An Innovative Green Cooling Approach Using Peltier Chip in Milling Operation for Surface Roughness Improvement

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Abstract**—**Surface roughness is one of the key quality parameters of the finished product. During any machining operation, high temperatures are generated at the tool-chip interface impairing surface quality and dimensional accuracy of products. Cutting fluids are generally applied during machining to reduce temperature at the tool-chip interface. However, usages of cutting fluids give rise to problems such as waste disposal, pollution, high cost, and human health hazard. Researchers, now-a-days, are opting towards dry machining and other cooling techniques to minimize use of coolants during machining while keeping surface roughness of products within desirable limits. In this paper, a concept of using peltier cooling effects during aluminium milling operation has been presented and adopted with an aim to improve surface roughness of the machined surface. Experimental evidence shows that peltier cooling effect provides better surface roughness of the machined surface compared to dry machining.

Keywords**—**Aluminium, surface roughness, Peltier cooling effect, milling operation.

I. Introduction

IN different machining process, the surface finish is a key issue in assessing and determining the value of a part. During machining, high friction between tool and workpiece results in high temperature generation at the tool-chip interface [1]. This high temperature is detrimental for the surface quality and dimensional accuracy of products. Generally, different types of cutting fluids are applied during machining to reduce tool-chip interface temperature. Around 16-20% of total manufacturing costs are due to usage of coolants and lubricants [2]. From the environmental point of view, dry machining is the best solution. It provides the advantage of non-pollution of environment, no waste disposal problem, no health hazard of the machine operator and it reduces manufacturing costs significantly [3]. However, dry machining is yet to achieve the level of beneficial effects that cutting fluids provide. For this reason, in order to keep the surface roughness within required limits, researchers are looking for dry machining and other alternative cooling techniques. In general, dry machining leads to more friction and adhesion between the tool and workpiece resulting in higher cutting zone temperatures, causing increased tool wear and poor surface quality. Higher cutting zone temperatures also produce ribbon-like chips, affecting dimensional accuracy of the machined surface [2]. Chip evacuation is also a problem in dry machining [4]. Sreejith [5] studied the effects of dry machining, minimum quality lubricant and flood coolant conditions on surface roughness, tool wear and cutting forces. The results revealed that, for machining at high cutting speeds, minimum quality lubricant conditions and dry machining provide satisfactory and acceptable performance. Klocke and Eisenblatter [6] mentioned a number of successful cases of dry machining of steel, cast iron, aluminium, titanium, and some superalloys. However, significant built up edges on tools were observed, which is undesirable. Aluminium and its alloys are one of the most critical materials when it comes to dry machining [2]. Due to their high thermal conductivity, heat absorption during machining is high. They also incur problems related to chip formation and deformation due to their high thermal expansion capability. In this paper, a new concept of peltier cooling effect during aluminium milling has been proposed and adopted with an aim to improve surface roughness of the machined surface. Peltier effect refers to the cooling and heating of two electrified junctions when an electric current is passed between two dissimilar conductors. Experimental results show that peltier cooling effect provides better surface roughness and surface temperature of the machined surface compared to dry machining.

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II. Working Principle of Peltier Chip

Peltier chips have positive and negative sides which are connected to the battery via wire. It contains different ceramic plates at upper and lower side. Inside the peltier, square shaped thermoelectric N, P elements are available which can produce a temperature difference in each block (Fig. 1). Basically, peltier elements are solid-state devices with no moving parts; they are extremely reliable and do not require any maintenance. When a voltage (12 V) is applied, the peltier chip creates temperature difference in both sides by reverse thermoelectric cooling process. In thermo-electric process, temperature differences at two side of wire are applied and a voltage is obtained as output. DC voltage is applied to the peltier chip (reverse thermo-electric process). As a result, one side of the peltier chip becomes cold, whereas the opposing side becomes hot. As the voltage is higher, the temperature difference becomes higher. It can make 15 to 18 °C temperature difference on its two sides. This paper shows the way to reduce the hot side temperature and to utilize the cold side temperature to decrease the cutting zone temperature.

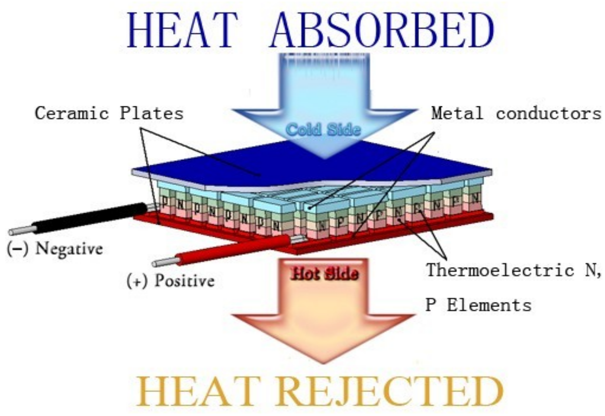

Fig. 1 Peltier chip working function

III. Methodology and Experimental Setup

In the designed experimental set up three basic components are needed for peltier cooling namely- peltier chips, a 12-V battery and salty ice. Theoretically if more voltage is applied to the peltier chips it can produce more temperature difference between hot and cold surface of it. But, in the market only, 12V peltier chips are available, that is why 12-V battery is used to meet that procurement. In case of industrial purpose, it can be modified by the manufacturer to have more efficient product. Beside some amount of salt was mixed with the ice.

The purpose of mixing salt with ice is- salt can increase the melting time of the ice. Thus, this characteristic is used to decrease the melting time of ice. The ice must be provided in a container. Experimental set up was taken as- the peltier chips was connected with the 12-V battery. Then, the hot and cold sides of the peltier chip should be identified, simply by touching two sides. Next, the cold side of the peltier chip has to put on the surface of the work piece to be cut. At the hot side, the salty ices on container should be put on to decrease the hot side temperature. After setting up all of these, the machining operation can be done. During the operation, a clearance must be maintained between peltier chips and cutting tool.

During the operation, the temperature was measured by the laser temperature detector. The laser temperature meter can measure the temperature from several distances to the cutting zone. After completing the operation at different cutting conditions, the surface roughness has been measured by the surface roughness tester. Experimental parameters are shown in Table I.

TABLE I
Experimental Parameters

Rotational Speed (RPM)	Depth of Cut (mm)	Tool Diameter (mm)
400, 500, 600, 700, 800, 900	0.5, 1.5, 3.0	8

Surface roughness can be explained by the deviation or the bifurcation of the surface vector from its real value. If the deviation of the surface is more than the real or base line, then the surface is rough, and if it is smaller, then the surface is smooth. Basically, roughness is just opposite to the smoothness, is the component of surface texture, and also consists of the waviness and lay. Surface roughness can be measured by the roughness meter. Figs. 2 and 3 show a sample view of experimental setup and surface roughness meter used in this experiment to measure the surface roughness.

Fig. 2 Experimental setup

Fig. 3 Roughness meter used to measure surface roughness

IV. Experimental Results

All the experiments were done to meet the manufacturer needs. During the experiment, the feed was kept constant, and at different cutting conditions as listed in Table I, the surface temperature and surface roughness were measured in both peltier worked machining and without peltier machining (dry machining).

A. Roughness Analysis

Effect of RPM on Surface Roughness: Roughness can be varied at different RPM during machining. During the experiment, the roughness was measured in both with and without peltier. Fig. 4 shows the variation of surface roughness at different RPM with and without peltier based cooling work. It has been observed that, at a certain depth of cut, surface roughness is going to be improved compared to dry machining. At 900 rpm, the measured surface roughness in dry machining is more than 6 µm, whereas keeping the same process parameters with the application of peltier backed cooling processes the surface roughness becomes less than 3 µm. This clearly indicates the surface improvement in aluminum machining more than 50%. During the experimentation, it has also been observed that some of the milling cutter at certain process parameters suddenly broke because of built up chip formation and melting of the chip adhering with the cutting tools, but with the same conditions the phenomenon is clearly eliminated in proposed peltier backed cooling process.

B. Effect of Feed on Surface Roughness

In Fig. 5, the effects of depth of cut on surface roughness at various conditions for dry machining and peltier chip cooling were shown. It has been observed that, in all conditions, the surface roughness for peltier cooling conditions showed better results compared to dry conditions machining. Also in high RPM, the value of the surface roughness significantly improved with peltier cooling compared to dry machining. So, it is a huge advantage for the manufacturer.

C. Image Analysis

Figs. 6 and 7 show that the surface profile with peltier cooling effect is more reliable than the normal condition. From the photographic evidence, it has been observed that, in all conditions with the variation of depth of cut and RPM, the surface conditions are better in the proposed method than the dry cutting conditions. Machined surface roughness in peltier cooling process is almost same with the machined surface process using cryogenic cooling process. Although in cryogenic cooling, the surface roughness is slightly smoother, but the cost of cryogenic cooling is almost 250% more than the peltier worked. Comparatively, the surface roughness is not so high in the peltier cooled machining with respect to its cost.

If dry machining is used at high depth of cut and high RPM cutting conditions, the temperature at the cutting zone becomes so high. This may cause the melting of machined surface and cutting chips of low melting point temperature; as a result, metal melts down and stuck to the cutting tool. That causes the damage of the cutting tool. But, in the proposed method, this type of problems has been eliminated, and better surface profile has been achieved.

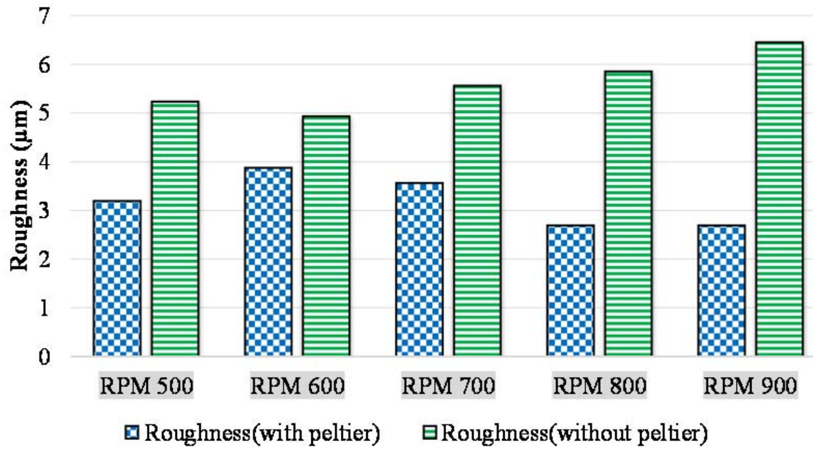

Fig. 4 Histogram of surface roughness vs RPM at depth of cut 3.0 mm

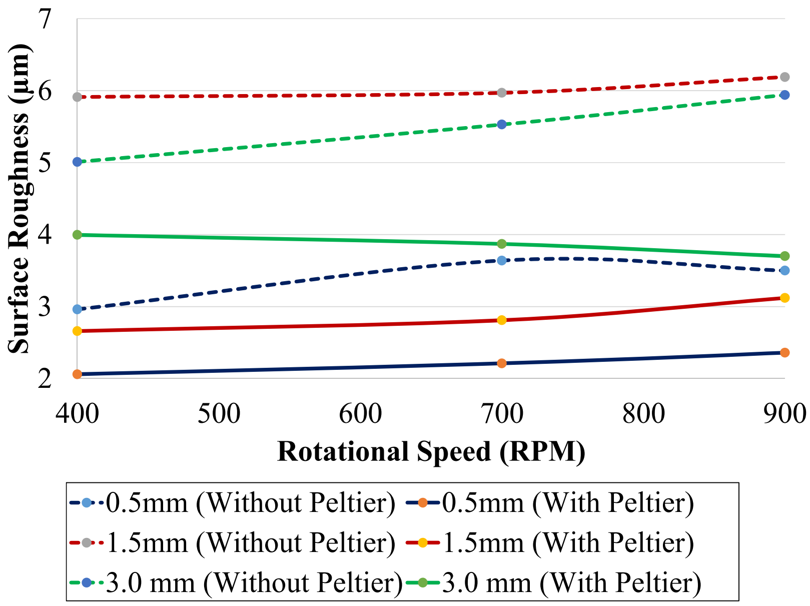

Fig. 5 Variation of surface roughness for different depth of cut with and without peltier

Fig. 6 Surface images after machining with and without peltier chip at 3.0 mm depth of cut

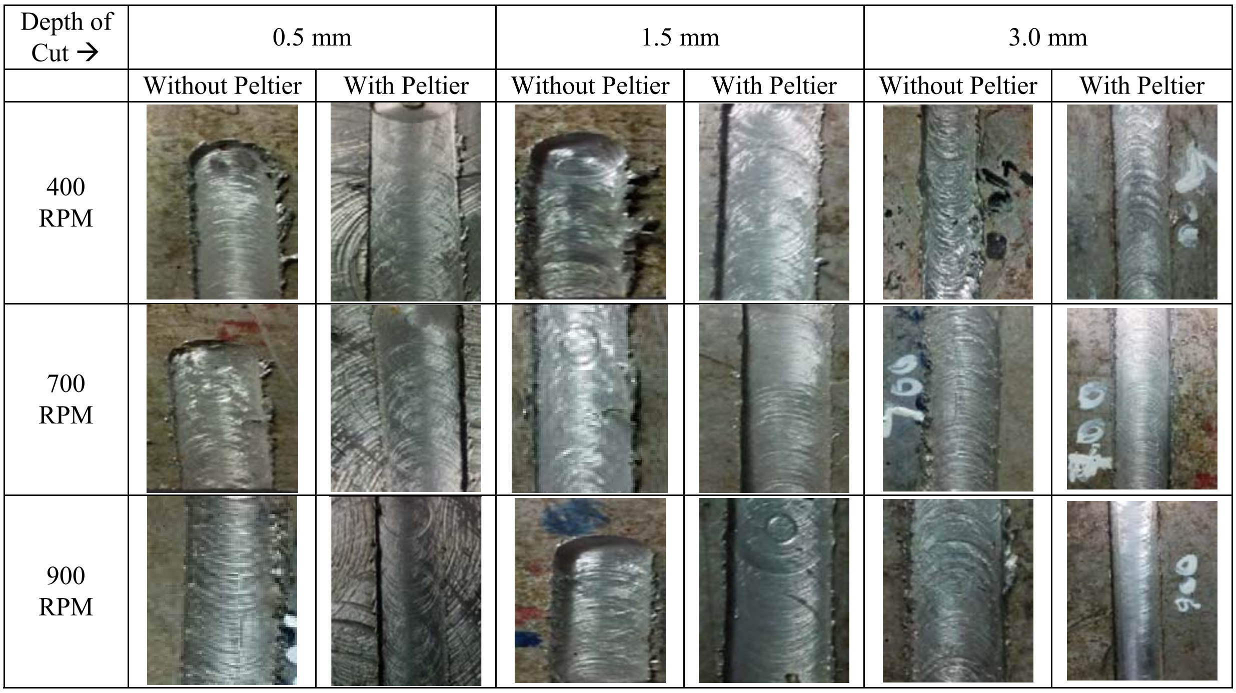

Fig. 7 Surface images after machining with and without peltier chip at different depth of cut

V. Conclusion

This investigation shows that the peltier cooling effect can be used as an alternative way to conventional coolant to improve the machinability of different materials used in CNC milling. Most significant interactions were found between work materials, cutting zone temperature, surface roughness, and cutting parameters. Studies documented in different sections suggest that the peltier effect has demonstrated vast promising results to improve the machinability of difficult-to-machine materials in milling operation. Experimental investigations also explored that peltier cooling is an effective method to eliminate the use of cutting fluids and to maintain the surface smoothness of the machined parts. Therefore, peltier cooling effect can be established as a new tradition to improve machinability. According to the data collection, it is clearly observed that, with the increase in RPM, it tends to improve the roughness, and more than 50% improvement can be achieved using the peltier cooling approach compared to dry machining. Interestingly, the optimal combination process parameters for minimum surface roughness are obtained at high RPM in case of the proposed method compared to the others.

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