International Journal of Machine Tools and Manufacture*, *41*(15), 2261-2270. https://doi.org/10.1016/S0890-6955(01)00047-5

Brandao, L. C., Neves, F. O., & Nocelli, G. C. (2011). Evaluation of hole quality in hardened steel with high-speed drilling using different cooling systems. *Advances in Mechanical Engineering*, *3*, 746535. https://doi.org/10.1155/2011/746535

Chen, W.-C., & Tsao, C.-C. (1999). Cutting performance of different coated twist drills. *Journal of Materials Processing Technology*, *88*(1-3), 203-207. https://doi.org/10.1016/S0924-0136(98)00396-3

Christianto, Y., Lubis, M. S. Y., & Rosehan. (2023). Analysis of feed and tool nose radius on surface roughness cast iron material and tool life. In *AIP Conference Proceedings* (Vol. 2680, pp. 020201). AIP Publishing LLC. https://doi.org/10.1063/5.0126488

Demir, Z. (2018). An experimental investigation of the effects of point angle on the high-speed steel drills performance in drilling. *Measurement and Control*, *51*(9-10), 417-430. https://doi.org/10.1177/0020294018797853

Galal, A. M., Elsherbiny, A. A., & AbouEleaz, M. A. (2024). A study of drilling parameter optimization of functionally graded material steel–aluminum alloy using 3D finite element analysis. *J. Manuf. Mater. Process*, *8*, 155. https://doi.org/10.3390/jmmp8040155

Haan, D., Batzer, S., Olson, W., & Sutherland, J. (1997). An experimental study of cutting fluid effects in drilling. *Journal of Materials Processing Technology*, *71*(2), 305-313. https://doi.org/10.1016/S0924-0136(97)00089-7

Kalidas, S., DeVor, R. E., & Kapoor, S. G. (2001). Experimental investigation of the effect of drill coatings on hole quality under dry and wet drilling conditions. *Surface and Coatings Technology*, *148*(2-3), 117-128. https://doi.org/10.1016/S0257-8972(01)01349-4

Kelly, J., & Cotterell, M. (2002). Minimal lubrication machining of aluminium alloys. *Journal of Materials Processing Technology*, *120*(1-3), 327-334. https://doi.org/10.1016/S0924-0136(01)01126-8

Li, W., Zhou, B., Xing, L., He, H., Ni, X., Li, M., & Gong, Z. (2023). Influence of cutting parameters and tool nose radius on the wear behavior of coated carbide tool when turning austenitic stainless steel. *Materials Today Communications*, *37*, 107349. https://doi.org/10.1016/j.mtcomm.2023.107349

Satoshi, E. (2012). Effects of twist drill point geometry on torque and thrust. *Sci Rep Fac Educ Gifu Unive (Nat Sci)*, *36*, 165-174. https://www.ed.gifu-u.ac.jp/file/3627.pdf

Sedlak, J., Zouhar, J., Kolomy, S., Slany, M., & Necesanek, E. (2023). Effect of high-speed steel screw drill geometry on cutting performance when machining austenitic stainless steel. *Scientific Reports*, *13*(1), 9233. https://doi.org/10.1038/s41598-023-36448-y

Solis, R., Lorain, R., Mehmet, C., André, T., Pascal, H., Chaize, E., Viéville, E., & Rech, J. (2024). Influence of a cutting fluid on the surface integrity and fatigue strength of 42CrMo4 drilled parts. *Procedia CIRP*, *123*, 24-29. https://doi.org/10.1016/j.procir.2024.05.007

Yavuz, M., Gökçe, H., Çiftçi, İ., Gökçe, H., Yavaş, Ç., & Şeker, U. (2020). Investigation of the effects of drill geometry on drilling performance and hole quality. *The International Journal of Advanced Manufacturing Technology*, *106*, 4623-4633. https://doi.org/10.1007/s00170-019-04843-3