ABSTRACT

Modern machining industries face continuous pressure regarding the cost and high quality of the product. To remain in competition, an industry must identify the factors that result in the cost reduction of the process and still maintain the quality of the product. One of the major aspects which decide the above said parameters is the nature of cutting or cooling lubricant used for metal cutting operations. A machining industry which aims for higher quality and higher productivity at low cost, will definitely face problem with elevated temperatures at the metal cutting zone during the machining process. An increase in the cutting temperature affects the dimensional aspects of the machined product, and also impairs the surface integrity of the product by inducing residual stresses, surface and subsurface micro cracks, in addition to rapid oxidation and corrosion. Further, the high cutting temperatures also affect the life of the cutting tool. As a solution for these problems, many machining industries are using conventional cutting fluids to control the rise in the cutting temperature of the machining zone. But, conventional coolants are not very effective in reducing the cutting temperature and tool wear as expected. Moreover, the unsuitability of the conventional coolants in terms of pollution, and increasing handling and disposal costs, lead the industries to go in for an alternative cooling method. Recently, cryogenic machining has become one of the effective alternative cooling approaches, which controls the cutting temperature and improves the tool life.

During the metal cutting operation, the energy dissipated gets converted to heat. Consequently, high temperatures are generated at the
cutting edge of the tool, and these temperatures have a controlling influence on the rate of wear of the cutting tool, and on the friction between the chip and the tool. The amount of heat arising from the cutting zone is the total heat produced, due to the plastic deformation of the metal ahead of the cutting tool, and the friction existing between the chip-tool and the work-tool interface. Many researchers had used different cooling methods to supply cryogenic coolants to different areas of the metal cutting zone. Most of the earlier experimental studies were carried out with the help of liquid nitrogen (LN₂) as the cutting coolant. One of the disadvantages of the LN₂ coolant would be its very low temperature (-196°C), that could increase the surface hardness of the machined component causing brittleness. Hence, in this research work, an attempt has been made to study the influence of cryogenic carbon dioxide (CO₂) as the cutting coolant in machining, and to investigate its effect on the cutting temperature, cutting force, chip thickness and its morphology, surface roughness, shear angle, and tool wear. The results obtained with cryogenic CO₂ as the cutting fluid are compared with those of dry, conventional wet and cryogenic LN₂ machining.

In the present research work, the cryogenic cooling setup for supplying cryogenic CO₂ and cryogenic LN₂ coolants was developed, and turning operations were carried out for analysing the performance of each coolant. The turning experiments were carried out with different work-tool combinations (i) AISI 1045 steel with multi-coated carbide inserts (CNMG 120412-5 TN2000) (ii) AISI 316 stainless steel with PVD coated carbide inserts (CNMG 120404 MP 431 KC 5010) and (iii) Ti-6Al-4V alloy with PVD coated carbide inserts (CNMG 120404 MP 431 KC 5010) under different machining environments such as (i) Dry (ii) Wet (conventional) (iii) Cryogenic CO₂ cooling and (iv) Cryogenic LN₂ cooling. Each work
material was machined at different cutting velocities (41 m/min, 94 m/min and 145 m/min) and feed rate (0.051 mm/rev, 0.096 mm/rev, 0.143 mm/rev and 0.191 mm/rev) with a constant depth of cut 1 mm. Cryogenic coolants during machining were supplied at a constant pressure of 2 bars. To study the effect of coolants on tool wear, turning experiments were carried out for 5 minutes duration with different cutting velocities (41 m/min, 94 m/min and 145 m/min) and a constant feed rate of 0.191 mm/rev. The inserts used for machining purposes were observed under the Scanning Electron Microscope to analyse the crater and flank wear.

The machining of all the workpiece materials under cryogenic LN$_2$ resulted in the lowest cutting temperature when compared with dry, wet and cryogenic CO$_2$ machining, due to its extreme low temperature which helps to remove the excess of heat from the cutting zone drastically. In terms of the cutting force, chip thickness and morphology, surface roughness, shear angle and tool wear, cryogenic CO$_2$ yielded better results when compared with the other machining conditions, due to its high capability to penetrate into the chip tool interface and to enhance the ability to reduce the friction existing between the chip and the cutting tool. While turning AISI 1045 steel with cryogenic LN$_2$ the cutting temperatures reduced in the range of 9 – 27%, and about 3 – 13% with cryogenic CO$_2$ when compared with the wet machining process. The cutting force was reduced up to 38% and chip thickness got reduced up to 23% in cryogenic CO$_2$ machining when compared to wet machining. An advantage in the range of 2 – 12% reduction in the cutting force and up to 14% reduction in chip thickness, and an increased shear angle was obtained in cryogenic CO$_2$ machining when compared to cryogenic LN$_2$ machining. Better surface finish in the range of about 2 – 14% and reduced flank and crater wear was obtained in cryogenic CO$_2$ machining when
compared with cryogenic LN$_2$ machining. While machining AISI 316 stainless steel work material cryogenic LN$_2$ was favourable with the least cutting temperature due to its extreme low temperature, and it was favourable in the range of 8 – 18% when compared to cryogenic CO$_2$ machining. The application of cryogenic CO$_2$ coolant reduced the cutting force and chip thickness in the range of about 11 – 25% and up to 14% when compared to cryogenic LN$_2$ machining. Improved surface finish and reduced tool wear were observed in the case of cryogenic CO$_2$ machining environment when compared with the other machining conditions. In turning Titanium alloy (Ti-6Al-4V), the cryogenic LN$_2$ cooling reduced the cutting temperature in the cutting zone up to 50% over dry machining and in the range of 24 – 47% over wet machining. Cryogenic CO$_2$ cooling produced an advantage in the range of about 8 – 25% reduction in the cutting force when compared to cryogenic LN$_2$ cooling. Acceptable forms of chips were produced both in cryogenic CO$_2$ and LN$_2$ machining. Better surface finish was obtained in the range of 13 – 48% in cryogenic CO$_2$ machining when compared with cryogenic LN$_2$ machining. The use of cryogenic CO$_2$ coolant reduced the crater and flank wear up to 57% and 61% respectively, when compared to wet machining.

Based on the results obtained from the experimental work, it can be concluded that machining with the cryogenic LN$_2$ and CO$_2$ cooling had a substantial benefit with respect to the cutting temperature, cutting forces, chip thickness and morphology, surface roughness, shear angle, and tool wear, when compared with the other conventional cooling methods. Further, the use of cryogenic coolants also reduced the adhesion and effect of friction at the chip-tool interface and work-tool interface, thereby reducing the tool wear, and improving the surface quality of the product.