ABSTRACT

A major problem in machining industry during machining process is increased temperature which affects quality and production cost. An increase in cutting temperature causes deviations in dimensional aspects of the product, impairs surface integrity, causes surface and sub-surface micro cracks, and rapid oxidation and corrosion. It also reduces the life of a cutting tool. To control the temperature at the cutting tool edge, machining industries use many cutting fluids and lubricating fluids. But usage of these conventional coolants are not effective in reducing temperature and tool wear. Further it has limitations in terms of pollution and increase in handling and disposal costs. In this context, cryogenic machining has become one of the alternative methods, to control the cutting temperature and tool wear.

During the machining of Al alloys and Al composites, the energy dissipated gets converted to heat. As a consequence, high temperatures are generated at the cutting edge on friction between the chip and tool. These high temperatures are generated due to the plastic deformation of the metal at the cutting edge and friction between the chip-tool and work-tool interface. In the case of Al/SiC composites, hard SiC particles adhere to the cutting tool edge and due to high temperature, Built Up Edge is formed which affects surface finish and tool life. Many researchers used different cooling methods to supply cryogenic coolants to different areas of the metal cutting zone in machining difficult to machine materials. Most of the earlier experimental studies were carried out with the help of liquid nitrogen (LN$_2$) as the cutting coolant to machine difficult to machine materials. However, very few investigations have been presented on machining of Aluminium alloys and Aluminium based composites. Hence, in this research work, an attempt has been made to study the influence of LN$_2$ as a coolant in machining
Aluminium alloys and Aluminium based composites and to investigate its effect on the cutting temperature, cutting force, chip thickness, surface roughness and microstructure. The results obtained with cryogenic LN$_2$ coolant as the cutting fluid are compared with the conventional wet cooling machining.

In this research work, the cryogenic cooling setup for supplying cryogenic LN$_2$ coolants was developed. The turning experiments were carried out with three different workpieces such as 7075 Al alloy, LM13 and LM28 composites with uncoated Tungsten carbide inserts under wet and cryogenic LN$_2$ machining environments. 7075 Al alloy work material was machined at different cutting velocities (51 m/min, 118 m/min and 181 m/min) and feed rate (0.079 mm/rev, 0.159 mm/rev and 0.205 mm/rev) with a constant depth of cut 1 mm. LM13 and LM28 composite work materials were machined at different cutting velocities (61 m/min, 145 m/min and 226 m/min) and feed rate (0.159 mm/rev, 0.205 mm/rev and 0.24 mm/rev) with a constant depth of cut 1 mm. The samples of inserts used for machining purposes were observed under the Scanning Electron Microscope to analyze tool wear.

The machining of all the workpiece materials under cryogenic LN$_2$ machining resulted in lower cutting temperature than under wet machining. Its extreme low temperature helped to remove the excess heat from the cutting zone drastically. The cryogenic LN$_2$ yielded better results due to its high capability to penetrate into the chip tool interface and its ability to reduce the friction existing between the chip and the cutting tool. The cutting force, cutting temperature, surface roughness, tool wear and chip thickness reduced, compared to wet machining.

While machining 7075 Al Alloy with cryogenic LN$_2$ coolant, the cutting temperature reduced in the range of 17–29% and the cutting force reduced in the range of 10–31%, when compared with the wet machining for
similar cutting conditions. An advantage in the range of 5–21% reduction in the chip thickness and an increased shear angle were obtained in cryogenic LN$_2$ machining when compared with the wet machining. Better surface finish in the range of 11-29% and reduced tool wear were obtained in cryogenic LN$_2$ machining when compared with the wet machining.

Cryogenic LN$_2$ coolant reduced the cutting temperature in the range of 19–30% and 19–33% in machining LM13 and LM28 composites, respectively, compared with the wet machining. Cutting forces were reduced in the range of 20–46% and 13–29% with cryogenic LN$_2$ cooling in machining LM13 and LM28 composites, respectively, compared with the wet machining for similar cutting conditions. The cryogenic LN$_2$ coolant reduced the thickness of the chips in the range of about 3–16% and 3–13% in machining LM13 and LM28 composites, respectively, when compared with wet machining. Surface finish improved significantly with cryogenic LN$_2$ and was found to be advantageous in the range of 6-20% and 7-18% in machining LM13 and LM28 composites, respectively, when compared with the wet machining.

Tool wear rate is less when cryogenic LN$_2$ coolant was used compared to the wet machining. A microstructure study after completion of wet and cryogenic machining revealed that there was no change in microstructure among wet and cryogenic LN$_2$ machining environments. The less thickness and smaller chips were produced in cryogenic machining on application of cryogenic coolants in machining 7075 Al alloy. Further, saw toothed and segmental type with longer radius chips were produced in machining LM13 and LM28 composites which favoured machinability.

Based on the results from the experimental work, it can be concluded that machining with the cryogenic LN$_2$ cooling has substantial benefit with respect to the cutting temperature, cutting forces, chip thickness
and its morphology, surface roughness, and tool wear when compared with the wet machining. Further, the use of cryogenic coolants in machining, reduces the adhesion and effect of friction at the chip-tool interface, which reduces the tool wear, thereby improving the surface quality of the product.