Sustainable MQL machining of hot die steel under nano-graphene reinforced sesame oil

A. Balasuadhakar[1], S. Thirumalai Kumaran[2*], M. Uthayakumar[3], S.Suresh Kumar[1]

[1]Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil–626126, Tamil Nadu, India.

[2]Department of Mechanical Engineering, PSG Institute of Technology and Applied Research, Coimbatore–641062, Tamil Nadu, India.

[3]Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri–690525, Kerala, India.

*Corresponding Author: thirumalaikumaran@yahoo.com; +91 9865954612

ABSTRACT

The AISI H11 is widely used for making tools, dies and aircraft landing gears, due to its outstanding mechanical characteristics and superior wear resistance. However, these distinctive properties make it to a difficult to cut material. Deprived surface characters, high tool wear and higher manufacturing cost are concomitant with the machining of AISI H11. To limit the effects of mineral oil based flooding technique which affects the operator's wellbeing, a vegetable oil based Minimum Quantity Lubrication (MQL) is represented as an alternative. In the present study, Graphene nanoplatelets (Gnp) enhanced green sesame oil based MQL is chosen for end milling. Initially the nanofluid characteristics such as density, thermal conductivity, viscosity and surface tension at various concentrations are studied. Later, cutting temperature, surface finish, burr development, chip morphology and crystallographic structure are thoroughly examined. The results indicate that the MQL environment with nanofluid decreases the temperature by 75% and 15% compared with dry condition machining and conventional MQL environments respectively; whereas the surface roughness reduction is observed to be 73% and 18% as compared with aforementioned atmospheres. Burr formation reduction is seen in the optical microscope examination. Smaller grain size of machined surface and minimal amount of fibrous and curve chips show the superiority of the proposed cooling environment.

Keywords: MQL; nanofluid; end milling; hot die steel; sustainability.

1. INTRODUCTION

The AISI H11 hot work tool steel is a vital material for manufacturing of machining tools and dies because of its greater hardness, toughness and wear resistance[1]. In the forming

tools manufacturing method milling process plays a significant role[2]. The major challenges in hard milling process are inadmissibly abbreviate tool life and poor surface integrity[3]. Therefore, the coolant is necessary to curtail the cutting temperature and friction to enhance the tool life and surface trait[4]. Despite the many benefits of using inorganic coolant accompanying with the conventional flooding technique in metal cutting process, they present serious environmental and economic shortcomings[5]. Subsequently, an effectual system of lubrication employment is required that concurrently improves the output machining performance and reduces the usage of coolants, here Minimum Quantity Lubrication (MQL) originates out as a substitute of conventional lubrication method[6].

MQL machining is one of the sustainable technique to provides various ecological, fiscal and communal advantages[7]. This system mixes optimum ratio of compressed air and cutting fluid with minimal quantity, then it is scattered to the machining region by the nozzle[8]. Vegetable based oils are greatly attractive replacements for inorganic cutting oils since they are renewable, ecofriendly nature and easily decomposable[9]. These oils have a greater viscosity index and consist of long chain fatty acids, which offer lubricant films with high strength. The friction and wear are reduced due to the strong interaction of film in metallic surfaces[10]. Vegetable cutting oil along with the MQL technique affords excellence environment friendly and green sustainable machining[11]. Do et.al. optimized the hard milling process for AISI H13 with TiAlN layered carbide tool on MQL environment and they developed the statistical model to predict the force for cutting and surface roughness[12]. Another study was conducted on similar material on vegetable oil MQL system for grinding and evaluated that the decrease in surface roughness and grinding force compared with dry grinding[13]. Rahim et. al. carried out the comparative study of drilling experiment on Ti–6Al–4V by using palm oil and synthetic ester. It was investigated that the MQL with palm oil performs well compared with the synthetic ester MQL in terms of power conception, cutting temperature and cutting force[14].

The cutting fluid property is enhanced by adding the nanoparticles in terms of convective heat transfer coefficients, viscosity, thermal conductivity and thermal diffusivity[15]. Padmini et. al. conducted the comparative study on machining AISI 1040 with the base fluid of sesame oil. They used nano and micro particles of molybdenum disulphide and boric acid for mixing with base oil and it was found that enhanced result in cutting temperature, surface roughness, tool wear and cutting force by using nanofluid[16]. Moreover, Ni et. al. studied Fe_3O_4, Al_2O_3 and carbon nanoparticles with sesame base oil for broaching of AISI 1045 and they found that carbon nanofluid has better viscosity, frictional coefficient,

- As an outcome of attraction between the intermolecular energy of nanofluid the surface tension value negatively influenced by the Gnps, which required for effective penetration and lubrication of nanofluid on cutting zone. There is a direct relationship amid the density value and nanofluid concentration. At the maximum concentration the density value of nanofluid increased by 4.3%.
- The maximum dynamic viscosity obtained was 86.12 Mpa-s at the highest concentration of Gnps. Owing to the reduction of intermolecular forces on nanofluid, the viscosity values reduces with the increasing temperature. Furthermore, the lowest viscosity value obtained by the pure sesame oil at all testing temperatures.
- As reasons for excellent heat convection by oil mist system and enhancement of cooling ability of sesame oil by Gnps, the MQLNSO and MQLSO reduces the temperature by 75% and 60% respectively compared with dry machining (at 0.8 wt. %).
- MQLNSO has shown a remarkable improvement in surface finish over other cooling environments. The surface roughness reduced by 73% and 18% with respect to dry machining and MQLSO condition (at 0.8 wt. %). It is due to the reduction of milling temperature and friction by the resourceful lubricating environment.
- The cushioning effect on the cutting zone by the MQLNSO greatly reduced the burr formation. By the reasons of convective heat transfer and enhanced cooling, the grain size was reduced on the machined surface at aforementioned cooling condition.
- In the MQLNSO situation, the fibrous and curve structure of the chips are reduced as a consequence of delimited notch growth and groove wear, and a higher heat conduction characteristic of Gnps.

The future scope of this study can be explored through the following research directions:

- The performance of MQLSO and MQLSNO will be investigated under varying jet pressures, flow rates, and nozzle positions. In addition, their effectiveness will be assessed when combined with assisted machining techniques. Furthermore, the behavior of MQLSNO with hybrid nanoparticles will be analyzed to improve lubrication, thermal conductivity, and machining efficiency.

DECLARATIONS

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Authors' Contributions:

A.Balasuadhakar: Conceptualization, Formal analysis, Writing-Original Draft, Data Curation.
S.Thirumalai Kumaran: Methodology, Investigation, Writing-Review & Editing, Supervision.
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