# Abstract

This doctoral thesis has attempted to study the machining characteristics and surface integrity of Incoloy 925 under eco-friendly novel hybrid nanofluid, including other suitable sustainable cutting environments. In this regard, first to select a suitable cutting base oil (fluid) to be used for MQL (minimum quantity lubrication), the machining performance of different types of vegetable oils, such as coconut oil, sunflower oil, groundnut oil, and rice bran oil have been tested. Coconut oil is found to be the most suitable base oil among the others. Thermophysical and tribological properties of this oil can be enhanced by dispersing the nanoparticles into it, and the colloid is called a nanofluid which may provide effective lubrication-cooling. It has been reported that hybrid nanofluids-assisted machining performs better than mono nanofluids. However, some solid lubricants (in nanoparticles) transform to another phase (like $MoS_2$ to $MoO_3$ and $WS_2$ to $WO_3$) at high temperatures, thereby providing a poor lubrication effect during machining, whereas hard nanoparticles like diamond or SiC create scratches on machined surfaces. In this research, a potential novel biodegradable hybrid nanofluid is developed by simultaneously dispersing ceramic nanoparticles (hBN) and soft metallic nanoparticles (Cu) in lubricious coconut oil, ensuring their chemical inertness at high temperatures without compromising the solid lubricant's properties. The physical stability of nanofluids is characterized using ultraviolet-visible near-infrared (UV-Vis-NIR) spectrophotometer and nanoparticles tracking analyzer (NTA); chemical stability is characterized using FTIR (Fourier transform infrared) spectroscopy, whereas the thermal stability of nanofluids is evaluated using thermogravimetric analysis (TGA) and derivative thermogravimetry (DTG) techniques. Thermal conductivity, viscosity, viscosity index, wettability, and tribological performance are also evaluated. The performance of the developed hybrid nanofluid in end milling of Incoloy 925 is investigated in terms of specific cutting energy, carbon emission, surface roughness, surface topography, chip morphology, tool wear, and microstructure, microhardness, and residual stresses of machined components. Formulated hybrid nanofluid performs better than dry, base oil, and mono nanofluid. The sustainability of machining performance is evaluated with a triple bottom line (TBL) approach, and it is found that product sustainability index (ProdSI) under hybrid nanofluid (HNMQL) assisted machining scores 3 times of oil (MQL) assisted machining and 1.85 times of mono nanofluid (NMQL) assisted machining.

Further, a statistical tool, such as analysis of variance (ANOVA), is used to investigate the combined effects of the radius of inserts and process parameters on the machining performance. Response surface methodology (RSM) and artificial neural network (ANN) are applied to develop the mathematical models between cutting parameters and machining responses, and their prediction results are compared. ANN models are found to be more effective than RSM models. In order to optimize the machining responses, ANN models are coupled with a non-dominated sorting genetic algorithm (NSGA-II). The technique for order performance by similarity to ideal solution (TOPSIS) is used to get the best solution from the optimal set of parameters. Moreover, in order to investigate the quality of machined components under different cutting environments at optimized cutting parameters, functional performance characteristics such as tribological performance, fatigue behavior, and electrochemical and hot corrosion behavior have been evaluated. It is found that surface characteristics of machined components, such as areal surface roughness/topography and residual stresses, strongly correlate with the product's functional performance.

**Keywords:** Incoloy 925; Nanofluid; MQL; TBL; ANN-NSGA-II; Surface integrity; Functional performance