

Experimental Investigation of Tool Wear Mechanism in Drilling Operations

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Abstract

It can be said that most of the metal cutting operations are done through drilling; in fact, drilling happens to be the most common machining process employed in the manufacturing industry. Many factors including dimensional tolerances, hole quality, productivity level, and cost associated with machining operations are significantly influenced by the rate of wear occurring on the tools used for drilling. This study attempts to conduct an experimental investigation of tool wear processes in drilling at different machining conditions. Drilling tests were performed on mild steel specimens using HSS drills and carbide drills at various spindle speeds and feeds. The results demonstrate that the dominant wear mechanisms occurring during drilling operations include chipping, flank wear, and crater wear. Faster feed rate causes abrasive wear and degradation of the tool edge, whereas higher cutting speed significantly increases tool wear due to elevated temperatures during the process. The research provides valuable data on the effect of the above factors on the rate of tool wear.

Keywords: *Drilling, Tool Wear, Flank Wear, Crater Wear, Machining Parameters, Tool Life, Cutting Speed, Feed Rate.*

Introduction

One of the most important and commonly employed processes in current manufacturing industries is drilling. Drilling is the most frequently adopted process in making circular holes in engineering parts, and it is believed that almost one-third of all machining operations performed in industrial settings are hole-making operations. Drilling operations are extensively employed for assembly, joining, lubricant passages, and structural purposes in various industries such as automotive, aerospace, marine, construction, power, and heavy industry. The performance characteristics, dimensional accuracy, assembly tolerance, and manufacturing productivity are influenced directly by the quality of the holes that are drilled [1]. Because of constant contact between the cutting tool and the work piece material, drilling processes subject the cutting tool to severe mechanical and thermal stresses. Due to the action of cutting force, friction, and high temperatures at the tool-workpiece interface, wear occurs in the tool because the interaction occurs at the interface of the drill and the workpiece. Tool wear is one of the key factors that play a major role in the productivity of the process, machining quality, life span of the tool, and costs of manufacturing [2].

The performance of drilling is highly affected by wear on the tool. As the tool wears out, there will be higher thrust force, increased torque, vibrations, power requirement, dimensions, poor surface finish, burr formation, and ultimately, the failure of the tool. The failure of the tool unexpectedly can affect the machining process, leading to downtime and increase in manufacturing costs. Thus, to improve drill efficiency and extend its tool life, one needs knowledge about the wear process [3]. Drilling is characterized by complex tribological phenomena which consist of mechanical, thermal, chemical, and metallurgical processes leading to the wear of the drill tool. Wear due to abrasion, wear due to adhesion, wear due to diffusion, wear due to oxidation, and wear due to fatigue are the most common types of wear experienced during drilling. Abrasive wear occurs as a result of scratching of the workpiece's hard particles on the cutting edge of the drill. The fatigue wear is brought about by the repetitive application of mechanical and thermal stresses while the oxidation wear arises out of the interaction of chemicals between the surfaces of the tool and its environment under high temperatures [4]. The common types of wear experienced in drills involve flank wear, crater wear, corner wear, margin wear, chisel edge wear, and edge chipping. It is generally accepted that the primary parameter used in estimating the life span of a tool involves flank wear, which commonly occurs along the drill's clearance face. Whereas the primary reasons for edge chipping and breaking off of the tool involve mechanical stresses, high temperatures bring about crater wear. Conditions of cutting, workpiece properties, tool geometry, tool

material, and cooling conditions are among the factors that influence the intensity and progression of the above-mentioned wear mechanisms [5]. Tool wear characteristics are largely influenced by the cutting parameters. As a factor influencing the production of heat during the cutting process, cutting speed becomes one of the most significant factors. This is due to the fact that a high level of cutting speed intensifies the processes of diffusion and oxidation wear. Likewise, a rise in feed speed causes greater frictional pressure, hence accelerating the development of abrasive wear [6]. Also, wear resistance is affected by the choice of materials for the tools. In most drilling operations, the tools used include High-Speed Steel (HSS), cemented carbide, coated carbide, cubic boron nitride (CBN), and polycrystalline diamond (PCD). The wear resistance and hot hardness of carbide tools is higher than that of HSS tools. Recently, the use of surface engineering technologies and coatings has improved the wear resistance and stability of drilling tools in difficult machining conditions [7]. In line with Industry 4.0 and smart manufacturing, researchers have focused on tool wear monitoring. The modern approach of wear progression recognition and estimating the remaining usable tool life is based on using the above-mentioned approaches such as sensors, machine vision, artificial intelligence, machine learning techniques, vibration analysis, acoustic emission technique, and thermal imaging. Such an approach aims at avoiding unexpected breakdowns and increasing efficiency of the operation [8]. Nevertheless, the issue of tool wear remains significant in drilling processes despite the progress that was made in this sphere. The interaction of different parameters in the tool wear process makes it extremely difficult to predict its development, thus conducting experiments appears to be one of the best ways. A comprehensive study on the process of wear formation provides valuable insights into determining optimal cutting conditions, improving machining efficiencies, enhancing tool design, and reducing manufacturing costs [9]. Hence, the experiment involving drilling tool wear analysis in different machining conditions forms the core focus of this investigation. The current investigation aims at evaluating the performance of drilling tools under different machining scenarios, determining dominant wear modes, and analyzing the influence of machining parameters on the wear process. This research will prove useful in developing efficient machining strategies that will result in improved tool life and drilling performance.

Material & Method

The aim of the experiment was to determine the wear of drilling tools when subjected to different machining conditions. Mild steel, AISI 1020, was selected as the material for the test pieces owing to its favorable characteristics and widespread usage within industry sectors. In order to ensure stable machining processes, all the test pieces had uniform dimensions and were tightly clamped on a vertical drilling machine. Prior to the tests, all test pieces were cleansed to eliminate impurities at their surfaces that may influence the tool wear process. All the machining operations were conducted in laboratory conditions to maintain accuracy of the experiment. The materials of the drill bits used in the experiment were High-Speed Steel (HSS) and Cemented Carbide drills, both having the same dimension of 10 mm in diameter. The reason for selecting these tool materials is to evaluate the differences in wear resistance under identical machining conditions. The superior hardness and heat resistance properties of the carbide drill compared to that of the HSS drill led to its expected superior wear resistance. In addition, the variable-speed vertical drilling machine was used to conduct the tests, and the parameters were systematically varied to determine their influence on wear formation. In the test, three different cutting speeds, including 500, 800, and 1200 rpm, and feed rates, consisting of 0.10, 0.20, and 0.30 mm/rev, were applied. In all of the tests, the drilling depths remained constant at 20 mm. The machining conditions were dry-cutting conditions. Dry drilling was deliberately done to be able to see the wear processes naturally without any influence of the cutting fluid. For monitoring purposes to see any changes that might occur in the geometry of the cutting edge due to wear, the drill bits had to be checked after a specific number of holes drilled. A digital camera attached to an optical microscope was used to determine tool wear. Because flank wear is widely accepted as a parameter for determining tool life, this method was used. Several points along the cutting edge were considered, and the flank wear width was determined, and then the average was taken. In order to identify the prevalent wear types such as abrasive wear, adhesive wear, diffusion wear, crater wear, and edge breaking, visual examinations of the worn tools' surfaces were conducted apart from the quantitative analysis. In order to help analyze the tool wear morphology, pictures of the worn tools were also taken.

For the purpose of establishing a correlation between the machining conditions and the tool wear characteristics, the collected data was analyzed. Comparison of the wear properties and performance characteristics of the HSS and

carbide drills was made. The relationship between number of holes drilled, cutting speed, feed rate, and flank wear was evaluated.

Table 1. Workpiece Material Properties (AISI 1020 Mild Steel)

Property	Value	Unit
Density	7.85	g/cm ³
Ultimate Tensile Strength	420	MPa
Yield Strength	350	MPa
Hardness	120	HB
Elastic Modulus	205	GPa
Thermal Conductivity	51.9	W/m·K

Table 2. Drill Tool Specifications

Parameter	HSS Drill	Carbide Drill
Tool Material	High-Speed Steel	Cemented Carbide
Diameter	10 mm	10 mm
Point Angle	118°	118°
Helix Angle	30°	30°
Number of Flutes	2	2
Cooling Condition	Dry	Dry

Table 3. Experimental Equipment Used

Equipment	Specification	Purpose
Vertical Drilling Machine	Variable Speed	Drilling Operation
Optical Microscope	50× Magnification	Tool Wear Measurement
Digital Vernier Caliper	±0.02 mm Accuracy	Dimensional Measurement
Surface Roughness Tester	Portable Type	Surface Quality Evaluation
Infrared Thermometer	Non-contact Digital	Temperature Measurement
Electronic Balance	±0.001 g Accuracy	Weight Loss Measurement

Table 4. Machining Parameters and Levels

Factor	Symbol	Level 1	Level 2	Level 3
Cutting Speed (rpm)	N	500	800	1200
Feed Rate (mm/rev)	f	0.10	0.20	0.30
Drill Diameter (mm)	D	10	10	10
Hole Depth (mm)	h	20	20	20

Table 5. Experimental Design Matrix

Experiment No.	Cutting Speed (rpm)	Feed Rate (mm/rev)
1	500	0.10
2	500	0.20
3	500	0.30
4	800	0.10
5	800	0.20
6	800	0.30
7	1200	0.10
8	1200	0.20
9	1200	0.30

Table 6. Tool Wear Measurement Criteria

Wear Type	Description	Observation Method
Flank Wear (VB)	Wear on clearance face	Optical Microscope
Crater Wear	Wear on rake face	Visual Inspection
Margin Wear	Wear along drill margin	Optical Microscope
Chisel Edge Wear	Wear at drill center	Microscopic Analysis
Edge Chipping	Localized edge fracture	Visual Examination

Experimental Detail

The objective of the study is to investigate the wear behavior of the drill bit used in the drilling of AISI 1020 mild steel under various conditions of machining. In all the machining operations conducted, a vertical drilling machine with spindle speed variation mechanism was employed. The two types of drill bits selected for the experimentation include High Speed Steel (HSS) and Cemented Carbide drill bits with a diameter of 10 mm each. In order to minimize vibration, the specimens were clamped tightly on the table of the drilling machine.

There were three levels of cutting speeds (500, 800, and 1200 rpm) and three levels of feed rate (0.10, 0.20, and 0.30 mm/rev). In all trials, the depth of the holes was kept uniform at 20mm, while cooling fluid was not used while cutting in a dry environment. For each set of parameters, several holes were drilled until there were signs of wear on the cutting tool. All experiments were performed thrice in order to ensure repeatability and reproducibility, and the average results were used. After each set of 20 holes were drilled using one drill, the drill was extracted from the machine and washed properly to remove all the accumulated debris from it. Wear measurement was done using an optical microscope having magnification of 50X. In all trials, the depth of the holes was kept uniform at 20mm, while cooling fluid was not used while cutting in a dry environment. For each set of parameters, several holes were drilled until there were signs of wear on the cutting tool. All experiments were performed thrice in order to ensure repeatability and reproducibility, and the average results were used. After each set of 20 holes were drilled using one drill, the drill was extracted from the machine and washed properly to remove all the accumulated debris from it. Wear measurement was done using an optical microscope having magnification of 50X.

Table 7. Experimental Conditions

Parameter	Value
Workpiece Material	AISI 1020 Mild Steel
Tool Materials	HSS and Carbide
Drill Diameter	10 mm
Machine Tool	Vertical Drilling Machine
Cutting Speeds (rpm)	500, 800, 1200
Feed Rates (mm/rev)	0.10, 0.20, 0.30

Hole Depth	20 mm
Cooling Condition	Dry
Wear Measurement Device	Optical Microscope (50×)
Wear Criterion	Average Flank Wear (VB)
Number of Replications	3
Data Analysis	Wear Progression and Comparative Analysis

Table 8. Response Variables Measured

Response Variable	Unit	Measurement Method
Flank Wear (VB)	mm	Optical Microscopy
Crater Wear	mm	Visual/Microscopic Analysis
Tool Life	Number of Holes	Experimental Observation
Surface Roughness	μm	Surface Roughness Tester
Cutting Temperature	°C	Infrared Thermometer
Wear Morphology	Qualitative	Image Analysis

Result & Discussion

From the experimental study, it was found that the performance of drilling operations greatly depends on drilling parameters as far as tool wear is concerned. In the case of drilling of AISI 1020 mild steel, it can be seen that tool wear increased as machining time, cutting speed, and feed rate were increased. From the observations taken from optical microscope analysis, it was determined that flank wear was the dominant wear mechanism in the experiments performed. Initially, tool wear increased gradually, but when drilling was continued for some time, wear rate increased rapidly because of thermal and mechanical loading effects. Additional evidence of abrasive wear, adhesive wear, crater wear, and edge chipping, especially under extreme machining settings, was found under a microscope. These findings suggest that choosing the right cutting parameters is crucial to reducing tool wear and enhancing drilling efficiency. From the figures recorded in Table 9 above, there is an absolute indication that flank wear increased as both cutting speed and feed rates increased for the two material tools. The lowest wear values were registered by carbide drill at speeds of 500 rpm with feed rate 0.10 mm/rev with the highest wear value of 0.43 mm recorded by the HSS drill at speeds of 1200 rpm and feed rate 0.30 mm/rev. Moreover, the carbide drills retained longer tool life compared to other drills under all machining conditions.

Table 9. Experimental Results of Tool Wear under Different Machining Conditions

Exp. No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Tool Material	Flank Wear (mm)	Tool Life (Holes Drilled)
1	500	0.10	HSS	0.12	180
2	500	0.20	HSS	0.18	160
3	500	0.30	HSS	0.24	145
4	800	0.10	HSS	0.20	150
5	800	0.20	HSS	0.28	130
6	800	0.30	HSS	0.34	115
7	1200	0.10	HSS	0.29	120
8	1200	0.20	HSS	0.36	105
9	1200	0.30	HSS	0.43	90
10	500	0.10	Carbide	0.08	300
11	500	0.20	Carbide	0.11	285
12	500	0.30	Carbide	0.16	265
13	800	0.10	Carbide	0.13	270

14	800	0.20	Carbide	0.17	250
15	800	0.30	Carbide	0.22	235
16	1200	0.10	Carbide	0.18	230
17	1200	0.20	Carbide	0.24	215
18	1200	0.30	Carbide	0.30	195

Conclusion

The experimental study showed that cutting speed, feed rate, and tool material have a significant impact on tool wear during drilling operations. The predominant wear mechanism was found to be flank wear, whose rate rose as cutting speeds and feed rates increased. Because of their superior hardness and thermal stability, carbide drills outperformed HSS drills in terms of wear resistance and tool life. The main wear processes seen in the trials were edge chipping, adhesive wear, diffusion wear, and abrasive wear. The findings show that drilling performance, tool life, and overall manufacturing efficiency may all be greatly increased by using the right machining parameters and tool materials.

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