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Chip Formation When Drilling AISI 316L Stainless Steel using Carbide Twist Drill

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[b]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor 81300, Malaysia

Abstract

Knowledge on the chip formation mechanism during drilling is very important to deliver the chips with size and shape as expected. Long chips cannot rid smoothly over drill flutes hence should be avoided while small chips can be removed easily from the machined hole. In this study, performance of a solid carbide twist drill through drilling of AISI 316L stainless steels was evaluated in terms of chip formation. This study aims to better define and further characterize the different chips shape and dimensions as a function of tool wear and cutting conditions in drilling the stainless steel. Experiments conducted on various combinations of cutting speed (18 and 30 m min^{-1}) and feed rate (0.03, 0.045 and 0.06 mm rev^{-1}) to present the differences in chip formation. Optical observation and comparative analysis of flank wear of the twist drill were done. As the results of the performed experiments, the lowest cutting speed-lowest feed rate reveals better performance due to desirable chips formation on austenitic stainless steels drilling.

Keywords: Chip formation; Drilling; Stainless steel; Carbide Twist Drill.

1. Introduction

Machining process can be schematized according to the orthogonal machining operation depicted in Figure 1a. Plastic deformation occurs along the highest shear stress (WW'CC') plane where the stress exceeds the shear strength of the material [1]. The workpiece material which forms a chip deform plastically before the chip's removal. Drilling operation is different from orthogonal cutting as cutting velocity increases linearly from the center

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to the outer edge of the drill. Drilling also has two distinct chip formation including extrusion process caused by the wedge point drill and shearing operations caused by the cutting edge of the drill (Figure 1b) [2].

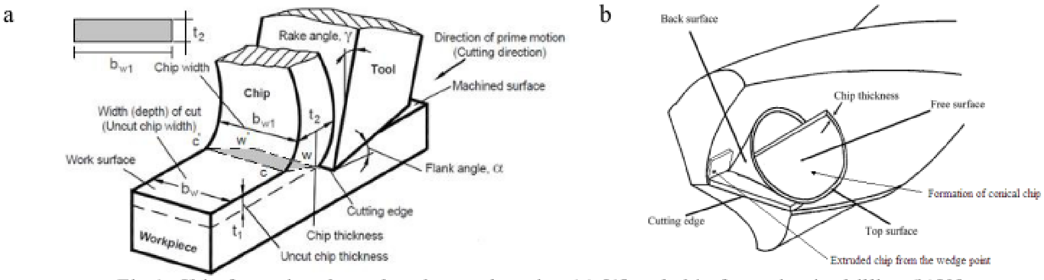


Fig.1. Chip formation through orthogonal cutting (a) [1] and chip formation in drilling (b)[2]

The success of a drilling operation depends on the ability to form chips that can be easily ejected from the drilled hole. Long chips are not desirable because the chips usually tangle along the twist drill body and have to be removed manually [3]. Conditions in which various types of chip form depend on many factors, including (i) cutting speed, temperature in the cutting zone, environment and, in anisotropic materials, orientation; (ii) the geometry of the cutting tool, its sharpness and its inclination to the direction of cut; and (iii) lubrication and friction between the drill bit and the workpiece [4].

Drilling is considered as a three dimensional cutting process involving complex cutting mechanism because of the complex cutting edge geometries. Chip shape is the most important factor for smooth drilling process. Drilling will be smooth if it forms well broken chips during process [5]. However, most ductile materials such as austenitic stainless steels are not broken during drilling, and instead, formed a continuous chip.

Certain materials show a very inhomogeneous strain in the chip formation. Strain started in a very strong defect and continues for a relatively long time because the thermal softening on shear plane is greater than the level of strain hardening. This type of chip formation, which can cause vibration and rough surface finish, most easily occurs when cutting materials that have low coefficient of thermal conductivity and specific heat. Stainless steel and high temperature alloys have such thermal properties and therefore tend to show the shear localized type of chip [5].

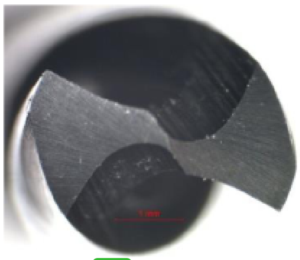
Ductile materials usually do not break during drilling, and form a continuous chip. When the chips are produced at the beginning, because the inner cutting edge moves slower than the outer cutting edge, the resulting chips form shorter inner than the outer. The difference in length of the chip, causing it moves towards the center of the drill instead of perpendicular to the cutting edge. Furthermore, the central part of the drill flutes forces the chip to curl and form a spiral shape. However, when it moves in drill flute, to maintain the shape of a spiral, it must constantly rotate on its own axis. This rotational motion causes the spiral chips have difficulty maintaining their shape as the hole deepens. If the chip cannot compete with the rotational motion, they will be forced to move along the flute without spinning, and forming a string chips [6].

While most studies of stainless steel drilling has been focused on the chip formation mechanism and tool wear characterization, it is very interesting to study the effect of tool wear on chip morphology evolution and effects of cutting conditions on chip morphology. This study is conducted with the purpose of to better define and further characterize the different chips shape and dimensions as function of tool wear and cutting conditions in drilling stainless steel.

2. Drilling experiments

The drilling tests were performed using DECKEL MAHO DMC835V CNC machining center using uncoated carbide drill bits. To guarantee the initial conditions of each test, a new drill tool is used in each trial (Figure 2a) with particular properties (Figure 2b). Through holes were drilled in each trial until average flank wear reached 0.3 mm [7] or stopped upon drilling 25 holes [8] . The experiments were performed at two cutting speeds (18 and 30 mm/min) and three feed rates (0.03, 0.045, and 0.06 mm/rev) while the hole depth was kept constant at 10 mm. Tool overhang was set at 30 mm. All drilling experiments were conducted under 18.4 l/min flood drilling with 6% commercial mineral oil Ecocool 68CF2 supplied by FUCHS as cutting fluid.

a



b

Properties of solid carbide drill	
Tool material	Carbide
Tool Reference	DIN 6539
Coating	Uncoated
Diameter	4±0.01 mm
Point Angle	135°
Helix Angle	30°

Fig.2. End view of a new drill used in the experiments (a) and its properties (b).

In the present study, AISI 316L austenitic stainless steel blocks with hardness of 179.4 HV were used as the workpiece material. The dimension of the workpiece material was 120x60x10 mm. Chemical composition of the AISI 316L austenitic stainless steel is given in Table 1.

Table 1. Chemical compositions of 316L austenitic stainless steel

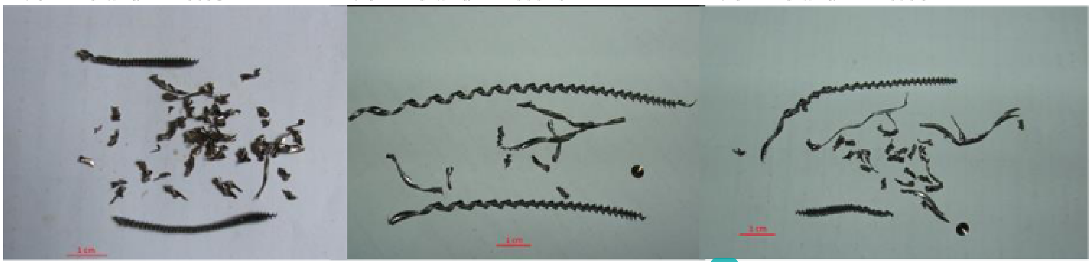
Fe	Cr	N	Ni	Mo	Mn	Si	S	C	P
Bal	16.5	0.1	10.23	2.6	2.0	0.6	0.03	0.03	0.03

3. Results and discussion

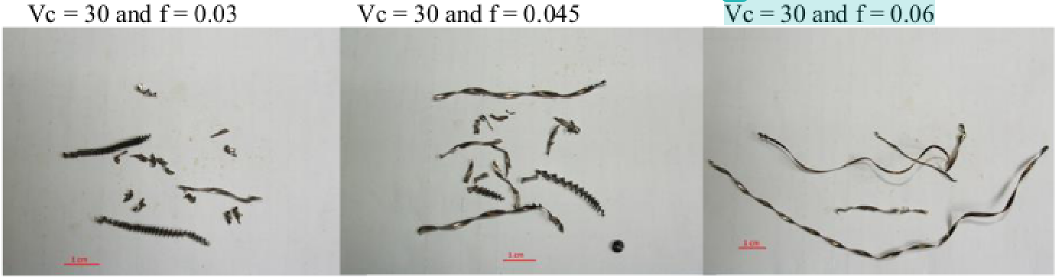
Some chip samples were taken to determine the chip morphology during drilling. The formed chip samples through drilling were shown in Table 2.

Table 2. Formed chip samples at different cutting speed (Vc, in m/min) and feed rate (f, in mm/rev)

Vc = 18 and f = 0.03 | Vc = 18 and f = 0.045 | Vc = 18 and f = 0.06



Vc = 30 and f = 0.03 | Vc = 30 and f = 0.045 | Vc = 30 and f = 0.06

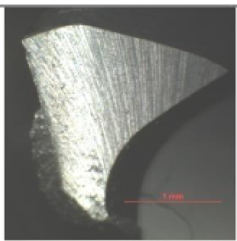
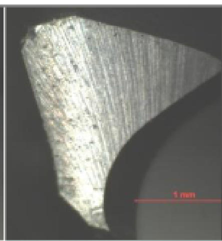
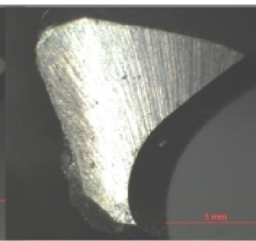
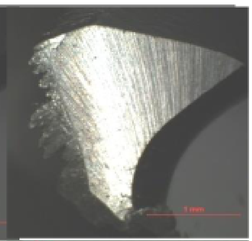
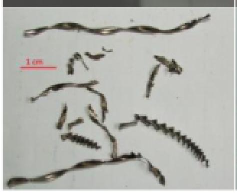
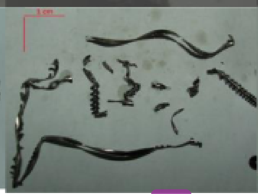
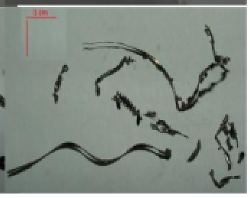


The drilling experiments showed that chips formed at 18 m/min cutting speed and 0.03 mm/rev feed rate were well broken chips and spiral with tight helix chip. When using higher feed rate of 0.045 mm/rev, short ribbon chips and spiral with loose helix chip formed, while with feed rate 0.06 mm/rev, spiral chips and short serrated ribbon chips formed. Using cutting speed of 30 m/min, with feed rate of 0.03, 0.045 and 0.06 mm/rev, tight helix spiral chips, short ribbon chips and long serrated ribbon chips formed respectively. A mixture of chip sizes usually indicates that that the two cutting edge angles and lengths or flank wear on both side are not the same.

Table 3 gives the chip morphologies during four stages, which presents the chips in the beginning wear, gradual wear, and catastrophic wear respectively. In the initial stage until average flank wear reached 0.1 mm, the chip was formed spiral with tight helix chips. After drilling until tool wear 0.2 mm, the chip was spiral with loose helix shape resulted. The outboard of chip was string with long ribbon chips until 0.3 mm of average flank wear while serrated ribbon chips occur when flank wear more than 0.3 mm.

The formation of the BUE detected in drills at initial wear stage and gradually grows until wear 0.1 mm. At the next stage, BUE sheared off and taken away by flowing chip until wear 0.2 mm. BUE start forming again at the 0.3 mm and growing as shown at next stage with tool wear 0.37 mm.

Table 3. Chip morphology at different circumstances of tool wear with Vc = 18 m/min and f = 0.06 mm/rev

	Circumstances			
	1	2	3	4
Tool Wear				
Chip Types				
Description	Spiral (tight helix) chips, flank wear 0.1 mm	Spiral (loose helix) chips , flank wear 0.2 mm	Long ribbon chips, flank wear 0.3 mm	Serrated (long ribbon) chips, wear 0.37 mm

Based on the chip forming mechanisms, continuous chips can be categorized into spiral chips (tight helix and loose helix chips) and string chips (short and long ribbon chips). Smaller drill wear produces a chip with a tight helix, whereas larger drill wear produces a chip with a long ribbon. Comparing Table 2 and Figure 3, the chip shape changes mostly affected by changes in feed rate. This can be attributed to the higher flank wear and higher material removal when applied higher feed rate to the process.

In general, the tight helix chip forms were obtained in drilling of AISI 316L with lower cutting speed. Both loose helix chip and long ribbon chip forms were obtained in the drilling with higher cutting speed. With higher feed rate, long ribbon chips were obtained in drilling. This indicates that severe wear on drill occurred during drilling with high feed rate. The loose helix chips were also produced due to little wear on drill at all cutting speeds.

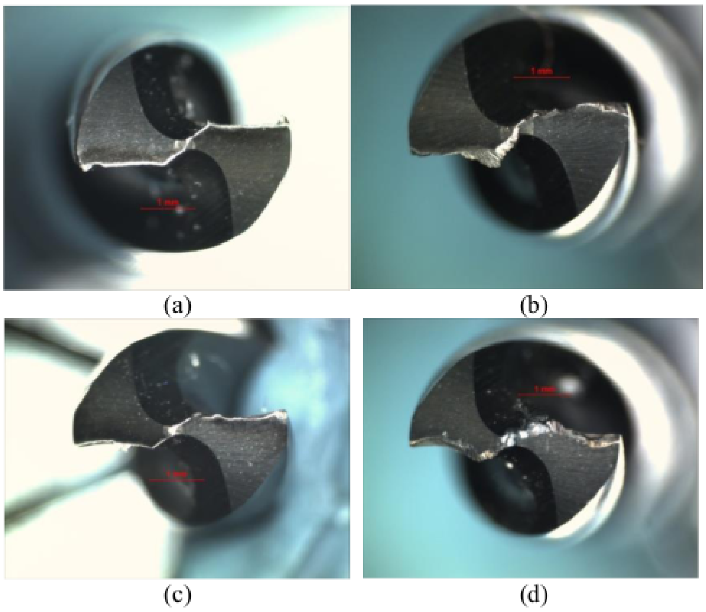


Fig.3. Worn drill after drilling last hole using, Vc 18, f 0.03 at 20th hole (a) Vc 18, f 0.06 at11st hole (b)Vc 30,f 0.03 at 17th hole (c) Vc 30, f 0.06 at 7th hole (d)

4. Conclusions

From the results obtained in the study, the following conclusions were drawn. The drilling of austenitic stainless steel with appropriate cutting parameters is possible without severe tool wear. The effect of cutting parameters on chip size and formation was examined. In term of desired chip formation, when using 4 mm solid carbide twist drill, a cutting speed lower than 30 m/min and feed rate 0.03 mm/rev or lower should be applied.

Acknowledgement

Financial supports from the Ministry of Education, Malaysia and Universiti Teknologi Malaysia through Research University Grant (No. 05H27) and Fundamental Research Grant Scheme (No. 4F285) are gratefully acknowledged.

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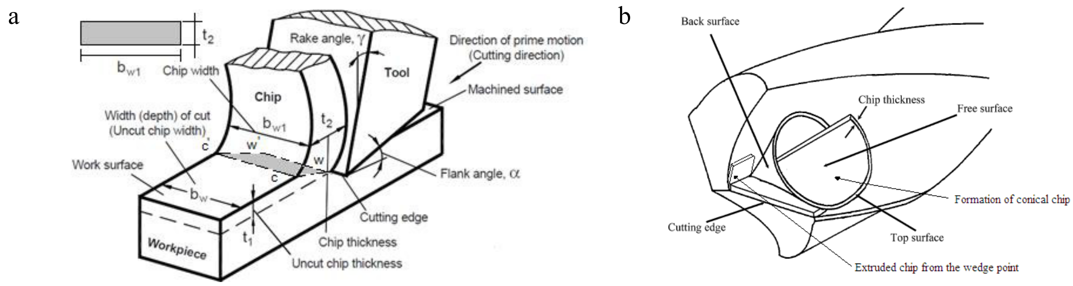

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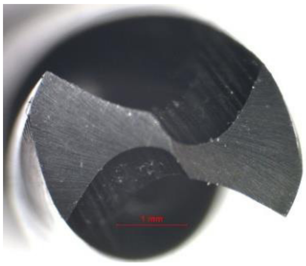

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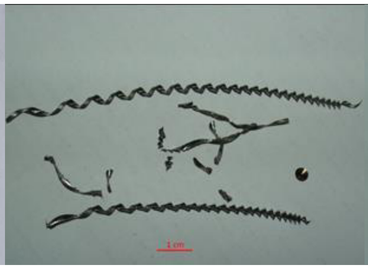
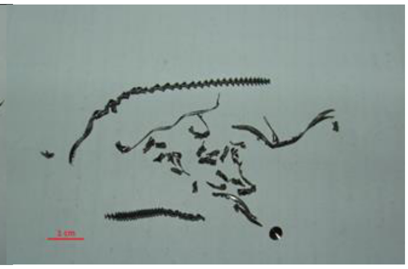
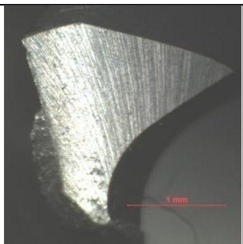
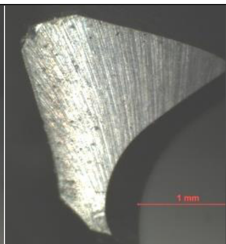
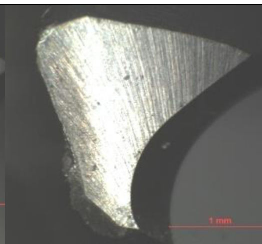
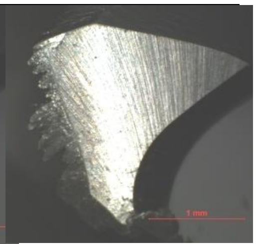
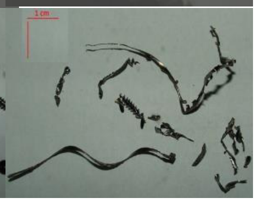
		
Vc = 30 and f = 0.03	Vc = 30 and f = 0.045	Vc = 30 and f = 0.06
		

The drilling experiments showed that chips formed at 18 m/min cutting speed and 0.03 mm/rev feed rate were well broken chips and spiral with tight helix chip. When using higher feed rate of 0.045 mm/rev, short ribbon chips and spiral with loose helix chip formed, while with feed rate 0.06 mm/rev, spiral chips and short serrated ribbon chips formed. Using cutting speed of 30 m/min, with feed rate of 0.03, 0.045 and 0.06 mm/rev, tight helix spiral chips, short ribbon chips and long serrated ribbon chips formed respectively. A mixture of chip sizes usually indicates that that the two cutting edge angles and lengths or flank wear on both side are not the same.

Table 3 gives the chip morphologies during four stages, which presents the chips in the beginning wear, gradual wear, and catastrophic wear respectively. In the initial stage until average flank wear reached 0.1 mm, the chip was formed spiral with tight helix chips. After drilling until tool wear 0.2 mm, the chip was spiral with loose helix shape resulted. The outboard of chip was string with long ribbon chips until 0.3 mm of average flank wear while serrated ribbon chips occur when flank wear more than 0.3 mm.

The formation of the BUE detected in drills at initial wear stage and gradually grows until wear 0.1 mm. At the next stage, BUE sheared off and taken away by flowing chip until wear 0.2 mm. BUE start forming again at the 0.3 mm and growing as shown at next stage with tool wear 0.37 mm.

Table 3. Chip morphology at different circumstances of tool wear with Vc = 18 m/min and f = 0.06 mm/rev

	Circumstances			
	1	2	3	4
Tool Wear				
Chip Types				
Description	Spiral (tight helix) chips, flank wear 0.1 mm	Spiral (loose helix) chips , flank wear 0.2 mm	Long ribbon chips, flank wear 0.3 mm	Serrated (long ribbon) chips, wear 0.37 mm

Based on the chip forming mechanisms, continuous chips can be categorized into spiral chips (tight helix and loose helix chips) and string chips (short and long ribbon chips). Smaller drill wear produces a chip with a tight helix, whereas larger drill wear produces a chip with a long ribbon. Comparing Table 2 and Figure 3, the chip shape changes mostly affected by changes in feed rate. This can be attributed to the higher flank wear and higher material removal when applied higher feed rate to the process.

In general, the tight helix chip forms were obtained in drilling of AISI 316L with lower cutting speed. Both loose helix chip and long ribbon chip forms were obtained in the drilling with higher cutting speed. With higher feed rate, long ribbon chips were obtained in drilling. This indicates that severe wear on drill occurred during drilling with high feed rate. The loose helix chips were also produced due to little wear on drill at all cutting speeds.

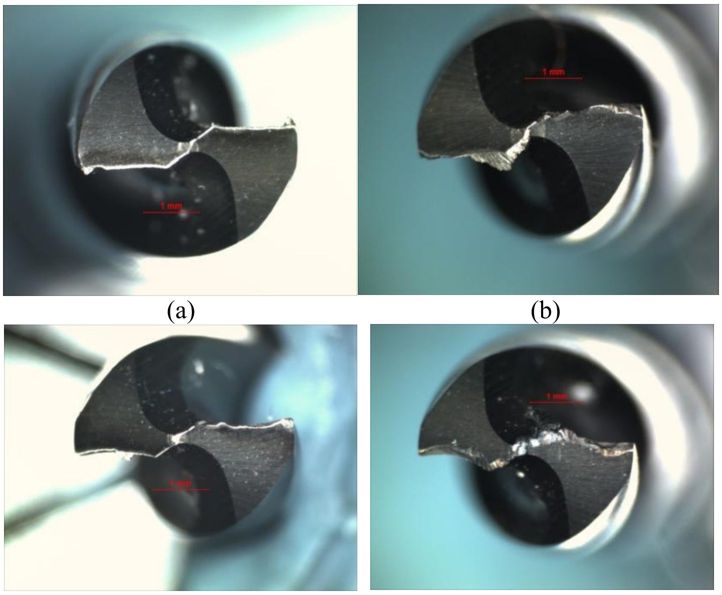


Fig.3. Worn drill after drilling last hole using, Vc 18, f 0.03 at 20th hole (a) Vc 18, f 0.06 at11st hole (b)Vc 30,f 0.03 at 17th hole (c) Vc 30, f 0.06 at 7th hole (d)

4. Conclusions

From the results obtained in the study, the following conclusions were drawn. The drilling of austenitic stainless steel with appropriate cutting parameters is possible without severe tool wear. The effect of cutting parameters on chip size and formation was examined. In term of desired chip formation, when using 4 mm solid carbide twist drill, a cutting speed lower than 30 m/min and feed rate 0.03 mm/rev or lower should be applied.

Acknowledgement

Financial supports from the Ministry of Education, Malaysia and Universiti Teknologi Malaysia through Research University Grant (No. 05H27) and Fundamental Research Grant Scheme (No. 4F285) are gratefully acknowledged.

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Chip Formation When Drilling 316L using Uncoated Carbide Twist Drill

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Abstract

Knowledge on the chip formation mechanism during drilling is very important to deliver the chips with size and shape expected. Long chips cannot move smoothly over a drill flutes hence should be avoided. Long chips tend to rotate along the drill body and lead to chip removal problems while small chips can be removed easily from the machined hole. In this study, performance of uncoated solid carbide twist drills through conventional flood drilling of AISI 316L stainless steels was evaluated in terms of chip formation. The purpose of this study aims to better define and further characterize the different chips shape and dimensions as function of tool wear and cutting conditions in drilling stainless steel. Experiments conducted on various combinations of cutting speed (18 and 30 m min-1) and feed rate (0.03, 0.045 and 0.06 mm rev-1) to present the differences in chip formation. Optical observation and comparative analysis of flank wear of the twist drill are used. As the results of the performed experiments, the lowest cutting speed-lowest feed rate reveals better performance due to chips desired on austenitic stainless steels drilling.

Keywords: Chip formation; Drilling austenitic stainless steel; Uncoated Carbide Twist Drill.

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