A Concise Study of Nanofluid-Assisted Machining of Al7075-T6 Alloy

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Abstract: This concise paper provides a review of the use of nanofluids in the machining of Al7075-T6 alloy using different lubrication strategies. This paper examines influence of nanoparticles like Al_2O_3, MoS_2, graphene, carbon nanotubes (CNTs), hexagonal boron nitride (h-BN), and MXene on cutting force, cutting temperature, tool wear and surface roughness (SR). According to the studied literature, nanofluid-assisted machining has much higher machinability, productivity and sustainability than dry and traditional lubrication approaches. In addition, the review discusses the growing use of hybrid nanofluids and highlights the statistical and optimization techniques used by researchers like Taguchi design, Analysis of Variance (ANOVA), multi-objective particle swarm optimization and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for parameter optimization.

Keywords: Tribology; Al7075-T6; surface roughness; tool wear; nanofluids

Introduction

Nanofluids are made up of a base fluid and nanoparticles with sizes typically less than 100 nm. Base fluids include vegetable oils, mineral oils, synthetic oils and water-based emulsions. Nanoparticles used in machining include aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), titanium dioxide (TiO_2), copper oxide (CuO), carbon nanotubes (CNTs), hexagonal boron nitride (h-BN), MXene and molybdenum disulfide (MoS_2). Nanofluids are establishing themselves as a possible alternative to traditional cutting fluids (CFs) because of their higher tribological performance, thermal conductivity and heat dissipation. The inclusion of nanoparticles improves the cooling and lubricating (C/L) properties of the base fluid, resulting in better machining performance. The superior performance of nanofluids is attributed to following mechanisms as shown in Figure 1.

Aluminum alloys are extensively utilized in aviation, automobile, and structural applications because of their high strength-to-weight ratio, robustness to corrosion, and ease of machining. Al7075-T6 is one of the most frequently employed high-strength aluminum alloys. Still, machining Al7075-T6 presents various obstacles, such as workpiece material adherence to the cutting tool, built-up edge (BUE) development, elevated cutting temperatures, and high tool wear [1]. These difficulties have an unfavorable effect on surface quality, dimensional accuracy, and tool durability. The use of nanofluids under Minimum Quantity Lubrication (MQL) and Nano-Minimum Quantity Lubrication (NMQL) conditions has shown great promise in meeting these issues. Nanoparticles like h-BN, MoS_2, graphene nanoplatelets, Al_2O_3, TiO_2, and MXene have been explored as inclusions in machining fluids.

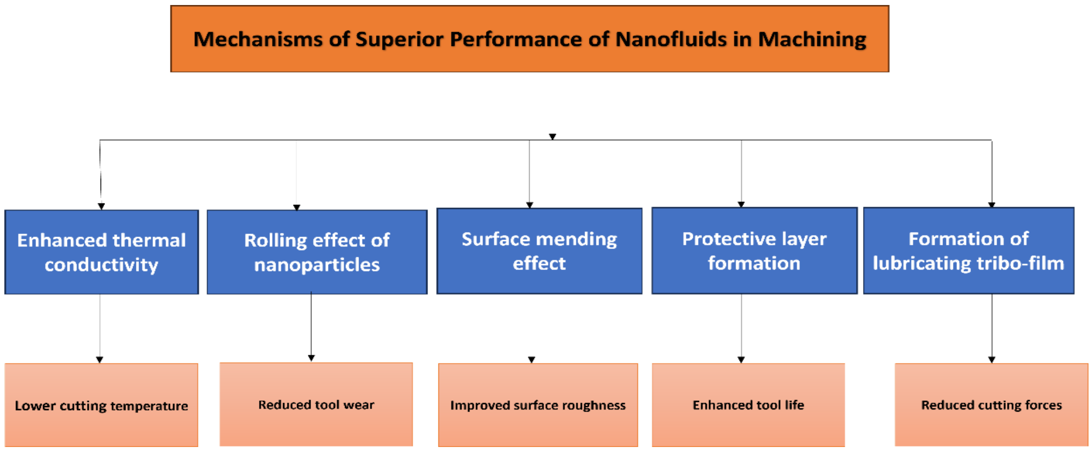

Fig.1. Mechanisms of superior performance of nanofluids in machining

Hybrid nanofluids are created by dispersing two types of nanoparticles into a normal heat transfer fluid. The hybrid nanofluids outperform conventional heat transfer fluids including ethylene glycol, oil and water as well as single nanoparticle nanofluids. Hybrid nanofluids are an emerging category of heat transfer fluids that are currently in development and require additional study to reach industrial scale. Some common hybrid pairings include Al_2O_3-CNT, MoS_2-CaF_2, h-BN-MXene, graphene-Al_2O_3, and TiO_2-SiO_2. These mixtures frequently outperform single-particle nanofluids in terms of heat transfer, friction reduction, and wear resistance. Hybrid nanofluids also contribute to sustainable production by minimizing the employ of traditional cutting fluids and lowering environmental impact. The use of biodegradable oils as base fluids boosts their environmentally beneficial properties.

Gajrani et al. (2019) utilized calcium disulphide and molybdenum disulphide to turn hardened steel employing a tungsten tool. The study found an 11.01% reduction in tool chip contact friction because nanoparticles reduced metal-to-metal contact and adhesive wear by forming a protective tribofilm, improving heat dissipation, and rolling/mending at the tool-chip interface. [2]. Jamil et al. (2019) employed a hybrid nanofluid including alumina and carbon nanotubes to machine titanium alloys. Machining employing hybrid nanofluid resulted in an 8.72% decrease in surface roughness (SR) and an 11.8% increase in cutting force [3]. Use of nanoparticles with a greater approach angle, reduced cutting speed, and feed rate lessened cutting force and improved surface finish when turning titanium alloy. Better tribological lubrication, lower chip load and cutting temperature all contributed to increased machining performance. Zhang et al. (2015) used nanoparticles (MoS2, CNTs, and MoS2-CNTs) for grinding nickel-based alloys with minimal lubrication. The use of hybrid MoS_2 and CNTs resulted in lower grinding force ratio and SR [4].

Application of Nanofluids in Machining of Al7075-T6

MQL method reduces SR, cutting temperature and tool wear as compared to Ranque-Hilsch vortex tube (RHVT), compressed air and dry mode as reported by Singh et al. 2023. MQL's better performance was ascribed to the simultaneous cooling and lubrication (C/L) provided by atomized oil droplets, which reduced tool-chip friction, suppressed built-up edge (BUE) development and increased heat dissipation [5]. The incorporation of nanoparticles to the fluid had a positive effect on lowering the temperature at the work tool contact while retaining milling performance parameters because of improved lubrication and cutting stable conditions [6]. The low-cost nano-graphene cutting fluid presents a viable solution for optimizing the machining of AA7075 alloys, resulting in improved performance and quality because nano-graphene improved fluid cooling, lubrication and tribological properties [7]. Textured tools minimize cutting forces greatly when compared to conventional techniques. The hybrid nanofluid demonstrated enhanced (C/L) capabilities, resulting in higher machining efficiency because of combined effects of textured tools and hybrid nanofluid. Taguchi and MOPSO can lower roughness values than the non-optimization method when turning Al7075-T6 by identifying the most favorable combinations of cutting speed, DOC and feed rate [8]. The application of CuO nanofluid improves surface finish significantly by lowering interface friction and increasing heat dissipation efficiency. A statistical test revealed that spindle speed has the greatest effect on SR, followed by feed rate and DOC [9]. Graphene greatly decreased friction (6.80%-17.04%) and wear showing the creation of a stable carbon coating that increased wear resistance. The MQL milling trials found that the optimized nanofluid reduced cutting temperatures by 11.31%-20.98%, SR by 7.35%-20.33% while also prolonging tool life by up to 52.9% [10]. Micro-textured inserts improved surface quality and tool wear in both MQL and dry environments when compared to non-textured inserts. Chen et al. 2024 reported that the combination of MQL and CO_2 cooling significantly improved the drilling process, reducing cutting forces by 32% and SR by 65% when compared to dry cutting. This combination of (C/L) considerably increases machinability, yielding superior machining outputs with surface smoothness and more accurate circularity [11]. Table 1 compares the previous work of different researchers.

Table 1. compares the previous work of different researchers

Ref. No.	Metalworking fluid (MF) Technique	Nanofluid additives	Statistical technique	Remarks
[5]	MQL, RHVT, Compressed air and dry cutting	No	No	Lower tool tip temperature by up to 16%, tool wear by up to 102–106%, average cutting forces by 17–21%, and SR reduced from 11–21%
[6]	MQL, NMQL and dry approach	MoS_2	ANOVA	MQL produced positive results than dry cutting
[7]	MQL	Graphene	No	Graphene enhanced wetting and cooling properties of cutting fluid
[8]	NMQL	Al_2O_3	TOPSIS and ANOVA	Feed is the most important parameter for improving MRR and surface roughness.
[9]	-	CuO	ANOVA and Taguchi	The right combination of parameters (600 rpm, 300 mm/min, and 0.4 mm) resulted in

				the lowest avg. SR (Ra) (1.174 µm).

Conclusions

1. The application of hybrid nanofluid reduced cutting force and improved surface quality.
2. The application of nanofluid outperformed traditional methods in reducing cutting temperature, SR and enhanced surface finish
3. MQL reduces friction between the tool and the workpiece, reducing thermal and mechanical stresses on the cutting tool, causing less tool wear while effectively increasing surface quality during turning of Al7075-T6 alloy.
4. Textured inserts improved surface quality and reduce tool wear.

Future Scope

1. Many authors have employed Al_2O_3, CuO, MoS_2, graphene and TiO_2 as the nanofluid and calcium disulphide and molybdenum disulphide, carbon nanotubes and h-BN and MXene hybrid nanofluid for production. Other base fluids and surfactants can be used to create hybrid nanofluids and test their performance throughout various machining procedures.
2. There is an absence of optimization for MQL, NMQL, and TNMQL approaches in the literature, highlighting a potential area for future research employing hybrid nanofluids.

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