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Environmental impacts and hazards associated with metal working fluids and recent advances in the sustainable systems: A review

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ABSTRACT

A review of advances in the use of lubrication techniques during machining operations as well as the application of state-of-the-art nanofluids in machining is presented in this research article. A brief review of the available literature on the environmental impact and the health hazards associated with metal working fluids is also included. The performance and drawbacks of different techniques are discussed in terms of machining parameters and output variables. The review of different lubrication techniques finally ends up in the favor of minimum quantity lubrication and cooling technique as a potential alternate to flooded and conventional cooling conditions in different machining processes in terms of dealing with the ecological, social and human health concerns and the finances coupled with the use of metal working fluids in machining processes.

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1. Introduction: cutting fluids in sustainable manufacturing

With the increasing demand of using sustainability as the business and economic practice, the manufacturing units all over the world are now adopting the notion of sustainable manufacturing. Sustainable manufacturing is a subset of the broader philosophy of sustainable development [155]. Sustainable manufacturing appends worth to materials, components, or products while maintaining the availability of natural resources and environmental quality for future generations [244]. Sustainable manufacturing can also be defined as the production of sustainable goods through the use of sustainable manufacturing practices [191]. In sustainable manufacturing, lean concept as well as a broad range of societal gages such as operational safety, personal health necessities and environmental issues, are included. Since all the three sustainability components i.e. environment, economy and society [173] are included in sustainable manufacturing hence it is more global and general than green and eco-manufacturing. Sustainable manufacturing encompasses all the technical and non-technical, deterministic as well as non-deterministic aspects and factors right from the selection of raw materials in the pre-manufacture stage to the final product with production processes and the organizational aims and the performance. Therefore the resultant sustainable products from sustainable manufacturing practices show compatibility with nature throughout their entire life-cycle [117,53]. A very common practice is to take sustainable manufacturing notion as equivalent to the eco-friendly manufacturing practices. Sustainability entails a great deal more than just characterizing, evaluating and improving the environmental performances of the manufacturing processes and systems [97]. Adopting sustainability concepts in manufacturing means driving beyond the very fundamental and conventional concept of green technologies based on 3R (i.e. reduce, reuse, recycle) to the state-of-art and comprehensive 6R concept (i.e. reduce, reuse, recover, redesign, remanufacture, recycle) [118]. It is therefore essential to take on more optimized technological advancement and the process development for reduced resource consumption, decreasing occupational hazards, reduced or no toxic wastes as well as product development by controlling the process-induced parameters and improving the process output variables [117,152,96]. It demands improvements in the systems that decrease energy, resource utilization and reduce the effects of the process or system on the environment.

Given the state-of-the-art, the major manufacturing activity is machining that involves many factors having potential for the sustainable development. These sustainability factors include usage of cooling and lubricating fluids, tool life, waste disposal and chip recycling along with energy consumption [96]. The two aspects of improvements in machining include higher productivity along with quality of the products with better tools and improved processes. The second aspect deals with the adoption of environmental friendly and clean machining technologies [259,96]. For this reason, the analysis of machining processes and optimization of these input factors and outputs has remarkable implication for sustainable manufacturing [195,96]. Keeping this in mind decision making with regards to sustainable manufacturing factors like time, quality, resources, and costs have to be considered along with environmental performance [34,98]. The most suitable candidates for the sustainable manufacturing research are the coolants and lubricants used during machining as cutting fluids since simultaneous advancements in the scope of economic, environmental and health scope are achievable.

This article presents a summary of the role of cutting fluids in machining, economic as well as occupational impacts of these fluids, current technological advances in the sustainable systems and the review of the role of minimum quantity lubrication (MQL) technique as a sustainable manufacturing method replacing the conventional flooded coolant machining. The authors have emphasized the use of MQL as a substitute to conventional flooded machining by quoting and comparing the results of published researches.

2. Economical, ecological and human safety challenges of metal working fluids

The use of metal working fluid as cooling and lubricating medium is integral to the machining processes since the inception of machining processes and these fluids are commonly considered necessary for higher quality of products along with higher machining productivity. It is generally believed the cutting fluids are used for decreasing the friction at the work–tool interface, for minimizing the wear by reducing galling, adhesion and welding thus improving the surface characteristics, for minimizing the heat generated at the mated surfaces and for flushing away the chips, debris and residues [179,192].

According to Adler et al. [2], the total consumption of machining fluids by Northern American manufacturers in the year 2002, was over two billion gallons. In another study by Marksberry and Jawahir [179] the annual global consumption of metal working fluids by the year 2007 was 640 million gallons and the estimated utilization in US was about 100 million gallons. But according to some other researchers the consumption is much higher. According to Lawal et al. [153] the total worldwide consumption of metalworking fluids in the year 2005 was 38 million metric tons (approx. over 1200 million gallons) with a projected increase of 1.2% over the next decade. The correct estimates for the utilization and hence the costs of cutting fluids cannot be presented on account of the diversity and pervasive nature of field processes.

According to many researches carried out on this topic cost of cutting fluids amounts to a major part of manufacturing costs. Cost of cutting fluids may rise to 15% of a production shop total cost [94]. Another research suggests that besides environmental and health issues, 15–20% of the overall machining costs are related to cooling and lubricating fluids [218]. According to Brockhoff and Walter [22] the costs associated with the procurement, maintenance and discarding of these fluids may rise to two-time the machining cost and may amount up to approximately 17% per component in automotive industry. According to King et al. [135], the total costs coupled with the use of cutting fluids often sum-up to 7–17% of manufacturing costs in contrast with 4% for tooling expenditures. Fluid related expenditures includes the fluid

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