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EXPERIMENTAL AND PERFORMANCE OF GREEN MACHINING: A SHORT REVIEW

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Abstract: Green machining is an environmental friendly metal removal process. There are few machining processes which can be categorized as green, such as Minimal Quantity Lubrication (MQL), dry machining and water mist jet cooling. This paper discussed the advantages and disadvantages of all green machining method. MQL that uses vegetable oil as lubricant is proved to be effective in reducing tool wear and small amount of wastage is produced. However, lubricant that penetrates cutting zone evaporates into tiny particles which can be hazardous to the workers. Mist collector is required to filter off the tiny particles. Dry machining is safe to both workers and the environment, but the high tool wear rate is not very economical especially when high speed machining. Water mist jet cooling reduces tool wear more effectively compared to flood machining and dry machining and maintains reasonable tool life. Reasonable tool life is more practical in industries as it involves high cost in tooling.

Keywords: Minimal quantity lubrication, dry machining, water mist jet cooling

Introduction

Green machining gradually becomes an aim for most manufacturing processes in these modern days, especially when the environmental issues are getting more attention and important. Initial researches (Debnath *et al.*, 2014; Dhar and Ahmed, 2007; Sreejith and Ngoi, 2000) of green machining focused on greatly reducing the amount of lubricant used which lead to the idea of MQL which will also greatly reduce the manufacturing cost as cutting fluid comprise 17% of it (Jia *et al.*, 2017). This machining technique has been proved by many researchers (Bulatov *et al.*, 1997; Deglurkar *et al.*, 2008; Goldberg and Welter, 2007) that it can improve machining process while avoiding large amount of wastage generated by that of conventional flood machining. However, removing or filtering the mist particle generated by oil/lubricant used has been a challenge for MQL to ensure the health of operators and safety of the environment. The work of (Fratila, 2009) discovered the drawbacks of these mist particles which can result in respiration and skin problems. Prior to the green issues, later (Zeng *et al.*, 2005) have reviewed the applicability of vegetable based oil/lubricants in machining ferrous metals. The reported results show that vegetable based oil/lubricants can achieve better cutting performance than mineral oil in machining ferrous metals. An increase of 117% in tool life and reduction of 7% in thrust force was reported but these are work piece dependent. On the other hand, extensive work of (Lawal *et al.*, 2009) have successfully developed dry machining as a resolution to environmental issues in metal cutting. Unfortunately, it is less efficient especially in machining of super alloy materials such as nickel based and titanium alloys, where higher cutting speed and surface quality are required because of their mechanical strength and resistance to surface degradation. Dry machining is not favourable in cutting super alloy materials as it is not cost effective and high cutting temperature can lead to undesirable surface finish. Consequently, researches advance the development cooling system of machining into water mist jet cooling. Water mist jet cooling applies water vapour as coolant and lubricant into cutting zone. This system implements the same mechanism of MQL but the cutting fluid is water. Water is accelerated by high pressure through a small diameter nozzle penetrating the cutting zone with fine water particles for optimum effect of cooling and lubricating. This is the latest milestone of green machining. Lately, few researches like (Fonda *et al.* 2008) and (Shchedrin *et al.*, 2008) have proven a very encouraging results in improving the cutting performance compared to other cooling techniques. However, more researches need to be done to have major understanding of the system in increasing tool life for all types of machining process (turning, milling, and grinding) which was the major reasons of this article.

Minimal quantity lubrication (MQL)

MQL, which is also known as "Near-dry Machining" (Tawakoli *et al.*, 2009), is the economical and practical metal working fluid delivery technique to cutting zone. Initially this technology is introduced to resolve the main environmental problem caused by flood machining which produces large amount of cutting fluid to the environment. This technology implements the idea of extremely low consumption of cutting fluid (< 80 ml/h) while maintain the main purpose of cutting fluid: cooling and lubricating the tool and work piece for required cutting performance. Enforcement from the authorities such as the U.S. Occupational Safety and Health Administration (OSHA) and the U.S. National Institute for Occupational Safety and Health (NIOSH) also leads to the development of MQL (Astakhov, 2008). They reported that the permissible exposure level (PEL) for metal working fluid aerosol concentration is 5 and 0.5 mg/m^3, respectively (Kalita *et al.*, 2012). Thus, in MQL, cutting fluids are selected based on their secondary characteristics instead of their primary benefits to cutting performance. Secondary characteristics include their safety properties (environment pollution and human contact), biodegradability, oxidation and storage stability (Carou *et al.*, 2015). These are important as the cutting fluid has to be environmental friendly and does not change in their chemical composition naturally in long term (Baloch, 2014). Milling process under MQL as depicted in Fig. 1.

Fig. 1: Milling process under MQL (Duchosal *et al.*, 2013)

In comparison with flood machining, MQL has several significant advantages (Barczak *et al.*, 2010). The most obvious advantage is the reduction of cost in cutting fluid. Consumption of cutting fluid which is less than 80 ml/h not only greatly reduces the cutting fluid cost but also reduces the cost needed to manage or eliminate the large amount of waste discharged from that of wet machining. Furthermore, the produced chips are in dry condition indicating the omission of cutting fluid recycling cost. Despite the minimal quantity of oil, reduction in tool's friction and prevention of adherence of material are still satisfactory. Lubricating effect is dependent on oil while the cooling effect is brought by the compressed air. MQL also reduces induced thermal shock and improves surface integrity of work piece when high tool pressure is used (Hadad and Sadeghi, 2013).

Dry machining

Dry machining is also considered as green machining as it totally eliminates the use of cutting fluids. This is the most common technique in machining process because it is inexpensive as no extra cost needs to be invested in the cooling system. However, tooling cost can be very high due to low tool life, especially when machining super alloy materials. Super alloy materials, also classified as difficult-to-cut materials, have exceptional high strength-to-weight ratio at high temperature, corrosion resistance, and longer service life. They have low thermal conductivity and chemical reactivity and relatively low modulus of elasticity (Sreejith and Ngoi, 2000). Most mechanical energy in machining process is converted into heat form and generates high temperature in cutting zone. Due to low thermal conductivity of these materials, 80% of the heat generated in the region conducts to cutting tool. As a result, tool wear rate is high. Rapid tool wear yields poor surface finish which is unwanted (Sreejith and Ngoi, 2000) and (Kaynak, 2014). Hence, there are three different ways to counteract the adverse situation of dry machining: using new tool materials, adapting new tool geometries, and applying coating materials on tool. The last solution is usually being implemented to give better tool life. Initial development in coating technology was coating of carbide tools using Chemical Vapour Deposition (CVD) technique (Gomez *et al.*, 2012) . Coating materials for instances, TiN, TiC and Al2O3, play an important role as a protective agent against abrasion, corrosion and oxidation wear on the surface of the tool. However, the effect of coating material is still uncertain on machining of titanium alloys due to their chemical reactivity (Jia *et al.*, 2017). The development of dry machining technology is still yet to be competitive enough to produce better tool life and cutting parameters, especially in machining of titanium alloy with high speeds as higher productivity is much preferable.

Water mist jet cooling

Despite of the invention of MQL, latest researches move the green cutting technology into whole new different era. Water mist jet cooling was introduced as new green cutting technology using the concept of mist application of cutting fluid which is similar to MQL. Mist application of cutting fluid indicates the minimisation of lubricant/coolant, thus, it is economically beneficial. Moreover, the usage of water as cutting fluid clears doubt on the environmental friendliness of this technique.

The work of (Knowles *et al.*, 2007) have successfully developed a water mist jet cooling system and tested on turning operations of mild steel using Tungsten carbide and High speed steel tool. He applied high pressure (60 to 70 bar) to create water mist after passing air through micro nozzles. He compared the cutting force, cutting temperature and roughness from dry machining, flood machining and water mist jet cooling. Comparable low cutting temperature and surface roughness as well as average cutting force were obtained from water mist jet cooling if compared to dry machining and wet machining. The aim of this technology is to replace the use of oil coolants with supersonic water mist jets in machining processes. It was claimed that it can provide economic and efficient cutting operations upon super alloy materials and applicable to all machining operations (turning, grinding, milling, boring, reaming, etc.). The characteristics of this green cutting technology are:

i. Use of pressurised water for mist generation
ii. High efficiency
iii. Employability on metals
iv. Environmental friendliness

Another research done (An *et al.*, 2011) shows appealing results too using cold water mist jet cooling, as shown in Fig. 2 and 3. They applied this technology on turning of TC9 titanium alloy. A very small amount of 0ºC water is pushed through the nozzle by high speed cold air at -20ºC and penetrates the cutting zone in the form of mist jet. A higher efficiency of cooling effect in the cutting zone has been achieved. Results showed relatively lower cutting temperature and tool life than that of cold air jet and flood cooling.

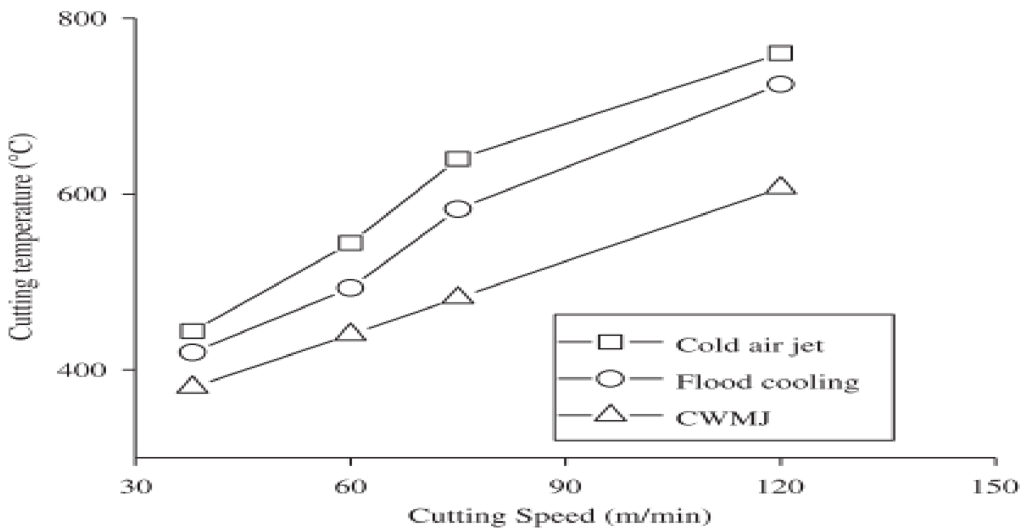

Fig. 2: Cutting temperature under different conditions (An *et al.*, 2011)

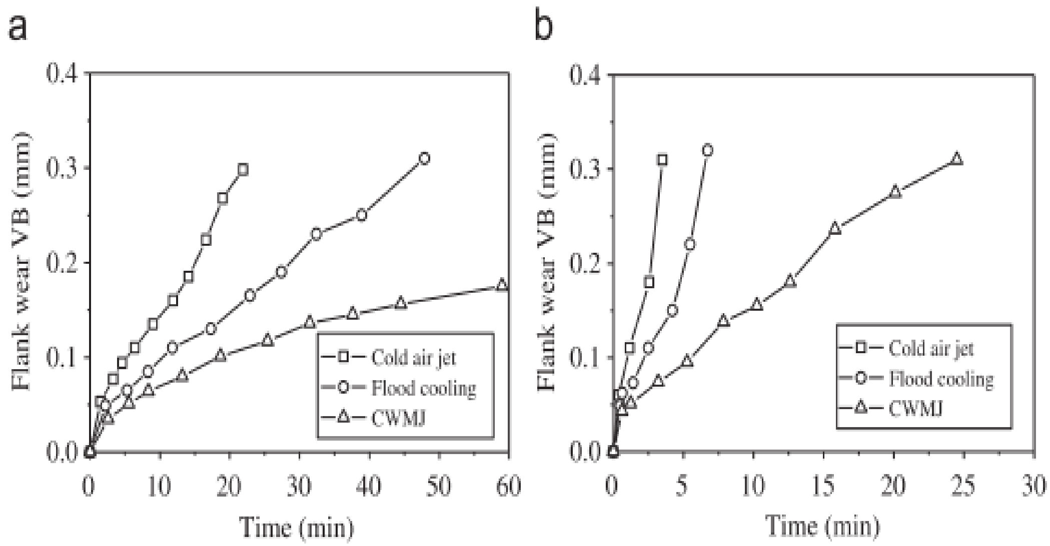

Fig. 3: Flank wear curves of cutting inserts under different cooling conditions, cutting Speed, *Vc* = (a) 38 m/min (b) 120 m/min (An *et al.*, 2011)

Water mist jet cooling gives very promising outcome in reducing cutting tool temperature and tool wear rate. However, limited number of researches had been done on this field for more compromising evidence and understanding of its cooling and lubricating characteristics.

Summary and Conclusion

Findings from the previous researches done on green machining conclude that among the discussed cooling methods in the machining process, MQL is a developed technology on effectively improves machining performance. However, the by-products (oil vapor, mist, and smoke) produced by MQL have to be filtered completely for a safe working environment. Application of vegetable based oil for MQL could solve the problem, but its stability of storage has to be investigated in the first place. Dry machining is not preferred in most cases as it produces high cutting temperature leading to low tool life which is not economical. The latest cooling method, water mist jet cooling, on the other hand, appears to have better cutting performance than other cooling methods.

Conflict of Interest

The authors declare that there is no conflict of interest.

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