Electrostatic Cooling System as Environmentally Conscious Cooling Technique: A Review on Its Potentials for Machining Processes

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Electrostatic Cooling System as Environmentally Conscious Cooling Technique: A Review on Its Potentials for Machining Processes

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Abstract

The use of excessive cutting fluids in machining has significantly improved the productivity and quality of machined parts. However, its negative effects on the manufacturing cost, health, and environment raise the need for alternative cooling technique. Electrostatic cooling technique, in which ionized airflow or very fine droplets of lubricant or coolant are generated through electrostatic charging, has positive notion on the environment, health, and safety. This mini review paper provides overview on the assessment of electrostatic cooling system in terms of machining responses, towards proposing its use as an environmentally conscious cooling technique.

Keywords: *Electrostatic cooling system, environmentally conscious, machining processes*

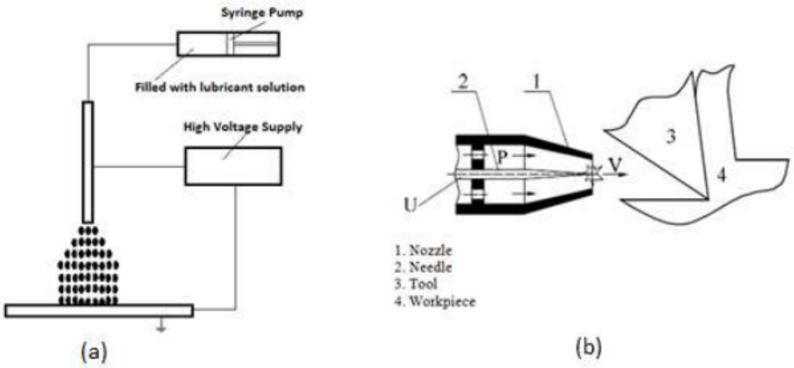
1. Introduction

One of the challenges of manufacturing industry today is how to reduce the use of metal working fluids. It was well understood that the use of cutting fluids in machining has significantly improved the productivity and quality of machining parts. However, the negative effects of cutting fluids on manufacturing cost, human health, and environment have raised alarming signal to the machining industries (Adler *et al.*, 2005; Boubekri *et al.*, 2010; Byers, 2006) These issues have motivated many researchers to look for alternative coolants and cooling techniques in replacing the excessive use of cutting fluids.

One of the alternatives currently under investigation is the application of electrostatic cooling machining. Electrostatic cooling machining uses ionized droplets or airflow for lubrication and cooling medium to assist the machining process. This technique is reported to have positive impact on the environment and can tackle the health and safety issues (Gao *et al.*, 2012; Liu *et al.*, 2011; Reddy *et al.*, 2010; Wang *et al.*, 2010). As such, the advantage of environmentally conscious is being addressed. Nevertheless its performance as an alternative cooling strategy for machining processes was less reported. This mini review aims at assessing the performance of this cooling system with respect to machining responses such as tool life, tool wear, cutting force and quality.

2. Principles of Electrostatic Cooling System

Electrostatic cooling system is generating very fine liquid aerosol of lubricant or coolant through electrostatic charging, with the cutting tool as the target by being neutral (Reddy and Yang, 2009). The lubricant or coolant used in electrostatic cooling system can be in the form of solid, liquid, or gas. For solid lubricant, the particles should be dispersed into solution. The solution or liquid is transformed into droplets in the electro spray. It is passed through a nozzle and is then electrically charged to a very high voltage. The charged liquid in the nozzle becomes unstable as it is forced to hold more charges. As the liquid reaches a critical point, at which it can no longer hold electrical charge, it blows apart into a cloud of tiny, highly charged droplets from the tip of the corona discharged nozzle as shown schematically in Fig. 1



(a) (b)

Fig.1 Schematic view of corona discharge nozzle from electrostatic cooling system (Liu *et al.*, 2011; Reddy and Yang, 2009)

Reddy, et al. (2010) developed this type of solid electrostatic lubrication system for drilling AISI 4340 (Fig. 2). In the system, a negatively charged lubricant solution is attracted to a neutral, grounded object which is the cutting tool. The plume of droplets is generated by electrically charging the liquid at high voltage into a cloud of charged droplets and then sent to cutting area through the nozzle.

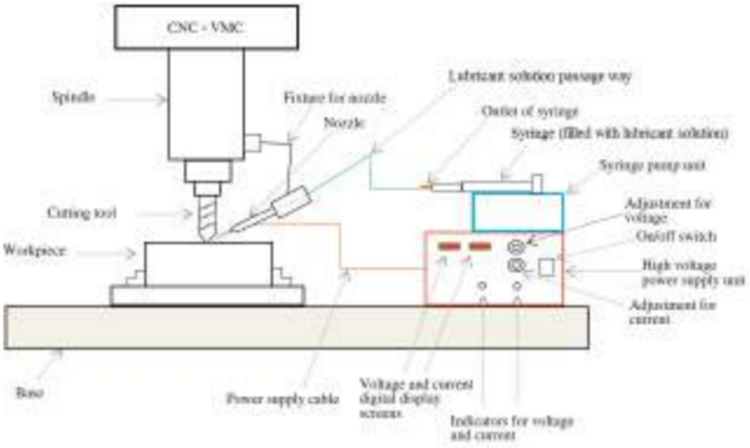


Fig. 2 Schematic diagram of the solid electrostatic lubrication experimental setup (Reddy *et al.*, 2010).

For gaseous coolant, corona discharge is used to generate ionized airflow. The gas molecules near the corona discharge region become ionized when a high intensity electric field is applied between a high tip corona electrode and a low tip collector electrode (i.e. the cutting tool). The ionized gas molecules travel towards the collector electrode, colliding with neutral air molecules. During these collisions, momentum is imparted from the ionized gas to the neutral air molecules, resulting in the movement of gas towards the collector electrode as shown in Fig. 3.

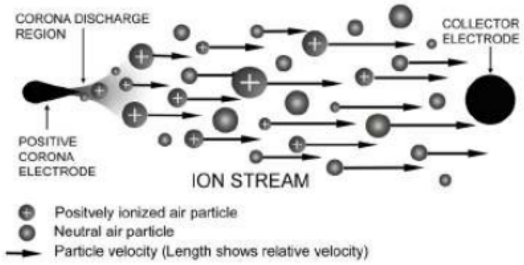


Fig. 3 Cloud of tiny, highly charged particles, where a high voltage is applied between the corona and collector electrodes. (Larsen *et al.*, 2008)

Liu, et al., (2011) developed a dry electrostatic cooling system (DESC) as shown schematically in Fig. 4. The compressed air consisted of charged ions and ozone molecules. The air treated by the corona discharge contain great amount of active species (O, O3, H+, O-, HO-, etc.). These active species flow towards the cutting zone with high temperature and decrease the surface energy of the workpiece. They are then absorbed by the friction interface between the tool-workpiece and tool-chip interfaces and combine with its chemical bond to form some boundary films which can play a role of lubrication. The ozone, oxygen and kinds of active charged particles existing in the ionized air have strong oxidizability. This and the flow of stronger air make the speed of surface passivation higher than that of conventional cutting fluid.

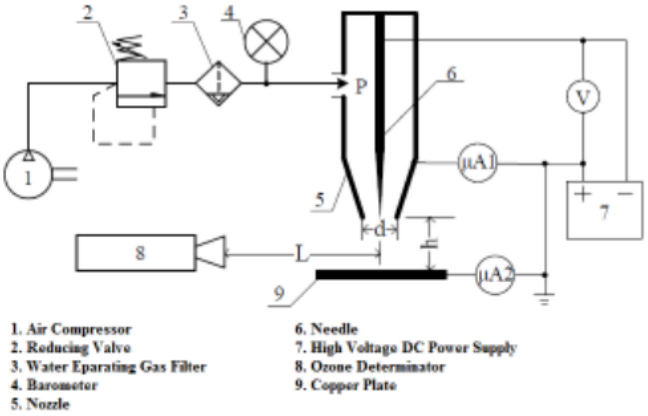


Fig. 4 Schematic diagram of the dry electrostatic lubrication experimental device (Liu *et al.*, 2011).

3. Performance of Electrostatic Cooling System

3.1. The Effect of Electrostatic Cooling on Tool Wear

In turning of tool steel (Liu *et al.*, 2011), improvements in tool life of up to 1.5-3.3 times was achieved when dry electrostatic cooling system was used as compared to dry machining process (Fig. 5).

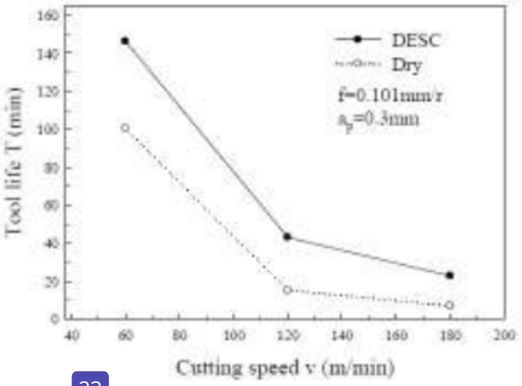


Fig. 5 The influence of the cutting speed on the tool life (Liu *et al.*, 2011)

Another similar finding was also reported (Reddy *et al.*, 2010) when dry electrostatic cooling system was used in machining AISI 4340 steel where tool life was increased by more than 66% (Fig. 6).

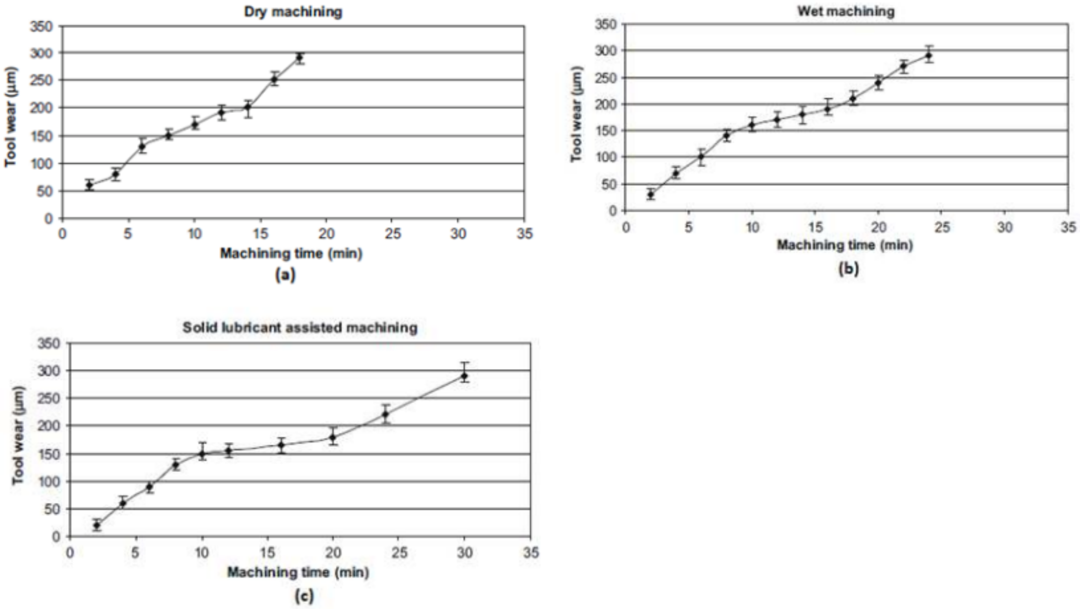


Fig. 6. Tool wear with machining time under wet, dry and solid electrostatic lubricant system (Reddy *et al.*, 2010).

Wang et al. (2010) applied dry electrostatic cooling in machining titanium alloy Ti6Al4V and found at cutting speed 120 m/min tool wear decreased almost 30% compared to dry turning (Fig. 7). Better results in tool life are achieved when decreasing the cutting speed.

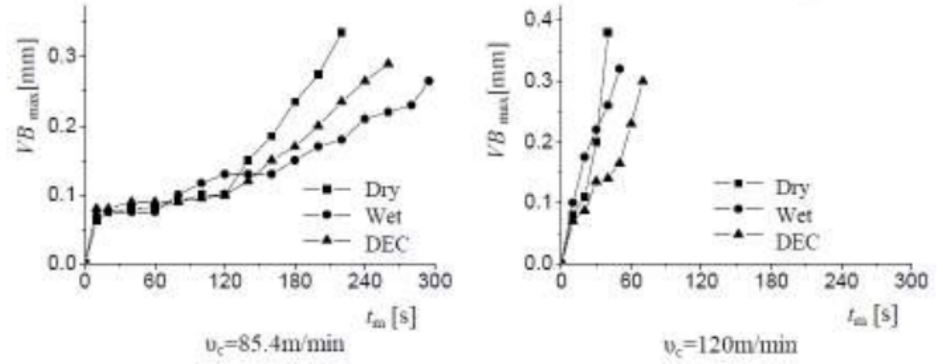


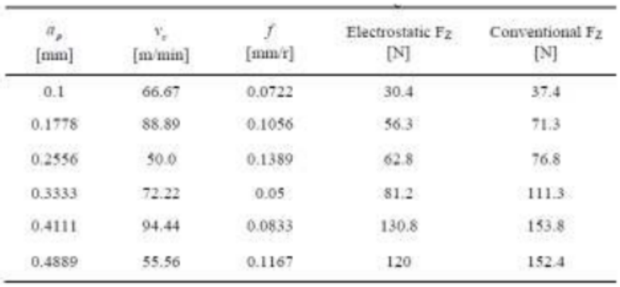
Fig. 7 Flank wear with time as affected by coolant technique (Wang *et al.*, 2010).

These showed that electrostatic cooling technique was capable of reducing wear rate and increasing tool life when used for machining steels and titanium alloy. This was because the emulsion and electrostatic played the roles of cooling and lubricating. The injection of ionized air jet contains a large number of ions and ozone molecular generated in discharge, the ozone could easily penetrate into tool-chip interface and developed lubrication films due to the strong oxidation. As a result, the friction area was reduced; the cutting temperature and tool wear decreased.

3.2. Effect of Electrostatic Cooling on Cutting Force

Gao et al. (2012) studied electrostatic cooling when turning titanium alloy TC11. Through the tests, the cutting force and surface roughness data from both machining using conventional and electrostatic cooling techniques were recorded as listed in Table 1. It was found that under dry electrostatic cooling cutting conditions, the cutting force was smaller and the fluctuation of cutting force was less than when conventional cooling was applied.

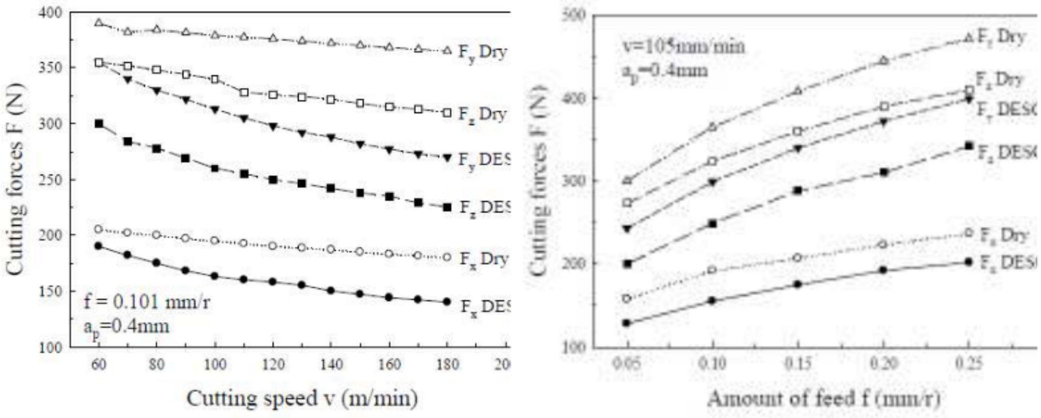
Tabel 1. Two conditions cutting force (Gao *et al.*, 2012)



a_p [mm]	v_c [m/min]	f [mm/r]	Electrostatic Fz [N]	Conventional Fz [N]
0.1	66.67	0.0722	30.4	37.4
0.1778	88.89	0.1056	56.3	71.3
0.2556	50.0	0.1389	62.8	76.8
0.3333	72.22	0.05	81.2	111.3
0.4111	94.44	0.0833	130.8	153.8
0.4889	55.56	0.1167	120	152.4

Similarly, Liu, et al., (2011) found that machining of tool steel under dry electrostatic cooling; the cutting force was smaller than when dry machining was performed. It was also found that the differences of cutting force increase as cutting speed increases (Fig. 8(a)).

Thus, in term of cutting force, application of electrostatic cooling system shows its advantages by inducing lower cutting force and less fluctuation compared to dry and wet machining.



(a) (b)

Fig. 8 The curve of the cutting force against rising cutting speed and feed (Liu *et al.*, 2011)

3.3. Effect of Electrostatic Cooling on Geometrical Accuracy

In drilling the main concern that the heat generated by the process can lead to thermal expansion of the drill, affecting the size (tendency to oversize) and quality of the holes (Reddy *et al.*, 2010). When electrostatic cooling using solid lubricant was performed, it was observed that the standard deviation of average diameter obtained is lower than that obtained using wet and dry conditions (Fig. 9). This improvement was perceived due to its lattice layer structure that allows it to act as an effective solid lubricant film. Thus, in term of geometrical accuracy, electrostatic cooling offers the advantage of more precise machined workpiece.

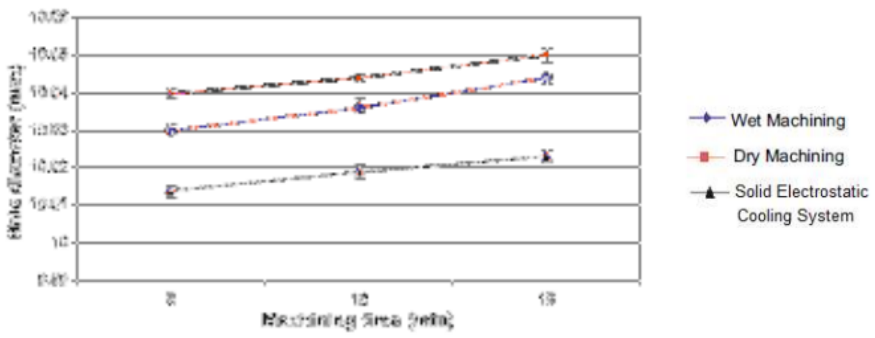
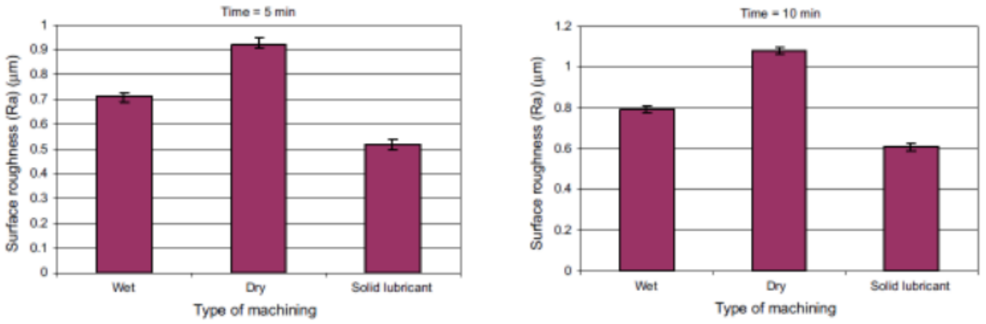


Fig. 9. Variation of hole diameter with machining time under wet, dry cutting, solid electrostatic lubricant cutting. (Reddy *et al.*, 2010).

3.4. Effect of Electrostatic Cooling on Surface Finish

Surface roughness is a widely used index of machined workpiece quality and a technical requirement for mechanical parts. A report comparing electrostatic cooling by solid lubricant with wet and dry machining processes on AISI 4340 steel revealed that the surface roughness was less by an average of 23% and 41% during solid electrostatic lubricant system as compared to wet and dry machining, respectively (Reddy *et al.*, 2010). This phenomenon was due to the lubricating action of the solid lubricant, causing reduced frictional forces between the tool and workpiece, which were still effective even at high temperatures during machining.



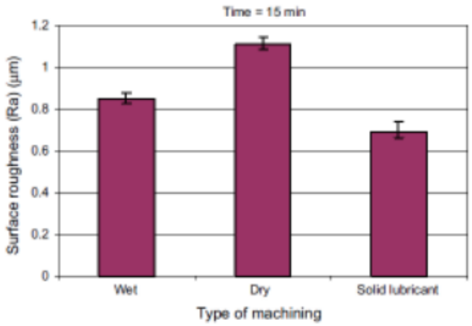
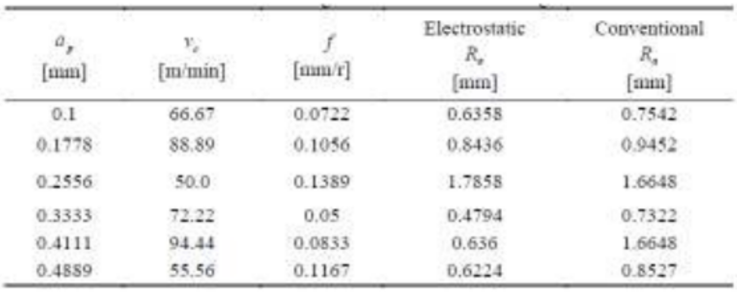


Fig. 10 Variation of surface roughness diameter with machining time and different machining types (Reddy *et al.*, 2010).

For machining titanium alloy, electrostatic cooling system was also reported resulting better surface finish compared to conventional cooling system (wet machining) and results as shown in Table 2 (Gao *et al.*, 2012). Again, electrostatic cooling showed its merit in machining tool steel and titanium alloy in term of surface finish.

Tabel 2. Two conditions of surface roughness (Gao *et al.*, 2012)



a_p [mm]	v_c [m/min]	f [mm/r]	Electrostatic R_a [mm]	Conventional R_a [mm]
0.1	66.67	0.0722	0.6358	0.7542
0.1778	88.89	0.1056	0.8436	0.9452
0.2556	50.0	0.1389	1.7858	1.6648
0.3333	72.22	0.05	0.4794	0.7322
0.4111	94.44	0.0833	0.636	1.6648
0.4889	55.56	0.1167	0.6224	0.8527

4. Concluding Remarks

This study reviews the performance of electrostatic cooling technique in machining of steel and titanium alloy. In terms of tool life, cutting force, geometrical accuracy, and surface roughness, this environmentally conscious cooling technique outperforms dry and conventional wet cooling techniques. Literatures on its use for other workpiece materials are still lacking. Considering its advantages, research on machining of other worpiece materials using electrostatic cooling system is worth pursuing in search of alternative cooling technique.

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