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Research Article

Experimental Investigation on Nano Oil Added Fluid Influence for the Machining of Hardened AISI H13 Hot Work Tool Steel

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Keywords

Tool wear,
Cutting forces,
Cutting temperature,
Cutting fluids,
AISI H13 hot work tool steel.

Abstract

This paper presents an experimental study on how to enhance the machining processes of the AISI H13 hot work tool steel by implementing a decent cooling and lubrication technic throughout the machining processes. Proper machining conditions and parameters for industrial applications are analysed namely; dry conditions, wet conditions of Boron and nano additive solutions. The flow rate is measured and calculated. The cutting fluid in different concentration is used in the hard-turning experiments. Different cutting speeds (100,150,200m/min), feed rates (0.03, 0.06, 0.09mm/rev), and a constant depth of cut (0.2mm) are considered. The assessments are equated against the machining forces and temperatures, using 12 pieces of PVD coated ceramic type turning insert-cutting tools. The results of experimental investigation show that the wet machining conditions have substantial effects across all the machining standards. It is indicated that the machining temperature is reduced tremendously during the both cases of wet machining conditions. Thus, wet machining by adding additives demonstrats enhanced machining conditions at the medium feed rates and lower cutting speeds by reducing the cutting force, which is a threat to the tool life.

1. Introduction

The history of manufacturing dates back to the history of human being of the Stone Age (at least 3 million years ago). Anciently, humans used different archaic methods to prepare their basic needs like food, cloth and shelter. They used stones to

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cut and prepare hide, wood, and other materials. With time, they improved their cutting tool to a single point cutting method by using bones, ivory etc. [1]. The 20th century has witnessed the inception of various refinements of machine tools in manufacturing, such as multiple-point cutters for milling machines, the evolution of automated operations controlled by electronic and fluid- control systems, and nonconventional techniques, such as electrochemical and ultrasonic machining [2]. During the past 10-20 years, new manufacturing technologies, automated systems and numerous system innovations had been implemented to improve CNC machine tool and operator efficiency and increase productivity to reduce the cost of manufacturing and improve productivity. More recent developments include incorporated probes, sensors and adaptive and hybrid machining processes that represent the eyes and ears of an operator. [3]. Tool steels are designed to have high hardness and durability under severe service conditions. These properties are obtained with the selection of optimum conditions for the heat treatment. Generally, after quenching process some austenite is retained in tool steels. It is important to recognize that a balance must be created between the mechanical properties of a component and the optimum percentage of retained austenite for a given application. Tool steels are produced in the annealed condition for ease of machining. This annealed state is considered too soft for most tooling applications.

The hardness of steel for tooling is usually measured on the Rockwell hardness “C” scale. Steel in the annealed condition will measure less than 20 on the Rockwell “C” scale. After machining, the steel is heat treated and quenched depending upon the type of steel being used. The heat-treating and quenching operations increase the toughness and strength of the material [4]. Tool steel is any steel used to shape other metals by cutting, forming, machining, battering, or die-casting or to shape and cut wood, paper, rock, or concrete. A mixed classification system is used to classify tool steels based on the use, composition, special mechanical properties, or method of heat treatment [5]. They are well matched for tool manufacturing, such as hand tools or machine dies and their hardness, resistance to abrasion as well as their ability to retain shape at increased temperatures are their key properties [6].

The continuous evolution of hot forming tool steels has brought about improved mechanical properties. An alteration in the alloying composition as well as a primarily decreased silicon content make them tougher and enhance their wear resistance at high temperatures. Although, this is at the cost of their machinability [7]. Tool steels are harder, tougher, and have better machinability and low deformation whilst heat treatment and hence used to manufacture hot forging dies [8]. These alloy tool steels, which have among other elements, relatively much tungsten, molybdenum, vanadium, and chromium, allows for severe service requirements and give an enhanced dimensional control and freedom from cracking whilst heat-treating [3]. Notably, tool steels have been widely used to manufacture forming dies and molds by machining processes. In general, cubic boron nitride (CBN) as well as ceramic tools are commended for finish-machining specific steel [9]. It is noteworthy that there are different bodies responsible for the standardization for these steels and they include; American (AISI & ASTM), German (DIN), Turkish (TS & MKE), British (BS) and Euro norm [10]. The AISI classifies steels basing on their salient characteristics like alloying (such as tungsten or molybdenum high-speed steels), application (such as cold-work or hot-work tool steels), and heat treatment (such as water-hardening or oil-hardening tool steels) [3]. Tool steels are also used in a wide variety of other applications where resistance or wear, toughness, mechanical strength and other properties are selected for optimum performance [11]. Research on hot work tool steels with various microstructures demonstrated that high working temperatures significantly affect the strength and softening of steels [12]. Hot work steels are used mostly in die making industries owing to their ability to retain hardness at relatively higher temperatures, with enough strength as well as toughness [13]. Nonetheless, high hardenability and toughness makes H13 to be used for making extrusion mandrels, plastic molds, dies and their holder blocks, cores and hot work punches [14]. H13 tool steel can also be used as the die material in precision molds of manufacturing tools for die-casting [8].

Numerous researchers have studied about tool machining. In [15], a number of investigations were performed on the hard turning of cryo-treated AISI H13 hot-work tool steel with two ceramic inserts under both dry and wet cutting conditions. Three categories of the hot-work tool steel were turned in the machinability studies: conventional heat treated (CHT), cryo-treated (CT) and cryo-treated and tempered (CTT). Experimental results showed that the lowest wear and surface roughness (Ra) values were obtained in the turning of the CTT samples.

Additionally, in terms of main cutting force (Fc), surface roughness (Ra) and tool wear, Ti[C, N] mixed alumina inserts (CC650) showed a better performance than SiC whisker-reinforced alumina inserts (CC670) under both dry and wet cutting conditions. The use of cutting fluid slightly improved the machinability of the tool steel. In [16], cutting performances of TiCN–HfC (TH) and TiCN–HfC–WC (THW) ceramic tools in dry turning hardened AISI H13 was investigated. A study on continuous turning of hardened AISI 52100 (~63HRc) using coated and uncoated ceramic Al2O3–TiCN mixed inserts, which are cheaper than cubic boron nitride (CBN) or polycrystalline cubic boron nitride (PCBN) was conducted in [17]. In [18], an FSP was applied on the Aluminum 7075-T651 alloy sheet. Application of multi-objective multivariable genetic optimization in FSP was presented.

A trade-off among various mechanical properties of an aerospace alloy and energy consumed during FSP was sought out. At first, the experimental data regarding the elongation, tensile strength, hardness and the consumed electrical energy with respect to various spindle rotational speed and feed rate of FSP were measured. Then an Artificial Neural Network-based approximation approach was used to approximate the value of measured data during the Genetic Optimization. The study in [19] presented an experimental investigation on the effects of rounded cutting-edge radius and machining parameters on surface roughness and tool wear in milling of AISI H13 tool steel (52HRC) in dry and cryogenic machining. Hard milling on AISI H13 steel in terms of productivity, quality, and cutting energy under nanofluid MQL condition was investigated in [20]. [21] focused on the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and thrust force (Ff). A number of drilling experiments were conducted using the L16 orthogonal array on a CNC vertical machining center.

In this study, the effects of the three different machining conditions on machining of hardened and conventionally heat-treated AISIH13 hot work tool steel using ceramic inserts. Different cutting parameters were used to analyze the stable machining processes by measuring the machining temperature and forces at the cutting zones. Thermal camera was used to measure the machining temperature at the cutting zones along the cutting tool path. The kirstler dynamometer fixed on the tool post was used to measure the machining forces applied on the work in three different angles. Then the results were equated and the enhanced machining condition and parameters were selected for this specific tool steel.

2. Materials and Method

2.1 Work Piece Material

The work piece material used in the experiment is the hardened and conventionally heat treated AISI H13 hot-work tool steel round bar of Ø56 × 200 mm dimensions. In order to homogeneously harden the steel bars, holes of 30 mm in diameter were axially drilled through it. The chemical composition and the heat treatment applied to the AISI H13 hot-work tool steel are shown in Table 1 and Table 2 below respectively.

Table 1. Chemical composition of the AISI H13 hot-work tool

Element	C	Si	Mn	P	S	Cr	Ni	Mo	V	Cu
Wt %	0.40	1.01	0.36	0.014	0.0009	5.18	0.11	1.44	0.92	0.06

Table 2. Heat treatment applied to the AISI H13 hot-work tool

Heat treatment	Thermal Cycles
Conventional heat treatment (CHT)	Vacuum hardening at temperature of 1020 °C for 20 min High-pressure nitrogen gas quenching for 2 h Tempering at 540 °C for 3 h Tempering at 600 °C for 2 h (48.8 HRc)

2.2 Cutting Tool

A PVD coated ceramic turning insert cutting tool was used throughout this experimental study. The specification for PVD coated ceramic turning insert cutting tool is given in table 3 below [5].

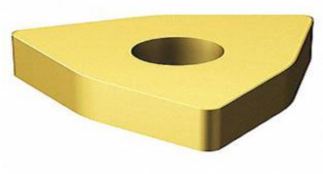

Figure 1. PVD coated ceramic turning insert cutting tool

Table 3. Specification for PVD coated ceramic turning insert cutting tool

Item	Turning Insert
Insert shape	Trigon
Insert style	WNGA
Insert Size	432
Insert Material	Ceramic
Coating Method	PVD
Coating Material	Titanium Nitride (TiN)
No. of Edges	6
Grade	6050
Work piece Compatibility	Hardened (H)
Inscribed Circle	0.500"
Insert Thickness	0.187"
Nose Radius	0.031"

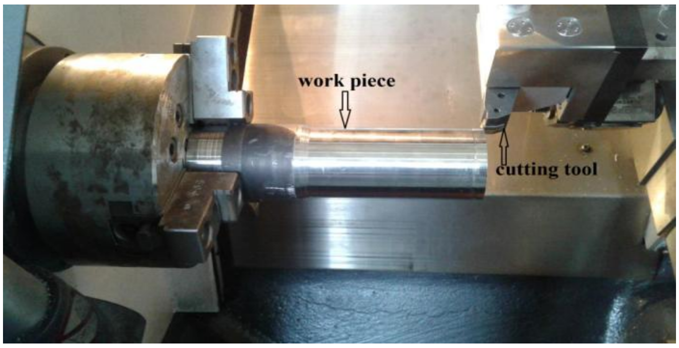

Figure 2. The positions of the cutting tool and the work piece

2.3 Cutting Conditions

The turning experiments were done using a GOODWAY CNC LATHE machine with the following specifications

Table 4. Specifications for the GOODWAY CNC LATHE machine used

Property	Value/Type
Name	GOODWAY CNC LATHE
Model	GLS-150
RPM	6000
Rated Capacity	25 KVA

The machining tests were conducted under dry, wet conditions and by adding additives. At a particular feed value (f), three different cutting speed values (v) and a constant depth using PVD coated ceramic insert WNGA432 6050 Trigon Turning Inserts. A Several 18 facing machining were made prior to the main 27 turning operations in order to specify (identify) the proper machining parameters (cutting speed, feed and depth of cut). A total 45 different machining experiments were conducted in total. The overall machining parameters and for the three machining conditions are summarized in Table 5 and 6 below

Table 5. Machining parameters used for the overall machining tests of the Hardened and conventionally heat-treated AISI H13 Hot work tool steel

Cutting Speed, V(m/min)	Feed, f (mm/rev)	Depth, d (mm)
150,200,250	0.03	0.2
150,200,250	0.06	0.2
150,200,250	0.09	0.2

Table 6. The machining experiments and the machining parameters for each of the three machining conditions during the machining of hardened and conventionally heat-treated AISI H13 Hot work tool steel

Exp.	Cutting Speed, V (m/min)	Feed, f (mm/rev)	Depth, d (mm)
1	150	0.03	0.2
2	150	0.06	0.2
3	150	0.09	0.2
4	200	0.03	0.2
5	200	0.06	0.2
6	200	0.09	0.2
7	250	0.03	0.2
8	250	0.06	0.2
9	250	0.09	0.2

The spraying mechanism of semi hydraulic pump with a 5 litres capacity tank was attached to the machine in order to spray the cutting fluids continuously (constantly) at the flow rate of 1 liter per minute for each experiment. There were three cutting conditions as dry, wet and adding additives. After the dry condition trials two wet machining conditions were done. The first wet machining was done with the concentration of 5% of the boron oil that has 5% emulsion (i.e. the hard water that provides very good cooling by taking friction heat between machining part and cutting tool), with 90% of tab water proportion. (0.25 liters of the boron and the rest 4.50 liters of the tab water). The second wet machining was done by adding 5% nano oil additives (an oil that provide good lubrication to the system) to the previous concentration. Throughout the trials, the three forces of thrust, feed and cutting forces were measured using the dynamometer. Along the machining processes the cutting temperature were also measured using the thermal camera at the fixed distances for constant measuring.

2.4 Cutting Force

A Kistler piezoelectricity dynamometer was used for the measurement of the three forces: Fc cutting force; Ff feed force and Fr radial force. The dynamometer was firmly fixed on the tool post of the machine. A Kistler 5070-A type multi-channel charge amplifier was used to amplify the force signal that was transmitted from the dynamometer. During the turning experiments, a Kistler dynamometer and a Kistler Type multichannel charge amplifier were used to measure the cutting forces Fc, feed forces Ff and radial forces Fr in all the dry, wet and by adding additives conditions. The average value of these forces value, which was measured by the dynamometer during the turning operations, was recorded as the concluding result.

2.5 Cutting Temperature

Metal cutting is a very common type of machining in a metal-cutting industry [6]. It is realized in a very complex environment and until today not completely investigated. Complex geometry of cutting part of the tool and troubles with taking away the chip and introducing the cooler and lubricant cause complex temperature phenomena on the cutting part of the tool. Cutting temperature is very important parameter of cutting process. Around 90% of heat generated during cutting process is transferred by chip, and the rest is transferred to the tool and workpiece [7]. For investigation of material machinability during turning, artificial thermocouple was placed just below the cutting top of insert, and for drilling; thermocouples were placed through screw holes on the face surface. In this way simple, reliable, economic and accurate method for investigation of machinability during cutting is obtained.

3. Results

3.1 Analysis of Machining Forces for All Machining Conditions

From the experiments, the medium cutting speeds and feed rates (200m/s and 0.06m/rev respectively) were promising parameters to stable machining for the overall machining conditions. For each machining condition, the main cutting forces exhibited the maximum reactions during the machining.

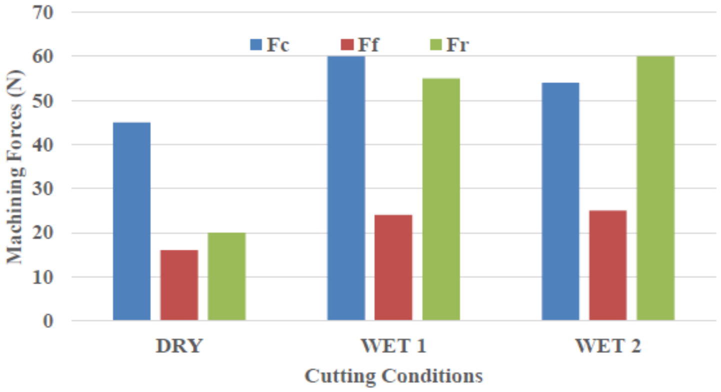

Figure 3. Comparing the three different machining forces: Cutting force; Feed forces and Radial forces for the three cutting Conditions: dry, Wet 1 and Wet 2 at the selected cutting parameters of cutting speed 200m/min and feed rate 0.06mm/rev

where Wet 1 is the machining conditions with the addition of boron coolants, Wet 2 is the machining condition with the addition of nano additives, Fc is the main cutting forces, Ff is the feed forces and Fr is the radial forces

3.2 Analysis of Main Cutting Force for All Machining Conditions at the Selected Machining Parameters.

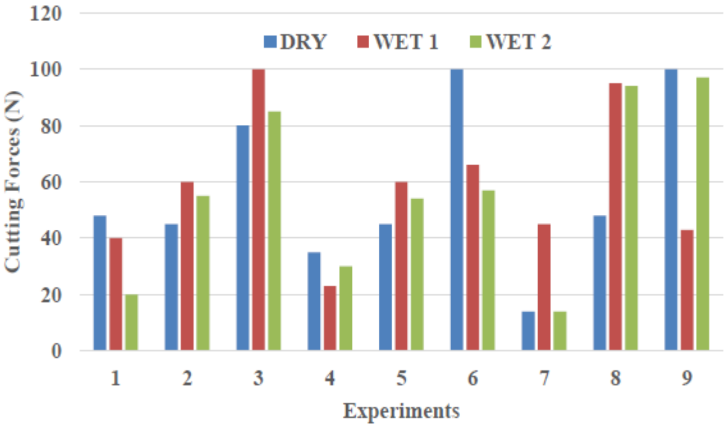

Figure 4. Comparing the main cutting forces for the three cutting Conditions: Dry Wet and by adding the nano additives at the selected cutting parameters for the 9 different experiments

The graph depicted above (Figure 4) shows how the main cutting forces deviates for the selected cutting parameters across the entire experimental studies.

3.3 Analysis of Feed Forces for All Machining Conditions at the Selected Machining Parameters.

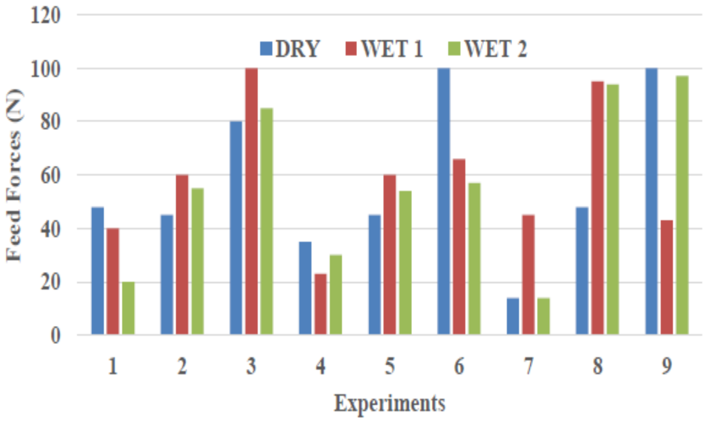

Figure 5. Comparing the feed forces for the three cutting Conditions: Dry, Wet and additive added machining conditions for the entire 9 different experiments.

The graph depicted above (Figure 5) also shows how the feed forces deviates for the selected cutting parameters across the entire experimental studies.

3.4 Analysis of Radial Forces for All Machining Conditions at The Selected Machining Parameters.

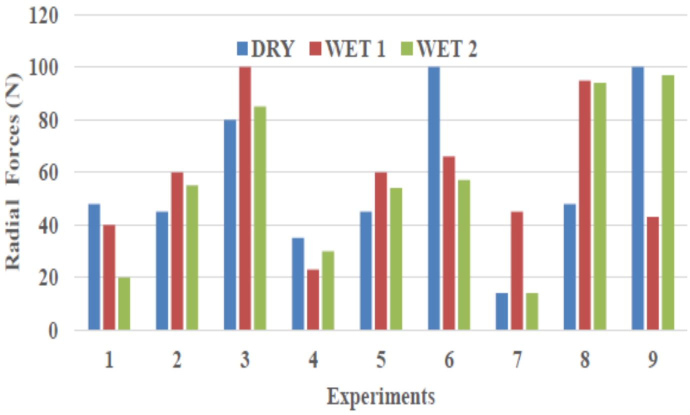

Figure 6. Comparing the radial forces for the three cutting conditions, dry, wet and additive added machining conditions for the selected cutting parameters of the entire experiments.

The graph depicted above (Figure 6) shows how the radial forces deviates for the selected cutting parameters across the entire experimental studies.

3.5 Comparison of The Initial and Final Machining Temperatures Against Selected Cutting Parameters of Cutting Speed 200m/min and Feed 0.06mm/rev.

Analysis of machining on the average temperature measurements with the selected cutting parameters: 200m/min Cutting speed, 0.06 feed rate and a constant depth of cut for the three machining conditions.

Clearly from the above diagram higher temperatures are recorded for the dry machining conditions. Even though the temperature was dropped drastically for both wet conditions, the addition of additives had great effect on the suitability of the machining processes by reducing the gap between the initial and final temperatures. Thus, addition of additives is considered very advantageous for smooth machining at the selected machining parameters.

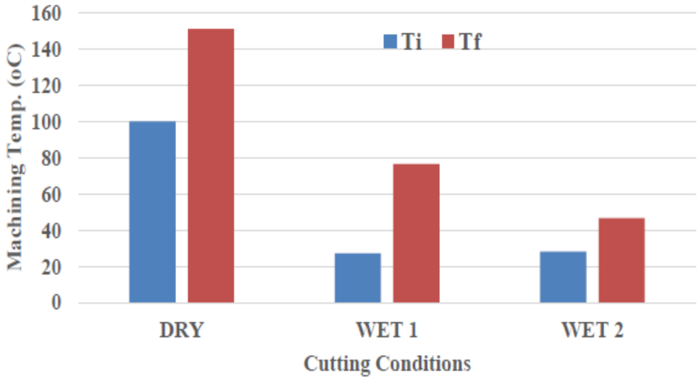

Figure 7. Analysis of machining on initial and final temperature measurements with the selected cutting parameters: 200m/min Cutting speed, 0.06 feed rate and a constant depth of cut for the three machining conditions.

3.6 Comparison of The Average Machining Temperatures Against the Selected Cutting Parameters of Cutting Speed 200m/min and Feed 0.06mm/rev.

Analysis of machining on the average temperature measurements with the selected cutting parameters: 200m/min Cutting speed, 0.06 feed rate and a constant depth of cut for the three machining conditions.

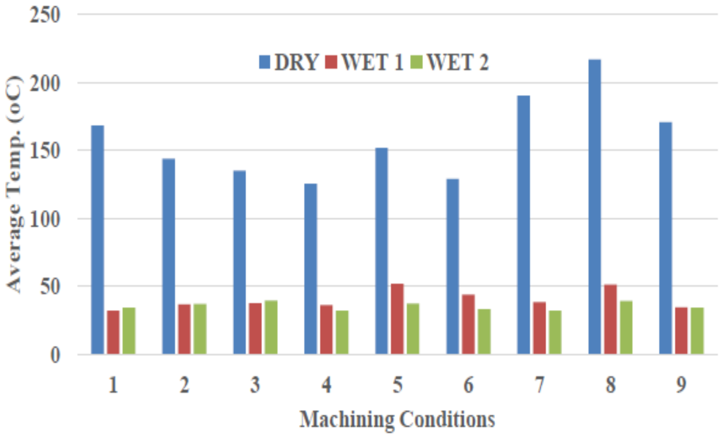

Figure 8. Analysis of machining on the average temperature measurements with the selected cutting parameters: 200m/min Cutting speed, 0.06 feed rate and a constant depth of cut for the three machining conditions.

where, DRY is Dry machining with the absence of any cutting fluids. WET 1 is wet machining by using boron for cooling effect. WET 2 is wet machining addition of nano-additives to the boron.

4. Discussion and Conclusion

In this experimental work-study, three different machining conditions dry, wet and by using additives, the cutting parameters (cutting speeds 150,200, 250m/min; feed 0.03, 0.06,0.09mm/rev, a constant depth of cut 0.2mm), were applied. The cemented carbide cutting tool material is used for machining of hardened and heat treated AISI H13 tool steel material, in order to analyze and compare against the three machining forces (cutting, feed, radial) and machining temperatures (Initial, final and average).

Previous research works for different conditions have been reviewed to ascertain their advantages and disadvantages. The machining temperatures and the forces applied have a strong effect on machining industries for the difficult to cut materials in general and the hardened and heat-treated AISI H13 materials in particular. The focus of this experimental study was to compare the different machining conditions and parameters by assessing the forces exerted and the temperature produced during the machining processes, and finally selecting the proper machining conditions and parameters that can be used in industries. Therefore, the outcomes of these experiments are listed as follows:

i. During dry machining, the machining forces increases with the increase of the feed rates and decreases with the increase of the cutting speeds for all machining conditions. In the meantime, the machining temperature increases with increasing the machining parameters.

ii. In addition, for dry machining at the medium feed rates of the three cutting speeds the machining forces shows very slight differences that let the machining processes to be uniform and very helpful to avoid the tool wear effect and produce good surface finish at the same time.

iii. During wet machining conditions for the very lower cutting speeds the temperature changes slightly for all feed rates. Thus, the lower cutting speeds favors to a very constant machining. However, comparing to dry machining conditions the temperature drops drastically.

iv. The use of additives makes the machining forces to increase with the increase of the feed rates and decrease with the increase of the cutting speed. Specifically, at the lower speeds, the machining forces changes with trivial differences that guarantees way to a better machining.

Generally, the addition of additives demonstrated enhanced machining than any other conditions throughout these experimental studies for all cutting parameters used. More specifically at the medium cutting speeds, it shows the most promising machining processes as the machining forces and temperatures were relatively low.

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Conflict of Interest Statement

On behalf of all authors, the corresponding author states that there is no confict of interest.

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