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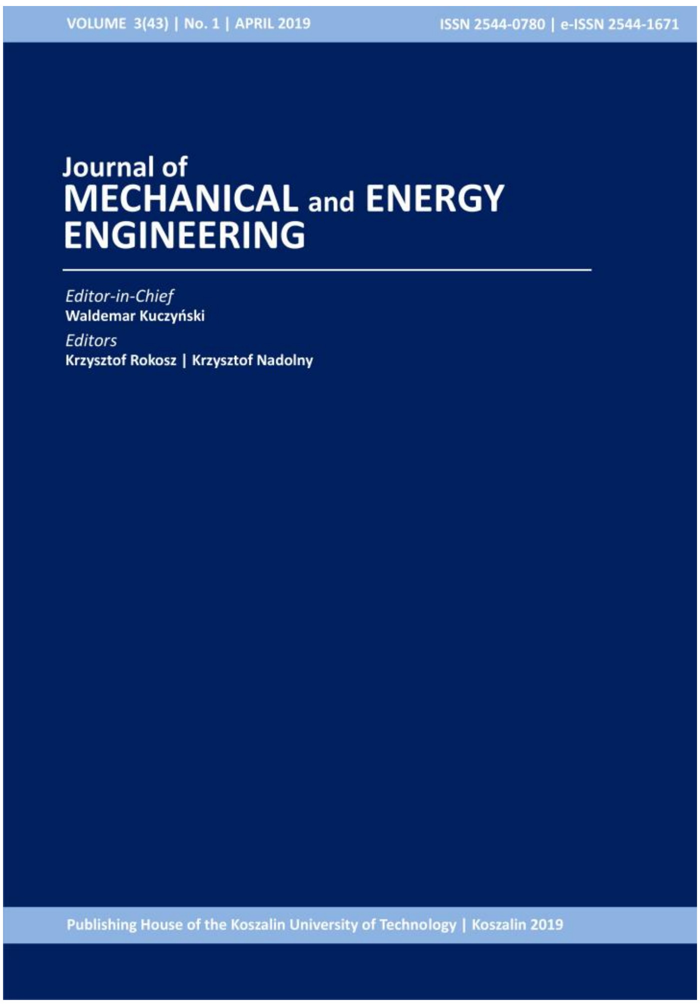

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AN EXPERIMENTAL STUDY OF CUTTING FLUID ON DRILLING AISI 1040 STEEL

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Abstract: This experimental study investigated the effects of a conventional cutting fluid during drilling cylindrical holes on workpiece materials made of the AISI 1040 steel. Drilling responses were compared between dry and wet (in presence of the cutting fluid) cutting conditions with respect to drilling force, roundness deviation and taper of the hole, and chip morphology. High production machining and drilling with high cutting speed, feed, and depth of cut were found to be inherently associated with the generation of a large amount of heat and high cutting temperature. In a dry condition such high cutting temperature not only reduces dimensional accuracy and tool life but also impairs the roundness deviation and taper of the hole. The use of a conventional cutting fluid, in such a situation, was very effective to reduce the cutting temperature. In a dry cutting condition, numerous tool-wears were found on the drill bits. Drilling in such a dry condition seriously affects roundness of the hole, and chip shape and color. Contrastingly, use of a traditional cutting fluid reduced temperature as well as improved roundness and taper of the hole. It also acted as a lubricate at the tool tip–work surface interface. Overall, the conventional cutting fluid enhanced the quality of the machine work and potentially can increase machine life of drill bits.

Keywords: drilling, cutting fluids, chip, force, torque, roundness deviation, AISI 1040

1. INTRODUCTION

Well dimensional accuracy and fine surface integrity both are desired for a finished product. Cutting fluid plays an important role in machining. Commonly, the use of cutting fluid can decrease cutting temperature, reduce the friction between tool and workpiece, extend tool life, and improve machining efficiency and surface quality [1].

During the drilling process, the most important factor affecting the cutting tool performance and workpiece properties is cutting temperature that emerges between drill bit and chip [2]. The cutting temperature directly influences hole characteristics such as diameter, perpendicularity, and cylindricity, as well as surface roughness and tool wear [3]. They also investigated the effects of cutting depth, cutting speed, web thickness and helix angle on the temperature. The temperatures associated with the drilling process are particularly important because drilling is one of the predominant industrial machining processes and heat effects in drilling are generally more severe than in other metal-cutting operations. Drills often experience excessive temperatures because the drill is embedded in the workpiece and heat generation is localized in a small area. The resulting temperatures can lead to accelerate tool wear, and reduce tool life and they can have profound effects on the overall quality of the machined workpiece. Drill designers often select the geometrical features of a drill based on the expected temperature profile in the drill point, so accurate prediction of the temperature distribution is imperative [4]. Temperature not only exaggerates the tool-wear but also affect the surface, hole quality, and chip formation. The cutting temperature directly influences hole sensitivity, surface roughness, and tool wear [3]. A turning tool typically will not fail due to thermal shock, because it is subjected to this quenching only three or four times per minute when it is withdrawn from the cut at the end of each pass. A face milling operation running at 1000 RPM, on the other hand, subjects every insert to 1000 damaging quenches per minute. Drilling fails somewhere in between with thermal shock occurring every time the drill pulls out of the cut [5].

A major portion of the energy is consumed in the formation and removal of chips. The greater the energy consumption, the greater are the temperature and frictional forces at the tool-chip interface and consequently the higher is the tool wear [6]. Drill wear not only affects the surface roughness of the hole but also influences the life of the drill bit [7]. Wear in the drill bit is characterized as flank wear, chisel wear, corner wear, crater wear and margin wear [7**,** 8]**.** Since wear on drill bit dictates the hole quality and tool life of the drill bit [7]. Worn drills produce poor quality holes and in extreme cases, a broken drill can destroy almost all finished parts. A drill begins to wear as soon as it is placed into operation. Thrust and torque depend upon drill wear, drill size, feed rate, and spindle speed. Research results show that tool breakage, tool wear, and workpiece deflection are strongly related to cutting force [8].

The application of cutting fluid during machining operation reduces cutting zone temperature and increases tool life and acts as a lubricant as well [9]. Also, it was found that without cooling and lubrication, the chip sticks to the tool and breaks it in a very short cutting time. It reduces cutting zone temperature either by removing heats as coolant or reducing the heat generation as a lubricant [14]. In addition, it serves a practical function as chip-handling medium [10]. On the other hand, the cooling and lubricating effects of cutting fluid influence each other and diminish with an increase in cutting velocity [15]. A large amount of heat is created in dry machining because of rubbing between the cutting tool and workpiece interface. Dry machining has not fully established itself in drilling technology, mainly because of the extremely high thermal load on the drilling tools resulting in accelerated tool wear and unsatisfying overall process stability [11]. The optimization of cutting conditions to make them more suitable for dry cutting is done through the increase of feed and decrease of cutting speed. With this, roughly the same amount of heat is generated, but the area of the tool which receives this heat is bigger, making the temperature lower and the amount of chip removed per minute constant (without increasing cutting time). This action may damage the workpiece surface finish due to the increase of the feed [12]. And also in dry drilling, the drilling tool has to withstand harsh environmental conditions, including high temperatures, frictional forces and large mechanical and thermal loads [3]. Therefore, it is also necessary to increase the tool-nose radius in order to keep the surface roughness at the same level.

Cutting fluids have the dual tasks of cooling the cutting surface and flashing chip. In some operations such as drilling, for example, cutting fluid is important to remove the chips from inside the holes, thus preventing drill breakage. They also help to control cutting-face temperature and this can prolong tool life, improve cut quality, and positively influence part finish. It has the benefit of a powerful stream that can reach onto the cutting area, provides strong chip removal and in some cases enough pressure to deburr [13]. The possibility of controlling a high cutting temperature in high production machining by some alternative method has been reported. Cutting fluids can reduce the coefficient of friction at the chip-tool interface and thus could reduce cutting forces and increase tool life to some extent. The main objective of the present work is to make an experimental investigation on the effect of conventional cutting fluid application in drilling AISI-1040 steel with HSS drill bits and overall benefits in respects of drilling force and torque, roundness deviation of the hole, taper of the hole, chip morphology, and drill bits investigation.

2. EXPERIMENTAL INVESTIGATION

2.1. Experimental Setup

Drilling metals by high-speed steel (HSS) is a major activity in the manufacturing industries. Drilling of steels involves more heat generation for their ductility and production of continuous chips having more intimate and wide chip-tool contact. Again, the cutting temperature increases further with the increase in strength and hardness of the steels for more specific energy requirement. Keeping these facts in view the commonly used medium carbon steel like AISI-1040 steel has been undertaken for the present investigations. Considering common interest and time constraint, only HSS drill bits have been used for the present investigation. A wide scope will remain for further study on cutting fluid effect in drilling steels by HSS and exotic materials by a high-performance drill bit. The drilling tests have been carried out by drilling of AISI-1040 steel on a Radial drill machine (RM-U9 Radial Drill Machine, Sweden) by HSS drill under dry and wet (with cutting fluid) conditions. The photographic view of the experimental set-up is shown in Figure 1.

2.2. Experimental procedure and conditions

Drilling experiments have been carried out under dry and wet (with cutting fluid) conditions. The conventional cooling system provided in the machine has been used for the wet Drilling operation. The present experimental conditions under which the Drilling experiments have been carried out are briefly given in Table 1.

Fig. 1. Photographic veiw of the experimental set-up

Tab. 1. Experimental conditions

Machine tool: RM-U1, Radial Drill Machine, Sweden, 1.5 kW. **Work material:** AISI-1040 [C-0.40%, Medium carbon steel] **Cutting tool:** High speed steel (HSS), diameter:8 mm, 6 mm, and 4 mm
Process parameters Spindle Speed**:** 200 RPM, 440 RPM, and 670 RPM. Feed rate, So**:** 0.16 mm/revolution Depth of cut**:** 19.5 mm
Cutting fluid supply: 1.2 litter/min Environment**:** dry and wet (with cutting fluid) conditions

The heating capacity of the metal AISI1040 used in this experiment is important. They were determined using a gas torch. The maximum temperature measured in the middle of the workpiece was 400°C, obtained after heating it by a gas torch for a period of 6 min and 50 s. After heating, the workpieces were submitted to air cooling condition. The temperature was measured by a K-type thermocouple for that time. This thermo-sensor was connected to the workpiece through a hole that allowed it to reach the center of the workpiece. The heating and cooling curves are shown in Fig. 2 and Fig 3.

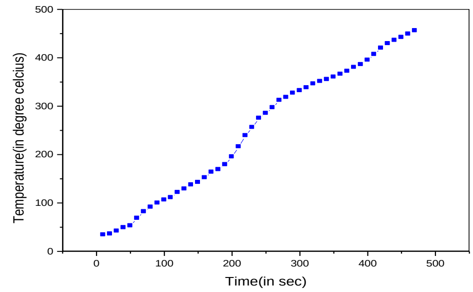

Fig. 2. Heating curve of AISI1040 steel

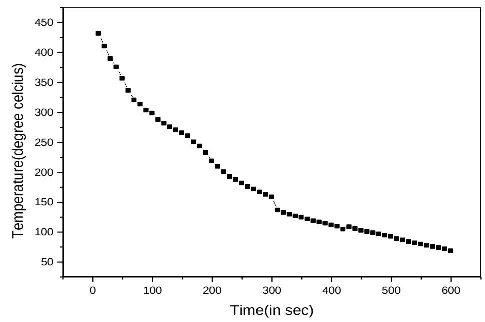

Fig. 3. Cooling curve of AISI1040 steel (air cooling)

3. EXPERIMENTAL INVESTIGATIONS

3.1. Drilling Force and Torque

Drilling force is an important factor in drilling operation. The force exerted by the rotating drill bit on the surface which is to be drilled, referred as drilling force. A force measuring device used to measure the drilling force. The effect of conventional cutting fluid on drilling force has investigated with different environment, different sized drill bits and various RPM. The investigations are represented graphically.

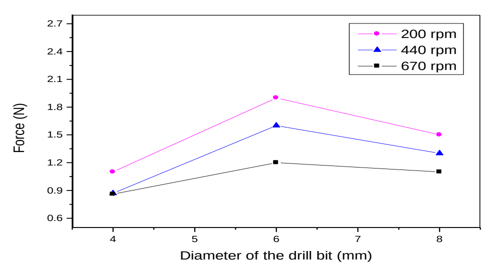

Fig. 4. Force vs. diameter of the drill bit curve (dry condition)

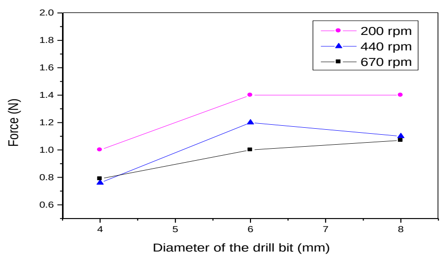

Fig. 5. Force vs. diameter of the drill bit curve (wet condition)

During drilling steel specimens, drilling force decreases with increasing the RPM of the spindle and drilling force increases with increasing the depth of cut. High drilling force influences the damages of the drill bits, poor machinability, chip formation mode, tool life and as well as the life of the machine. So, it is important to reduce this detrimental drilling force. The investigation shows in Fig 4 and Fig 5 shows the drilling force is higher in a dry condition than a wet condition. From the investigated curve it is clear that the drilling force decreases with the increment in RPM. Basically, the force exerted in dry condition is always higher than in wet condition. So, the use of conventional cutting fluid is efficient to reduce the drilling force and torque.

3.2. Roundness Deviation (8 mm and 6 mm drill bit diameter)

The diameter and roundness deviation of the holes were measured by a slide caliper. The measurement is done for both 8 mm and 6 mm dia drill bit. The readings are taken at close to the beginning of the hole and end of the hole for both 8 mm and 6 mm drill bit. The standard deviation of the drill hole diameter was measured by means of a statistical approach. The variation of roundness deviation with the increment in spindle speed or rpm for the drill bit of 8 mm and 6 mm diameter are shown below.

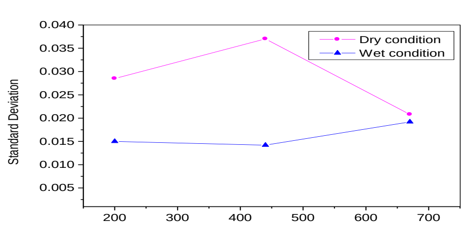

Fig. 6. Standard deviation vs. rpm curve (8 mm)

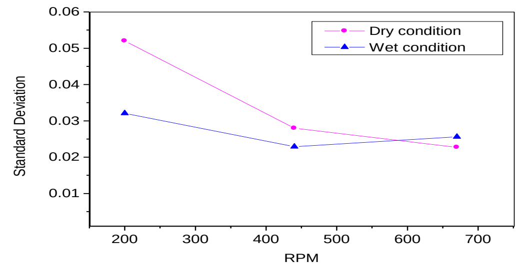

Fig. 7. Standard deviation vs. RPM curve (6 mm)

The investigation shows that fluctuation of the curve occurs due to the irregular drilling force, increment of drilling temperature, a variation on the feed rate and vibration; these causes mainly occurred in the dry condition. But in case of a wet condition, the drilling operation is comparatively smooth. The curves for wet conditions are straighter than the dry condition. They do not fluctuate suddenly. It can be observed that the standard deviation of the average diameter obtained under a wet condition is lower than that obtained using a dry condition, which means that the cutting fluid presented a better quality.

3.3. Taper Values

Diameters of both top-surface hole (D_{Top}) and bottom-surface hole (D_{Bottom}) were used to calculate taper values. The equation and graphs are shown below:

$$Taper\ Value = (D_{Top} - D_{Bottom}) * 100 / Length\,. \quad (1)$$

The variation of taper values with respect to the increment in RPM for the drill bit of 8 mm and 6 mm diameter are shown below.

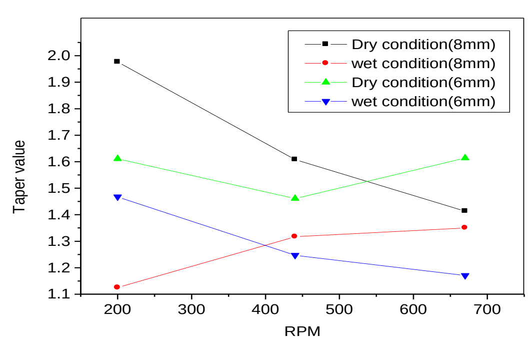

Fig. 8. Comparison curve of taper value vs RPM for 8 mm and 6 mm drill bit

Fig. 8 indicates that the maximum taper value occurs at 440 rpm in the dry condition for both sized drill bits (8 mm and 6 mm).

3.4. Chips morphology

In the experiment, the drilling chips are investigated. The chips for various spindle speed, different drill diameter, and dry and wet conditions are observed. From the chip morphology, the quality of different types of chips for different conditions shows a neat concept about the contribution of cutting fluid properly (Tab. 2).

Tab. 2. Photographic view of drilling chips while drilling AISI 1040 steel by 8mm Size drill bits at different RPM and different environments

Environments	
Dry (220 RPM)	Wet (220 RPM)
	
Dry (440 RPM)	Wet (440 RPM)
	
Dry (670 RPM)	Wet (670 RPM)
	

Cutting fluid played a very effective role for cooling and provided lubrication between drill bit and chip interface. The shape of the chip produced under dry conditions was spiral but under wet conditions they became strings. The color of the chips became metallic from burnt blue due to a reduction in drilling temperature by wet conditions. By studying the chip characteristics, it is evident that in dry drilling the mechanism of chip formation is mainly due rubbing and some are by shearing. On the other hand, in wet conditions the mechanism of material removal is mainly shearing; there are some irregular shapes also observed.

3.5. Drill bit investigation

Drill bits are investigated using photographic views. Dry and Wet conditions also created a great difference. Drill bits investigation shows the beneficial effect of cutting fluid on drilling operations (Tab. 3).

Tab. 3. Photographic view of drill bits while drilling AISI 1040 steel at 440 RPM and different environments

Environments	
Dry (drill bit 8 mm)	Wet (drill bit 8 mm)
	
Dry (drill bit 6 mm)	Wet (drill bit 6 mm)
	

During the drilling operation, a high temperature is generated. The hardness property of drill bits decreases in high temperature. It wears more at dry conditions. But drilling with conventional cutting fluid solves this problem. The tool-wear decreases in wet condition. It also increases the drill hole accuracy.

4. CONCLUSIONS

The experimentally observed role of cutting fluid in drilling medium carbon steel (AISI-1040) by HSS drill may be summarized as follows:

1. The drilling force is higher in dry conditions than in wet conditions.
2. Roundness deviation was smaller at both the entrance and end of the holes under wet conditions compared to dry conditions. When high cutting depth was used, the drilling with dry conditions was not possible because of poor cooling and lubrication action.
3. Taper values and their dispersion were smaller under wet condition. Moreover, in both conditions the average taper values were positive i.e., the diameters in the entrance of the holes were bigger than at the end.
4. The formation of chips under wet conditions is more favorable in comparison to dry conditions because of high lubricant capacity.

5. The drill bits wear less in dry conditions than in wet conditions because of the coolant property of the conventional cutting fluid.
6. The beneficial effects of cutting fluid may be attributed to effective lubrication action, which prevents the chip from sticking on the tool and makes the cut feasible.

Nomenclature

Acroynyms

RPM – Rotations per minute
AISI – The American Iron and Steel Institute
HSS – High Speed Steel

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Biographical notes

Md. Abdul Alim received his B.Sc. degree in Mechanical Engineering from the Rajshahi University of Engineering Technology, Bangladesh in 2009. Since 2009 he has been working in the field of mechanical engineering at various organizations in Bangladesh. Currently, he works as a workshop superintendent in the Bangladesh Institute of Marine Technology. His scientific interests focus on advanced manufacturing and materials engineering, investigation of machining processes and tools, efficiency, monitoring and diagnostics of machining processes as well as tribology. He has participated in various international and national conferences of mechanical engineering and co-authored several conference papers. He is specialized to conduct and manage Mechanical Workshops, and to teach Mechanical Engineering related subjects to the diploma engineering students. He is a young researcher and organizer of various research clubs, skill competitions, and the centre of innovations.

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