INVESTIGATIONS ON DRILLING SCM 440 STEEL WITH ELECTRO STATIC LUBRICANTION (ESL) SYSTEM

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ABSTRACT

The rapid wear rate of cutting tools due to high cutting temperature is a critical problem to be solved in machining of hardened steel. Application of cutting fluid influences the performance of machining because of its lubrication and cooling actions. But, the environmental concerns call for the reduced use of cutting fluids in machining operations. Near-dry machining such as minimum quantity lubrication is regarded as one of the solutions to this difficulty. In the present work, cutting fluid was applied as a high velocity jet at the machining zone continuously at an extreme low rate using a fluid application system developed namely Electro Static Lubrication (ESL) during drilling of hardened steel. The performance of ESL has been compared with that of dry and MQL (minimum quantity lubrication) machining.

Key words: Electro static lubrication, drilling, tool wear, hole quality

INTRODUCTION

Heat generation and friction between tool and chip usually limits machining performance in machining operations. Coolants and lubricants are therefore used in high quantities to reduce the temperature and friction in machining area. However, the costs of cutting fluids are increasing due to environmental concerns related to fluid handling, disposal and the coming legislations from governmental enforcing agencies. Therefore all the problems related to the use of cutting fluids have urged researchers to search for some alternatives to minimize or even avoid the use of cutting fluids in machining operations. In this era of eco friendly sustainable manufacturing, technological improvements have resulted some of the alternatives to cutting fluids such as dry machining, minimum quantity of lubrication, etc.

Dry machining has been proven successful in minimizing the use of cutting fluids in machining processes. For this to be possible without causing a large decrease in tool life and loss of workpiece quality, it is mandatory to have suitable tool materials and cutting conditions. Hard coatings of tool materials, including diamond coating, have been used to accomplish this task [1]. The dry machining as the machining of the future has been reported that it can eliminate cutting fluids with the advancement of the cutting tool materials [2]. Dry machining requires less power and produces smoother surface than wet turning at specified cutting conditions [3].

In those processes where dry cutting is either not possible or not economical, another technique can be tried to reach the goal of minimizing the amount of cutting fluid in machining process: minimum quantity of lubricant (MQL). MQL is a technique, which consists of the application of a very small amount of cutting oil, 6–100 ml/h, delivered in a compressed air stream, directed at the tool cutting edge [4]. Some good results have been obtained with this technique [5, 6]. Lugscheider et al. [7] used this technique in the reaming process of gray cast iron and aluminum alloy with coated carbide tools and concluded that it caused a reduction of tool wear when compared to the completely dry process and, consequently, an improvement in the surface quality of the holes. Machado and Wallbank [8] also used this technique in the turning process of medium carbon steel and concluded that, in some cases, air, or a mixture of air+water, or air+soluble oil, has been shown to be better than the overhead flooding application of soluble oil. The satisfactory performance has been achieved by applying MQL in many practical machining operations such as turning, milling and drilling, etc. [9, 10].

Above mentioned studies indicate that the use of MQL in machining as one of the possible alternative to cutting fluids. However, good results are not always obtained with this technique for all types of cutting. In MQL machining, removal of heat generated during cutting is achieved mainly by the convection of the compressed air and partially by evaporation of cutting oil [11]. The main limitation of MQL is its small effectiveness in cooling the cutting surface. This could be due to the fact of difficulty of lubricant reaching to the machining zone. If the fluid can be applied in more refined and defined way exactly to the machining zone, improved results can be expected.

Hence in this research work, an Electro static lubrication (ESL) system setup has been designed and developed for the purpose to supply a small amount of cutting fluid continuously to the machining zone at a constant flow rate. Another main goal of this work is to verify the performance of ESL in the drilling operation of SCM 440 steel, in comparison with that of dry and MQL machining, based on tool wear and hole quality.

EXPERIMENTS

The drilling experiments were carried out on a high speed CNC milling machine. The material was SCM 440 steel (medium carbon chrome molybdenum steel) specimens with the chemical composition of 0.38% C, 0.15% Si, 0.60% Mn, 0.030% max P, 0.030% max S, 0.90% Cr, 0.1 M, and it was prepared in 400x500x50 mm^3 block.

Selected tool was a TiAlN coated fine grain coated carbide drill supplied by Oerlikon Blazers Co Ltd. Geometry of the drill is 8 mm and has two flutes. Based upon the trial experiments, cutting speed and feed were fixed at 5000 rpm, 6000 rpm, 7000 rpm and 0.2 mm/rev respectively and at a depth of cut of 5 times the diameter of the drill tool.

The drilling tests under ESL, MQL and dry conditions were carried out. During MQL (lubricant+ air) and ESL the cutting fluid used in the experimentation was soluble oil with water in the ratio of 1:3. Within the practical range investigated (literature), a low delivery rate of 30ml/hr has been selected for MQL and ESL set up. In case of MQL, it was supplied at a pressure of 0.6 Mpa.

Surface finish of the drilled hole was measured with a talysurf. Hole diameter was measured with a three point internal micrometer of 0.001mm resolution. Tool wear was measured by means of a tool maker's microscope. This type of test requires the drilling operation to be stopped to allow the measurement of tool wear. Tool was assumed to be replaced when a tool life criterion of 0.3mm maximum wear has reached.

Experimental setup

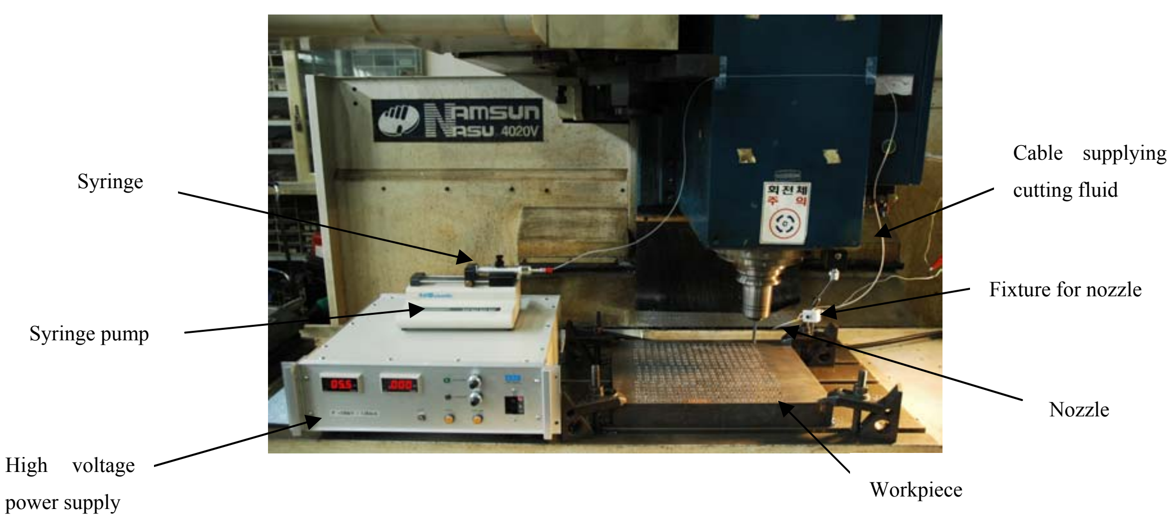

Fig.1. Electro static lubrication (ESL) system setup for fluid application

The Experimental setup namely electro static lubrication (ESL) developed for minimum quantity lubricant supply at the machining zone is presented in Fig.1. It is a method of generating a very fine liquid aerosol through electrostatic charging, rather than the more familiar gas (pneumatic) methods. The electrostatic solid lubricant apparatus consists of a sharply pointed hollow metal tube, such as a syringe, with liquid pumped through the tube. A high-voltage power supply is connected to the outlet of the tube (nozzle) and the tube is positioned in front of a plate, called a counter-electrode, commonly held at ground potential.

Principle of ESL system

Electro static lubrication system, as the name implies, uses electricity instead of gas to form the droplets. In electro spray, a liquid is passing through a nozzle. The plume of droplets is generated by electrically charging the liquid to a very high voltage. The charged liquid in the nozzle becomes unstable as it is forced to hold more and more charge. Soon the liquid reaches a critical point, at which it can hold no more electrical charge and at the tip of the nozzle it blows apart into a cloud of tiny, highly charged droplets as shown in Fig.2.

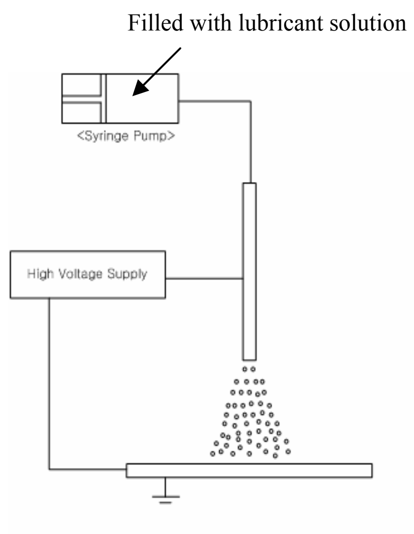

Fig.2. Schematic view of electro static lubrication set up

RESULTS AND DISCUSSION

The aim of the performed experiments was to assess the performance of ESL in comparison with MQL and dry cutting technique in drilling SCM 440 steel. To evaluate the performance of this techniques, tool life and hole quality tests have been performed, analyzing tool wear and hole quality in terms of hole diameter and surface roughness.

Tool wear

To compare the performances of different lubrication techniques tool wear values have been plotted with respect to the number of holes drilled in Fig.3. Fig.3 shows that the tool life can be enhanced apparently by MQL and ESL as compared to dry cutting at all considered levels of process parameters. This is due to the fact that the cutting fluid used in MQL and ESL machining reduces the temperature and friction in the cutting area. Further in comparison with MQL, ESL technique results in less tool wear. Lubrication condition can be ranked in decreasing performance order as: ESL, MQL, and dry. Adhesion levels were reduced when the lubricant supply with ESL technique. This is due to the fact that, it is possible to suppose that when MQL is applied on the rake surface the lubricant does not reach the machining zone (due to the difficulty of lubricant reaching the machining zone). In case ESL; the cutting fluid is applied at the tool–work interface and there is a possibility of some tiny fluid particles penetrating the work surface near the cutting edge, which will form the top of the chip in the next revolution. These particles, owing to their high velocity and smaller physical size can penetrate and firmly adhere to the work surface resulting in the promotion of plastic flow on the backside of the chip due to Rebinder effect [12]. This relieves a part of the compressive stress and thereby reduces tool chip contact length and results in longer tool life.

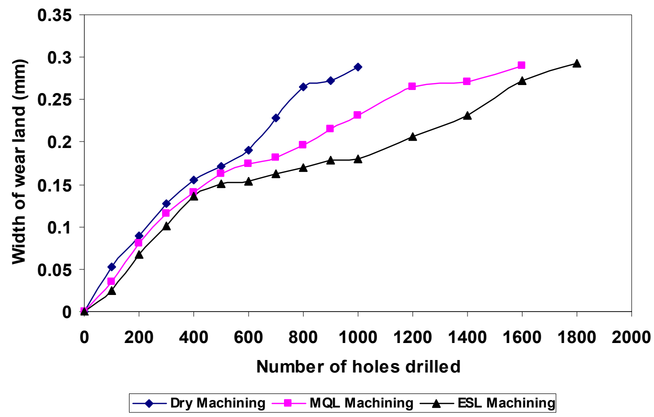

Fig.3. Variation of tool wear with respect to number of holes drilled(S=5000 rpm, f=0.2 mm/rev)

Hole diameter

Hole diameter has been measured at two points located at different height and orientation. Standard sample deviation of these measurements was always inferior to 0.015 mm. There is concern that the heat generated by the process can lead to thermal expansion of the drill and work-piece that will affect the size and quality of the holes leading to oversized holes. However, diameter measurements were similar in all the conditions tested, and no significant changes in diameter were observed neither with ESL, MQL and dry conditions. All diameter measurements ranged from 8.01 to 8.07 mm, and mean values ranged from 8.03 to 8.06 mm. These values correspond to a dimensional tolerance reasonable in drilling operations. The ESL technique presented the best results related to the average diameter of the hole (their values are closer to the drill diameter), as can be seen in Fig.4. Similar results have been obtained for other cutting conditions also.

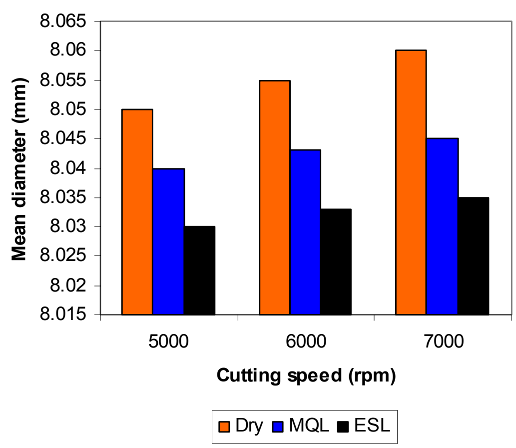

Fig.4. Average diameter for different types of machining conditions (f=0.2 mm/rev, after 200 holes)

Surface finish

In order to explore the effect of ESL method of application of lubricant on surface finish, the surface roughness values, recorded under all the conditions employed, were compared. Two surface roughness readings were taken at four positions spaced at 90^o intervals around the hole circumference and approximately midway down the depth of the hole. Fig.5 illustrates the variation of surface roughness values with the cutting speed when machining SCM 440 under dry, MQL and ESL conditions.

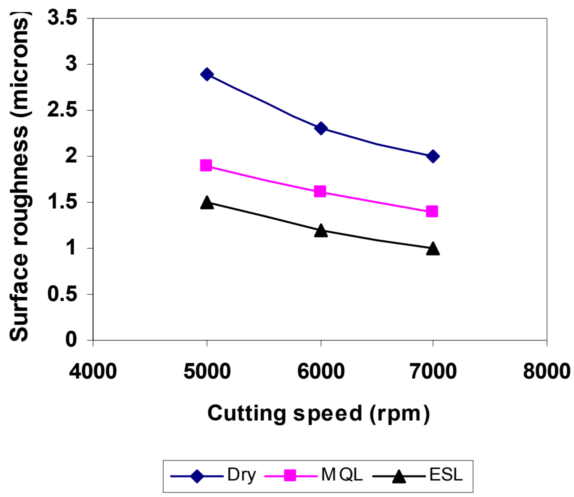

Fig.5. Surface roughness variations for different machining conditions (f=0.2 mm/rev, after 200 holes)

It can be seen that the smallest surface roughness values were obtained with ESL machining, followed in an increasing order, by the application of MQL and dry machining. As is well known, the surface finish is largely depends upon the sharpness of the cutting edge during machining operation apart from feed and other conditions. So, with the application of ESL and MQL, the drastic reduction of surface roughness values attributed to the reduction of tool wear under these two conditions. This is due to the fact that penetration of the cutting fluid with fluid additives into the interface can reduce the frictional contribution and also penetration of the fluid through the mass of the chip can influence chip curl and the primary deformation process. Through high-pressure injection the fluid is fragmented into tiny droplets the size of which is inversely proportional to the pressure of injection [13]. The velocity varies as a function of the square root of the injection pressure. This high velocity facilitates better penetration of the cutting fluid on impact to the root as well as the underside of the chip facilitating its passage to the tool–chip interface resulting in the reduction of friction. Such a condition is not possible in conventional wet machining where no such fragmentation is taking place and the kinetic energy of the fluid jet is in no way comparable to that during fluid injection. Further, in comparison with ESL machining, MQL machining presented slightly higher surface roughness values. This indicates that the surface roughness does not depend on the flank wear alone. The reduced cutting temperature caused by cooling air (MQL) made chip formation and shearing of the hardened steel material difficult and hence higher surface roughness values obtained when machining SCM 440 steel material under MQL condition. This substantiate the results obtained with ESL technique in case of tool wear and hole quality.

CONCLUSIONS

The overall performance during Electro Static Lubrication (ESL) is found to be superior to that during MQL and dry machining on the basis of tool wear and hole quality (hole diameter and surface roughness). ESL presented 80% and 12.5% improvement in tool life over dry machining and MQL respectively. The surface roughness values obtained with ESL were lower that those obtained with MQL and dry machining. The details presented in this paper can form a scientific basis for developing commercial ESL system considering the stringent environmental regulations on the shop floor. Hence, it was concluded that, this technique (ESL system) can form a viable alternative to conventional wet machining, as it can be implemented without drastic alterations in the existing facilities on the shop floor.

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