ABSTRACT

Nimonic 90 is a nickel-based alloy that offers many desirable attributes for industrial and commercial use in terms of its high hot hardness, high wear resistance, and good corrosion resistance. Due to these attributes, the Nimonic 90 finds extensive application in aerospace, automobile, nuclear power plants, and petrochemical industries. Despite having many favorable properties, Nimonic 90 is classified as difficult-to-machine material due to its ability to retain high strength at elevated temperature, high strain rate sensitivity which leads to work hardening, low thermal conductivity, and high chemical reactivity. In general, petroleum-based metal working fluids (MWFs) under flood mode are used as a conventional method to reduce the cutting temperature and friction during grinding. However, the MWFs are considered as the most unsustainable component of grinding processes. High costs associated with operational and disposal, environment pollution, operators' health-related issues, and high energy consumption due to the use of MWFs in grinding are the major hurdles for the machining industries. Therefore, the present research aims to eradicate, reduce, or replace the MWFs from the grinding process using sustainable techniques such as minimum quantity lubrication (MQL) and cryogenic cooling using liquid nitrogen (LN_2). The application of these sustainable techniques in grinding can make the grinding process more economical, ecological, and socially viable.

In the present study, MQL has been used as a strategy to reduce the quantity of cutting fluid during the grinding process. The conventional cutting fluid has been replaced with indigenously prepared cutting fluids such as biodegradable emulsion (sunflower oil in water (SOIW), Soybean oil in water (SYOIW), and Palm oil in water (POIW)) and water-based nanofluids. The nanofluids have been prepared by mixing the nano sized alumina (Al_2O_3), graphene nanoplatelets (GnP), and hybrid of them in deionized water and have been employed for the grinding of the Nimonic 90 in a CNC surface grinding machine. The grinding output in

terms of grinding forces, surface roughness, ground surface topography, wheel topography, and grinding chips morphology are obtained when using the prepared fluids and the same has been compared with the dry grinding condition. Upon investigation, the use of alumina-graphene nanoplatelets (Al-GnP) hybrid nanofluids (NFs) with 0.75 Vol.% has been proven to be a better environment than other conditions in terms of reducing grinding forces and surface integrity.

In the last experimental phase of this research work, a comparison between the cryogenic cooling condition, sunflower oil in water (SOIW) with 5 Vol.% biodegradable emulsion and hybrid Al-GnP with 0.75 Vol.% has been conducted by varying the grinding speed, table speed, depth of cut, and grit size. Overall, the cryogenic sustainable cooling technique has been found to be the best sustainable cooling technique followed by MQL with Al-GnP hybrid NFs and MQL with SOIW biodegradable emulsion during grinding of Nimonic 90.

In the last section of this research work, an attempt has been made to develop a pseudo analytical model predicting the grinding force under the sustainable MQL environment. The grinding force is one of the key response variables. It is essential to study the force during grinding because of its direct effect on the ground surface quality, wheel wear, grinding zone temperature, and grinding fixtures' design. Till now, only a few authors have modelled the grinding force and that too under a dry grinding environment. Therefore, the present work deals with developing a mathematical model for predicting the force during the grinding of a Nimonic 90 under a sustainable MQL environment. The model takes into consideration all the three force components such as cutting, rubbing, and ploughing. The total tangential and normal force components equations have been developed during these three processes and stated in terms of experimental constant coefficients and grinding process parameters such as grinding speed, table speed, and depth of cut. All coefficients have been determined by conducting grinding experiments under a sustainable MQL environment. The rubbing force

component has been estimated using experimental grinding contact length and dynamic grit density. The single grit experiments have been performed to model the ploughing force component. The single alumina abrasives with different sizes, i.e., 24, 20, and 16 mesh numbers, have been used to investigate the actual material deformation behavior during single grit grinding. These grinding experiments have been performed using in-house developed alumina brazed tools fitted into a dummy aluminium grinding wheel. The geometrical parameters of the scratches have been measured and analyzed using a coherence correlation interferometer optics microscope to investigate the ploughing phenomenon. The present study indicates that the ploughing becomes more influential due to the size effect during grinding of harder material like Nimonic 90 alloy at low depth of cut. The total normal and tangential force values obtained from the analytical model have been validated based on experimental data of total normal and tangential forces in surface grinding under a sustainable MQL environment. A good agreement between the predicted and experimental force values have been noticed.

Keywords: Cryogenic grinding, MQL, Hybrid nanofluids, grinding force model