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Performance Assessment of Sustainable Machining Techniques

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Abstract: One of the often used strategies in the machining process is to lower the cutting temperature and enhance the tool life with the application of cutting fluids. The application of conventional cutting fluids is wide spread and commonly found in industries. In spite of their advantages, the application of these conventional cutting fluids is not financially feasible because of their high disposal costs, non eco-friendly and also damages the operator's health. In this context, alternative techniques to cutting fluids that can be more sustainable is the need of the hour. This work focuses on a comprehensive experimental investigation of such alternative techniques, including MQL (Minimum Quantity Lubrication) using vegetable oil-based hybrid nano fluids which are more environmentally friendly, and machining processes that are assisted by ultrasonic vibration without the use of cutting fluid. The study also highlights the advantages of these processes over machining using conventional cutting fluids and provides insights in to the available alternate techniques in terms of their machining performance. These approaches can be a better alternative option for reducing cutting forces, cutting temperatures, and tool wear while improving surface finish.

Keywords: MQL, Vegetable oils, Nano fluids, Hybrid nano fluids, Ultrasonic machining

Introduction

The standard technique for improving surface quality of workpiece and productivity is through lubrication and cooling by employing cutting fluids. By decreasing friction between contacting surfaces, lubrication reduces heat generation, and provides cooling action that lowers the cutting temperature by dispersing heat.(HMT & Production Technology, 2001) Most of the industries were utilizing lubricants for lubricating their machines.Among the constituents of lubricant, petroleum remains the primary ingredient with significant percentage (De Silva & Wallbank, 1999). Furthermore, In the machining industries, metal working lubricants are the form of lubricants that boost product efficiency by lubricating and cooling actions. As a result, the consumption of metalworking fluids in the machining industries increased. Despite the numerous advantages they offer, it was discovered that standard cutting fluids have certain drawbacks. Conventional cutting fluids need to be disposed of since they lose their effectiveness and quality over time. Because these fluids are not biodegradable, their disposal causes ecological imbalance. Due of their concern over the environment and sense of responsibility, manufacturing industries have thus started to put an endeavor to clean up the zones that are prone to cutting fluids slurry. Mist production is another issue connected to the application of cutting fluids. Aerosol buildup in the respiratory systems of workers exposed to these conditions, causes chronic pulmonary diseases. According to numerous studies undertaken by academia, exposure to cutting fluids causes chronic skin

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conditions including dermatitis in machine tool operators, accounting for over 80% of their work-related medical disorders. (Bennett, 1983).

When used as lubricants during machining, conventional cutting fluids cause a number of technological and environmental issues. Some of these include respiratory and skin issues for the workers, water and soil contamination while disposal, and more significantly, chemically disassociation of cutting fluids causes environmental pollution (Howes et al.1991; Passman & Roosemoore et al. , 2002) reported that gram-positive bacteria produced by the use of artificial and semi-synthetic cutting lubricants is growing, which promotes the spread of diseases to workers exposed to such conditions. According to Korde et al. (1993), over 7–10 lakh operators in the United States alone were exposed to cutting fluids, based on the bio degradation of chlorinated chemicals. The existence of bacteria and fungi, especially in water-soluble cutting solutions, results in the production of toxic microbial byproducts. Zeman et al.(1995) and Sreejith et al. (2000) concluded that standard cutting fluids harm both the operators health and environment. Also, due to increased environmental concern and positive actions for pollution control, manufacturing businesses have been facing a significant barrier to minimize the application of conventional cutting fluids (Tan et al.,2002) . The amount of lubricants used worldwide in manufacturing industries totaled about 38 mmt (million metric tonnes), with an (estimated growth of 1.2% over the next ten years (Kilne& company, 2006). According to Filipovic et al.(2000), using cutting fluids in bulk results in a significant share of the overall manufacturing cost. Installation and maintenance expenses for fluid supply systems, the fundamental cost of purchasing fluid, the price of fluid disposal, and the economics of treating fluid waste are only a few of the costs associated with cutting fluids. The aforementioned expenses are substantial because production facilities use numerous reservoirs that have a storage capacity of thousands of gallons of fluid.

Due to issues with quality, it is occasionally necessary to flush out all of the fluid in the tanks systems to clean the system. (Byrne & Scholta, 1993). Relative to cutting tools, manufacturing facilities spend higher cost on cutting fluids (Sokovic & Mijanovic, 2001; Sanchez et al., 2010). Researchers were urged to do in-depth study on cutting fluid substitutes that could eventually lead to environmental friendliness and sustainable production. To be able to reduce the negative impact on the environment and worker's health, a variety of alternatives to the usual cutting fluids are presented, including solid lubricants, dry machining, Minimum Quantity Lubrication (MQL), cryogenic coolant, vegetable oils, and nanofluid (Padmini et al., 2015).

In view of the reported literature, it can be understood that the conventional cutting fluids in spite of the widespread use in the manufacturing industry, has lot of disadvantages from environmental and human health perspectives. In addition, cost of production also increases due to the high cost incurred in their disposal. This work suggests alternative techniques that can be more advantageous and ecofriendly. The study deals with a consolidated experimental study of the development of environmentally friendly cutting fluids, such as vegetable oils based nanocutting fluids, and cutting fluid-free ultrasonic machining methods.

Alternative Sustainable Techniques

Nano Cutting Fluids Based on Vegetable Oil

One of the alternatives proposed is the employment of nano fluids in place of traditional cutting fluids following a thorough analysis of the application of vegetable oils, solid lubricants, and nanofluids in turning operation utilizing the MQL (minimum quality lubrication) method.

Vegetable oils were used to prepare nanofluid, which is a base fluid with nanoparticle suspensions. Due to their efficient cooling and lubricating qualities, coconut, sesame, and canola oils have been used as base fluids. Nano boric acid (nBA) and nano molybdenum di-sulphide ($nMoS_2$) suspensions were dispersed in base fluids at different percentages by weight (0.25%, 0.5%, 0.75%, and 1%) to produce various nano fluids.. The viscosity, thermal conductivity(k), and stability of the newly created nanofluid were examined to test whether they are suitable as cutting fluids for AISI 1040 steel. Figure 1 illustrate the experimental setup used to supply nanofluids. The cutting parameters that could be configured on the machine tool utilized for the turning operation are selected based on the literature reviewed. Cutting speeds of 40, 60, and 100 m/min, depth of cut of 0.5 mm and feed rates of 0.14, 0.17, and 0.2 mm/rev were chosen for the turning process.. By using the MQL approach, 10 ml/min of the nanofluid was fed to the machining zone by means of a nozzle. Surface roughness measurements and tool flank wear studies were done offline where as observations of machining conditions, cutting temperatures, and forces were done online. Several factors were looked at in order to determine how well nanofluid improved machining performance.

In contrast to dry machining with similar cutting conditions and 0.25% nano particle inclusion, results from experiments indicated that cutting temperature, cutting force, tool wear, and surface roughness were reduced by 33%, 45.5%, 19% and 46%, respectively due to the presence of nano fluids in the machining zone. CC+nMoS_2 performed better than the evaluated vegetable oil based nanofluids. Additional research found that 0.5% of nMoS_2 displayed greater performance, which is also evident from Figs.2 (a) – (d). This effect is a result of less friction at the tool-work interface and improvement in heat transfer from the cutting zone. ANOVA and Grey Relational Analysis are also used to anticipate the principal cutting force, cutting tool temperatures, surface roughness, and tool wear that are produced by employing nano fluids during machining. The findings indicated that the percentage of nanoparticles followed by the type of base fluid are the major factors. In addition, cutting speed was found to be an important machining parameter. The use of nano particles at low concentration in bio degradable vegetable oils under MQL condition ensures the sustainability of the process.

Figure 1. Experimental setup

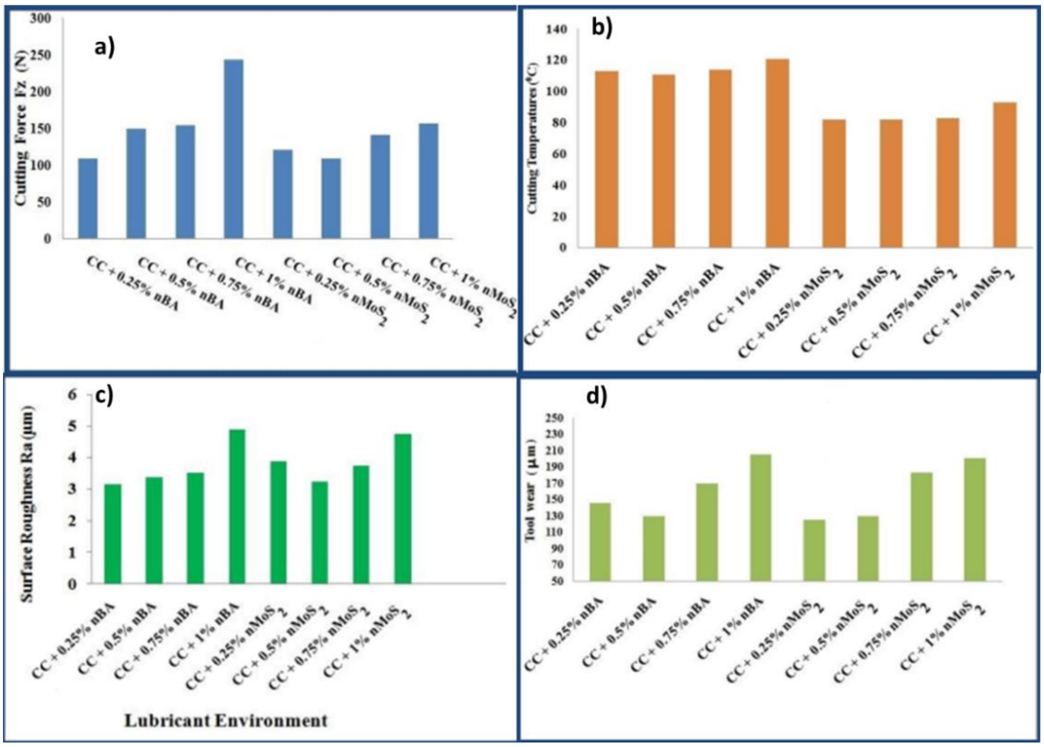

Figure 2. Machining responses with different combinations of nano fluids a) Cutting force b) Cutting temperature c) Surface roughness d) Tool wear

Hybrid Cutting Fluids Made with Vegetable Oil

In-depth investigation was made into the MQL technique's ability to reduced cutting force, cutting temperature, surface roughness, and tool flank wear. As mentioned earlier, dry machining and vegetable oil-based nano fluid (VOBNCF) offer distinct advantages over conventional cutting fluids (CCF). Also, research showed that hybrid nano fluid (HNF) outperformed nanofluid in terms of anti-wear and anti-friction performance. Unfortunately, relatively few studies on the assessment of HNF stability and use of HNFs in machining were reported by researchers.. The improved thermophysical, anti-friction, and anti-wear characteristics of HNCFs serve as the driving force behind this effort, which aims to comprehend the ability of HNCFs when turning AISI 1040 steel. The same experimental set-up used for nanofluids is employed in the investigation of hybrid nanofluids also. Initially, three vegetable oils namely , sesame, neem and mahua oil were used with 1% weight of CNT/BA and CNT/MoS_2 nanoparticles. The distinct HNCFs were prepared using SDS (sodium dodecyl sulphate), TritonX100, and Tween80 as surfactants. Moreover, the weight proportion of nanoparticles in the surfactant composition varied between samples. The preparation of these HNCFs involved the use of hybrid ratios of 1:1, 1:2, and 2:1. Using the sedimentation test and the Zeta potential test, stability was assessed. On the basis of stability, the Taguchi method was used to choose the optimal HNCF composition. In contrast to CNT/BA hybrid nanofluid, it is discovered that the CNT/MoS_2 hybrid nanofluid based on sesame oil is more stable. The best hybrid ratio for improved nanofluid stability is CNT/MoS_2 hybrid nanofluid based on sesame oil with SDS surfactant at 15% concentration of nanoparticles by weight in base oil.

The same stable HNCF was used to assess and compare the machining performance under constant cutting conditions (80 m/min cutting speed; 0.161 mm/rev feed rate; 0.5 mm depth of cut). MQL flow rate for supplying cutting fluid in machining zone is 10 ml/min. By dispersing CNT/MoS_2 nanoparticles in sesame oil at a hybrid ratio of 1:2 in concentrations of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% (wt.), HNCFs are prepared. Sodium dodecyl sulphate (SDS), was employed as surfactant. The content of SDS was taken as 15% weight of nanoparticles in all concentrations. Stability of prepared HNCFs was evaluated using sedimentation technique.

The optimal concentration of CNT/MoS2 is shown to have the lowest coefficient of friction and better machining performance in terms of reduced cutting force, cutting temperature, surface roughness, and tool flank wear. Turning experiments were carried out under various cutting conditions to evaluate the effectiveness of HNCFs in the machining of AISI 1040 steel. Analysis of variance (ANOVA) was also carried out while designing experiments utilising the RSM technique. Using hybrid nano cutting fluids, significant reductions in cutting force, cutting temperature, surface roughness, and tool flank wear were found and the same is illustrated in Figs. 3 (a) - (d).

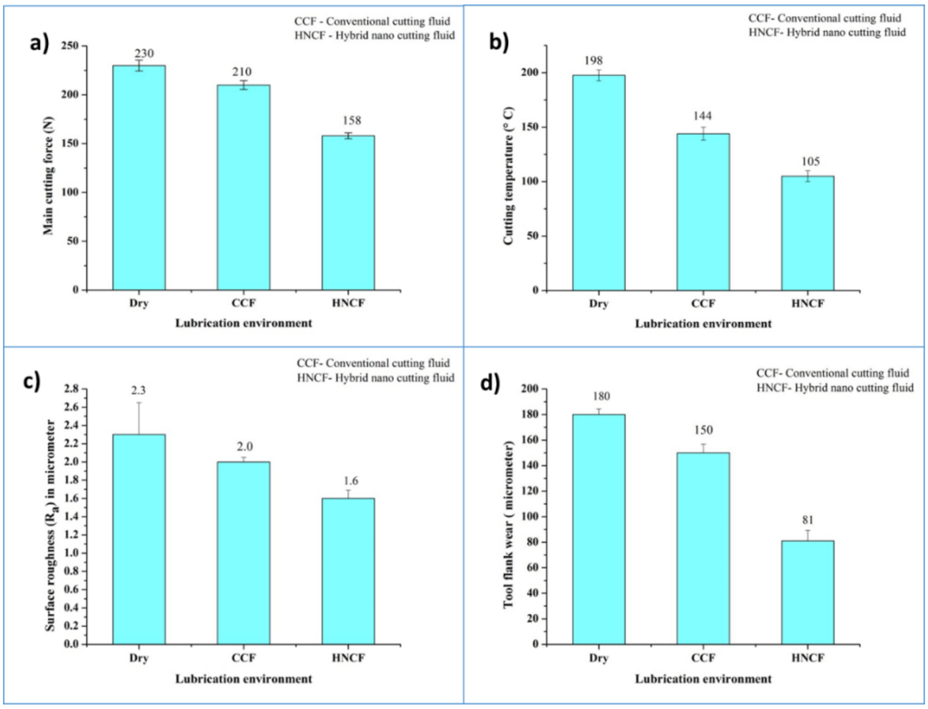

Figure 3. Machining responses with different cutting fluids a) Cutting force b) Cutting temperature c) Surface roughness d) Tool wear

At 2 weight percent of CNT/MoS_2 hybrid nano cutting fluid, in comparison to dry machining and CCF, the thrust force, feed force, and primary cutting force are reduced by 22% and1.2%, 28.3% and 13.8 %, and 32 % and 27.3 %, respectively. CNT/MoS_2 (1:2) hybrid nano cutting fluid at 3 wt% reduces cutting temperature by 43.4% and 28%, tool flank wear by 81.3% and 75%, compared to dry machining and CCF, respectively. Surface roughness is decreased at 2 wt% of the hybrid CNT/MoS_2 (1:2) nano cutting fluid by 28.5% and 18.3% when compared to dry machining and CCF, respectively. Cutting speed, feed, and depth of cut are significant variables effecting the cutting temperature and cutting force. Cutting speed and feed are more significant than depth of cut when it comes to tool flank wear and surface roughness.

Vibration Assisted Machining

To circumvent the issues with CT, one of the best machining techniques for challenging materials like Ti6Al4V alloy is ultrasonic vibration assisted turning . The UVAT(Ultrasonic Vibration Assisted Turning) setup is shown in Fig. 4. In this technique, the cutting tool was subjected to low amplitude and high frequency vibrations. The intermittent cutting nature due to applied vibrations is the reason for improved machinability of UVAT process. When compared to CT of Ti6Al4V alloy, UVAT method significantly improves surface finish while reducing cutting force and cutting temperature, according to experimental and numerical observations. The surface integrity induced by the machining process may have significant effect on fatigue life of components. The surface integrity refers to the surface characteristics (topography characteristics) and sub surface characteristics (sub layer characteristics). These characteristics may change due to variation of thermomechanical loading during cutting process. Residual stress is one of the important characteristic affected by the variation of thermomechanical loading during cutting process. So, it is crucial to research how machining factors affect residual stresses in Ti6Al4V alloy UVAT. According to numerical and experimental investigations, when machining Ti6Al4V alloy using the UVAT process, compressive residual stresses are produced on the surface of the machined component. The TWCR (tool work contact ratio), which is a function of the cutting speed, frequency, and amplitude employed in the process, significantly effects the performance of UVAT. With lower TWCR, the machining process performs better. Studies indicate that frequency, amplitude, and cutting speed are the three key factors influencing TWCR in the UVAT process. TWCR increased with increasing cutting speed but decreased with increasing frequency and amplitude.

This study assessed UVAT's ability to machine Ti6Al4V alloy in terms of cutting force, cutting temperature, and surface roughness. The trials were conducted using various machining and vibration conditions. According to the observations, cutting force, cutting temperature, and surface roughness were reduced in UVAT than CT. Cutting forces are reduced at lower cutting speeds and they are increased as the cutting speed is increased.This is due to increased TWCR with increase in cutting speed. For both UVAT and CT processes, increasing cutting speed causes the cutting temperature to increase while decreasing surface roughness.

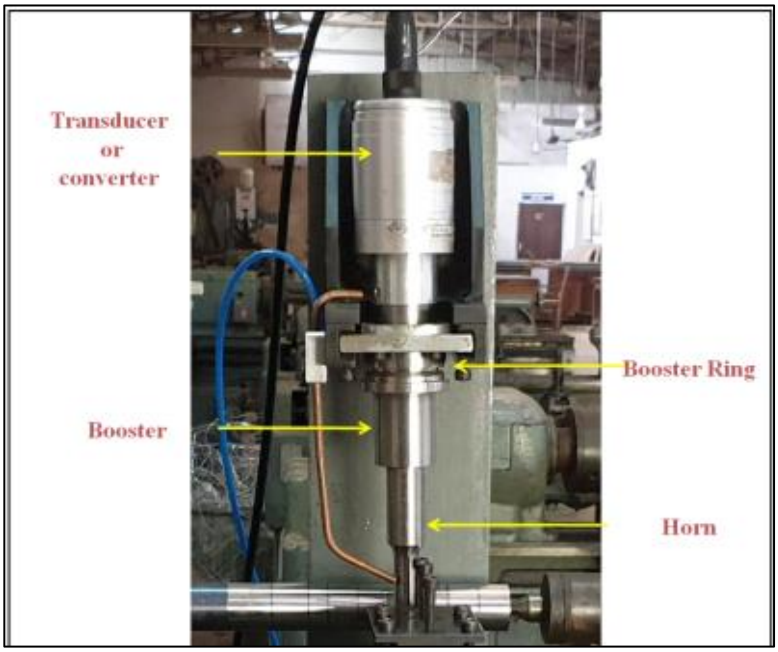

Figure 4. Ultrasonic turning setup

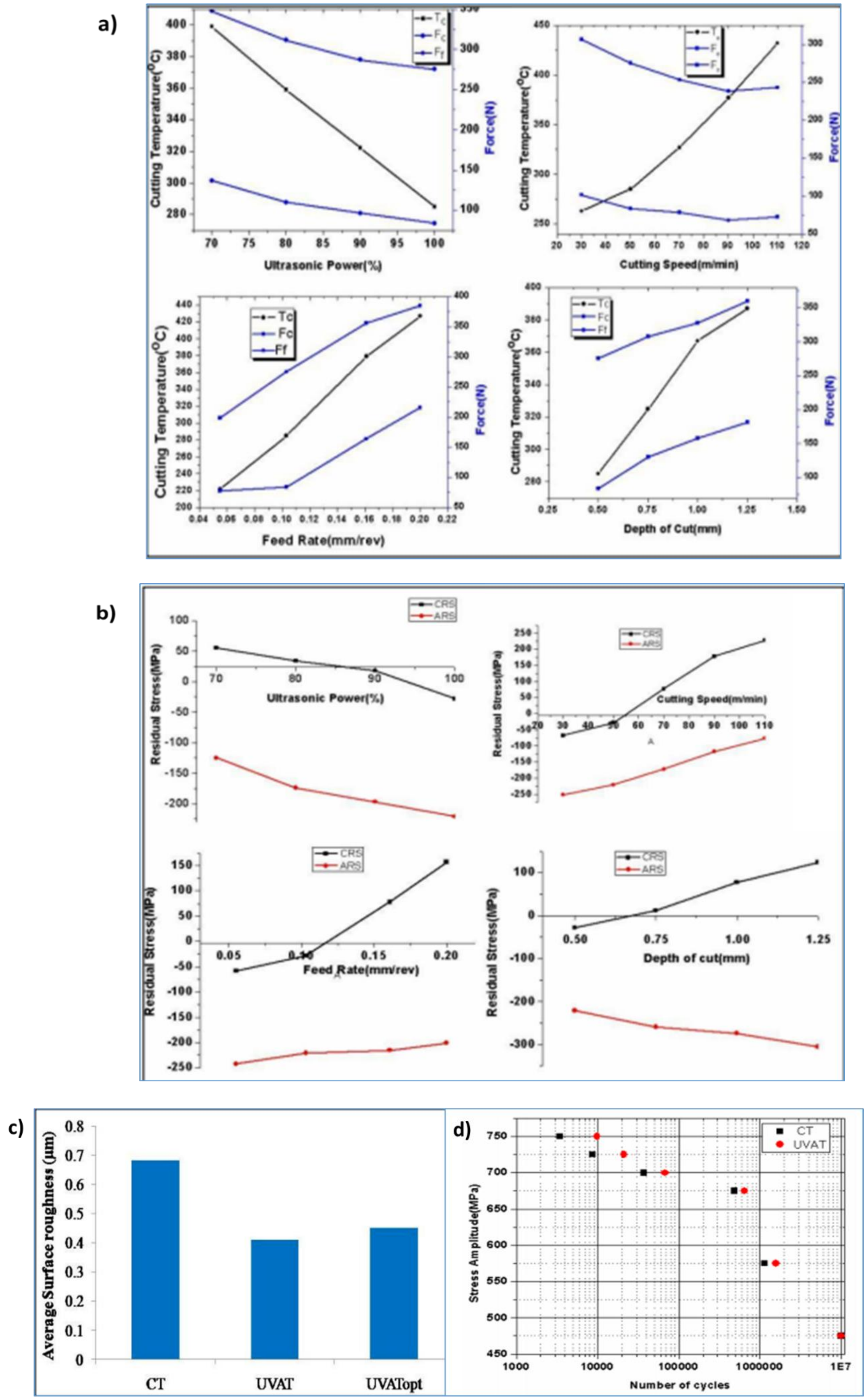

Figure 5. Machining responses in UVAT a) cutting temperature b) residual stress c) surface roughness d) fatigue life

The machining performance in the UVAT process is influenced by both mechanical and thermal loading. However, because to the combined effects of TWCR, adiabatic heat, and aerodynamic lubrication, the influence of mechanical loading dominates at lower values of machining conditions whereas thermal loading dominates at higher values of machining conditions. Because to shorter contact time in the UVAT process compared to CT at higher ultrasonic powers, the maximum and average flank wear of the tool decreases with increase in ultrasonic power. When ultrasonic power is increased from 80% to 90%, the tool life was doubled. Moreover, UVAT generates compressive residual stresses that are intended to improve the component's fatigue life. The responses from the experimental studies were shown in fig. 5 (a) – (c). The variation in fatigue life for specimens machined using UVAT and CT is shown in fig. 5 (d). The Fatigue life of UVAT sample performed is better than the CT in the selected range of machining parameters.

Conclusion

The conclusions form experimental studies conducted on alternate to cutting techniques are as follows:

Nano fluids made from vegetable oil and solid lubricants could lower the cutting force by 45.5%, cutting temperature by 33%, and tool wear by 19% and Surface finish is improved by 46% in comparison with dry machining making the cutting better and sustainable. The performance is inflenced by workpiece material, base oil, type of nao particle and percentage of nano particles.

Hybrid nano cutting fluids showed a reduction in cutting forces by 27.3%, cutting temperatures by 28%, tool wear by 75%, and surface finish is enhanced by 18.5% compared to conventional cutting fluids. Hybrid nanofluid performance depends on base oil and type of nano particles used, ratio of nano particles and quantity of nano particles in the base fluid.

UVAT of Ti6Al4V alloy is found to reduce cutting force and temperature by 10 % to 40% and 10% to 30%, respectively, while improving surface finish by 20% to 50% compared to dry cutting. Notably, the procedure uses no cutting fluid, which increases its sustainability. In UVAT cutting speed, vibration frequency and amplitude are the significant parameters on the performance of the process.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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