Achievement of Green Manufacturing using Alternative Types of Cooling in Machining Processes

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Abstract: Machining is a process commonly used in the production of mechanical workpieces. Improving efficiency must be accompanied by environmental awareness with special emphasis on the social protection and labor. Higher values of the cutting parameters offer the possibility to achieve higher productivity, but at the same time present a risk of deterioration surface quality and tool life. Cutting fluids are used in metal machining for a variety of reasons such as improving tool life, reducing workpiece thermal deformation, improving surface finish and flushing away chips from the cutting zone. In order to increase the efficiency, there are incorporated some new parameters, such as environmental and social acceptability and greater economic profitability. More attention focused to the negative effects of the cooling and lubrication as well as the multiplication of these effects has led to the necessity of finding new solutions. Alternative types of cooling in combination with new materials for making tools and special coatings represent an area of finding appropriate replacement of the cooling and lubricating. The main focus of this paper is demonstration the capabilities and benefits of applying dry machining and alternative types of cooling in terms of reaching a better surface quality with longer tool life.

Keywords: green manufacturing; machining sustainability; cutting fluids; dry machining; alternative types of cooling; cooling with cold compressed air.
1. INTRODUCTION

The environment is closely linked with human civilization. Healthy environment is main criterion in order to ensure preservation of the human race. Nowadays, mankind is no less dependent on technology than nature. Technology has made lifestyles more pleasurable, but in many cases it has a great negative impact on the environment. In the early 1970s, public discussion of the consequences and measures necessary to conserve the environment has been stimulated by citizens, action groups, and parliamentary movements (Youssef & El-Hofy, 2008). All parties realized that if proper attention is not paid to the environment we will have to face a lot of health and survival problems. As a result, in the early 1980s they had integrated environmental protection into their political programs. Lastly, the global environmental problems caused by the consumption of natural resources and the pollution resulting from the life of technical products have led to increasing political pressure and stronger regulations and legislations being applied to both the manufacturers and users of such products (Jegatheesan, Liow, Shu, Kim, & Visvanathan, 2009). The restrictions resulting from such legislation pose a challenge to scientists and engineers to develop new and alternative manufacturing technologies.

As currently configured, manufacturing has a large material impact on economy and the environment. Manufacturing is responsible for around 35% of the global electricity use, over 20% of CO₂ emissions and over a quarter of primary resource extraction. Along with extractive industries and construction, manufacturing currently accounts for 23% of global employment. It also accounts for up to 17% of air pollution-related health damages. During this critical time, an advanced manufacturing mode called green manufacturing (GM) as become popular as a sustainable development strategy in industrial processes and products (Dixit, Sarma, & Davim, 2012). GM is a modern manufacturing strategy integrating all the issues of manufacturing with its ultimate goal of reducing and minimizing resource consumption and environmental impacts like waste and pollution, during a product life cycle.
One of the major manufacturing processes is machining process. Machining processes constitute a major manufacturing activity that contribute to the growth of the global economy. Research and development (R&D) in machining processes have, on one hand, improved machining performances through advanced tool materials, higher productivity, and quality, while on the other hand, environmentally and health-friendly technologies are becoming increasingly important for achieving cleaner, healthier, and safer machining (Westkamper, 2008). In considering a clean machining process, the interaction between society, economy, ecology and technology has to be considered, as shown in Figure 1.

2. CONVENTIONAL MACHINING

Machining is generally performed after other manufacturing processes such as casting, forging or bar drawing. Those processes create the general shape of the starting workpart, and machining provides the final geometry, dimensions, and finish. Conventional machining is a manufacturing process in which a sharp cutting tool is used to mechanically cut away material to achieve the desired geometry. The predominant cutting action in machining involves shear deformation of the work material to form a chip; as the chip is removed, a new surface is exposed. Higher values of the cutting parameters offer the possibility to achieve higher productivity, but at the same time present a risk of deterioration surface quality and tool life. Cutting fluids (CFs) are used during the machining of metals for a variety of reasons such as providing lubrication and cooling, improving tool life, reducing workpiece
thermal deformation, improving surface finish and flushing away chips from the cutting zone.

In early 1960s, researchers have begun to recognize and express concern about the impact of CFs on the environment and health of workers. Today’s cutting fluids manufacturers are in the position that they must follow and abide by the rules and regulations of various governments about the impact of certain chemicals on the environment and a society. Manufacturers around the world currently use about 2.4 billion litres of CFs forming a significant demand for this type of non-renewable raw materials (Glen & Van Antwerpen, 2004).

2.1. Economical aspects of CFs

Many studies bring consumption data in tonnes, costs in the billions of dollars which is evidence of the extent of cutting fluids usage and costs in amounts to 17% (Feng & Hattori, 2000). Some research determined that the 60% of the total energy required for the machining is used for cutting fluids supplying, which is a serious problem due to the continuing trend of growth in energy prices (Rahäuser, Pflüger & Regenfelder, 2011). In order to capture the real total cost of using CFs, which involves a process of procurement CFs, its storage, use, maintenance, collection, treatment and disposal, it is necessary to take into account all the stages in the life cycle of CFs with detailed costs of each. Bierma and Waterstraat in their studies have been measured the costs of the two components and the results showed that the ratio of the CFs cost and hidden costs (costs associated with use of CFs) are from 1.0 : 1.5 as well as up to 1.0 : 5.5 for some studies, favor of the hidden costs (Bierma & Waterstrat, 2004).

![Figure 2. Overview of the total manufacturing costs and cutting fluids costs](image-url)
2.2. Health hazards of CFs

Different terms to characterize the physico-chemical properties of a CFs like explosive, oxidize, extremely flammable, highly flammable and flammable, and the toxicity of CFs such as very toxic, toxic, dangerous, corrosive, irritant, carcinogenic indicate high the risk of adverse impacts of CFs on health when handling such assets. The U.S. National Institute of Health estimates that the annual state-level 1.2 million workers adversely affected by CFs. CFs has negative health effects on the workers that appear as dermatological, and malignant and nonmalignant respiratory, and pulmonary diseases. Those hazards associated with CFs using, present CFs as hot button issues with a number of potential short-and long-term consequences for humans (Dixit, Sarma, & Davim, 2012).

2.3. Environmental issues associated with CFs

The total amount of satisfactory disposed (removed) CFs is the amount of CFs recycled or incinerated as a fuel, and according to the data from the EU area, it is only 32% of total consumption, which is concerned (Mortier, Fox and Orszulik, 2010). Aforesaid, nearly 30% yearly used amount of CFs has been disposed from the production systems (Byrne, Dornfeld & Denkena, 2003). Storage and disposal of used cutting fluids raises many environmental issues especially since it is one of the most complex types of waste. Large amounts of nondisposed CFs in the area of Western Europe have forced EU in 2006. to adopt a regulation called REACH, i.e. Registration, Evaluation, Authorisation and Restriction of Chemicals. This regulation as a new EU legal framework for chemicals covers all types of CFs and all phases, from production via use to final disposal.

3. DRY MACHINING

Competitive cost pressures and increasingly stringent environmental and occupational health standards are inspiring current machining industry to seek ways to minimize or eliminate their use of cutting fluids. Dry machining is ecological desirable process of metal removal that does not involve the use of wet cutting fluids. The elimination of coolant also imposes the loo of its positive effects, namely lubrication, cooling and flushing. Consequently, the mechanical and thermal loads on the cutting tool are increased. This means that there is more
friction and adhesion between tool and workpiece. Therefore, cutting tool for dry machining applications can be designed in three different ways: by using new cutting tools material, by adapting new cutting tool geometries or by applying special cutting tool coatings. Important factor affecting the choice of dry machining is the workpiece. Sometimes, a cutting fluid can stain the part or contaminate it. Consider a medical implant, such as a ball joint for a hip. Fluids are undesirable where there is the fear of contamination. A cutting fluid can be superfluous for cutting most alloys of cast iron, and carbon and alloyed steel, for example. These materials are relatively easy to machine and conduct heat well, allowing the chips to carry away most of the heat generated. The exception is low-carbon steel, which becomes more adhesive as the carbon content falls. These alloys might need a fluid as a lubricant to prevent welding. Cutting fluids normally are not necessary when machining most aluminum alloys because of the relatively low cutting temperatures. Machining stainless steels dry is a little more difficult. Heat can cause problems in these materials. Cutting fluids are mandatory for cutting titanium.

4. ALTERNATIVE TYPE OF COOLING

Advanced cutting tool materials, coatings and designs, along with different strategies for lubrication, cooling and chip removal, make it possible to achieve the same or better results with minimum quantity lubrication machining, cryogenic machining and air cooling or other viable alternative for liquid coolants: shorter cycle times, better surface finish, longer tool life, and higher recycling value for clean chips.

4.1. Minimum quantity of cooling and lubrication (MQCL)

In the machining of the above mentioned materials, an interesting option is the use a lubrication/coolant system based on the injection of pressurized air with small quantities of media. This technique is designated as minimum quantity of cooling and lubrication (MQCL). There are two type, minimum quantity cooling (MQC) and minimum quantity lubrication (MQL), depending on the type and on the main function of the fluid medium supplied. When oils are used as the fluid medium, the emphasis is on their good lubrication properties. Their function is to reduce friction and adhesion between the workpiece, the chip and the tool. As a result, the amount of friction heat generated is also reduced. Consequently, the tool and the workpiece are exposed to less heat than they would be if the machining operation was
performed completely dry (Aoyama 2002). However, the minimum quantity cooling technique can make a major contribution to the solution of thermal problems affecting the tool and/or the part in dry machining operations.

4.2. Cryogenic machining

Cryogenic machining relates to delivering a super cold medium to the cutting region of the cutting tool, which is exposed to the highest temperature during the machining process, or to the part in order to change the material characteristics and improve machining performance. The coolant is usually nitrogen fluid which is liquefied by cooling to 196°C (liquid nitrogen). As most cryogenic coolants used in machining operations such as liquid nitrogen and liquid helium are made from air, they are not considered as pollutants for the atmosphere. Nitrogen in particular is an inert gas which forms 78% of the atmosphere and is lighter than air. As a result it is dispersed into the atmosphere and does not harm the workers on the shop floor.

4.3. Air cooling

Employing compressed cold air for cooling in machining operations is a relatively new technique which has attracted many researchers. A vortex tube is a device which produces cold and hot air from compressed air, Figure 3. As in this technique the cooling media is air, it could be defined as the cleanest and most environmentally friendly method of cooling in cutting operations.

![Figure 3. Separation of a compressed air into a hot stream and a cold stream](image)

Most studies indicated that using chilled air as coolant in machining resulted in longer tool life (Sun, Brandt & Dargusch, 2010). The effect of chilled air on the surface finish is highly dependent on the machining parameters. In general it could be claimed that air cooling produces lower surface roughness than dry cutting.
5. RESULTS AND DISCUSSION

Reviewing of the factors shown in Table 1., choice of alternative types of cooling in the form of compressed cold air cooling would mean a relatively small investment cost and application, almost no maintenance requirements with maximum fulfillment of sustainability terms. However, the efficiency of the process in terms of tool life, the quality of the machined surface, the possible selection of relatively lower (milder) cutting parameters, the material removal amount, the cost of the process, it is lower in some cases compared to the MQL technique and cryogenic cooling procedures. However, the selection of an alternate type of cooling creates opportunities in comparison with conventional cooling methods for the investigation purposes of the process sustainability

Table 1. Influence factors for choosing a particular alternative type of cooling

<table>
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<th>Alternative type of cooling</th>
<th>Investment cost</th>
<th>Application cost</th>
<th>Maintenance necessity</th>
<th>Technique efficiency</th>
<th>Achievement of sustainability terms</th>
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L – low, M – medium, H – high

The type of machine used for the milling test was machining center VC 560 manufactured by Spinner. Test sample used in experiment were made of steel 42CrMo4 with dimensions 100x250x100 mm. The end milling experiments were executed by a tool CoroMill 390 with three TiN coated inserts, produced by Sandvik. Average surface roughness Ra of machined workpieces was periodically measured by a Surftest SJ-301, produced by Mitutoyo.
Figure 4. End milling process with alternative type of cooling, compressed cold air

In figure 4 is shown position of a cold air gun in machining process. Figure 5 shows surface roughness values for three types of machining specified as dry machining, air cooling and CFs machining.

Figure 5. Graphical representation of the experimental results

Application of cooling with cold compressed air has two positive features. The first one is reaching a minimum value of surface roughness, and the other one is that the tool wear is delayed what is not the case for dry milling, because tool wear affects the increase in surface roughness.
6. CONCLUSION

This paper gives an overview of the machining process with the respect to the sustainability manufacturing. There are emphasis on the impact of machining process on the environment, health and economic conditions. The CFs viewed from three different aspects such as ecological, economical and sociological, represents a big challenge to scientists in their looking for better solutions in the field of cooling and lubrication in the machining, which will be technically and economically competitive and will not be a threat to the future, or to the sustainability machining. According to the theoretical study there is a great potential in replacing the traditional ways of cutting fluids applications in terms of shorter cycle times, better surface finish, longer tool life, and higher recycling value for clean chips. Alternative types of cooling in combination with new materials for making tools and special coatings represent an area of future research.

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