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Performance Evaluation of Hybrid MQL-Brass Nano-Fluid Coolant on Aisi 304 SS for Efficient Machining Operation

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Abstract: *Brass Nanofluid is a substance made from synthetic copper and zinc powder. It has outstanding mechanical, electrical, thermal and optical qualities employed in a variety of applications including, solar, touch screen, bison. The nanoparticles used in this study were developed from brass alloy which was locally sourced and machined to the required nano-size of 40 µm. A top-down strategy was used for the preparation of nanofluid and ball milling utilized to ground the brass alloy and sieved after grinding using a 40 µm sleeve. A double approach strategy was applied to prepare the nanofluid and the sonification process of brass nanofluid was conducted using ultra sonic equipment. The result shows that the light paraffin oil with varying concentration percentage of brass alloy and conventional cutting fluid (castrole oil) with varying concentration percentage of brass alloy display similar performance. Optimizing the additive ratio of nano particle provided better outcomes identified in the range of 2-10g with 200 ml of cutting fluid. This improves the surface roughness finish of machined part while inclusion of brass nano particle with cutting fluid improves the material removal rate, reduce the temperature and the cutting zone providing a guaranteed finish product compared to other base fluid.*

Keywords: *Hybrid MQL-Brass, Nano-Fluid, Coolant, Machining, Efficient Operation.*

1. INTRODUCTION

Nanomaterials have unique optical, electrical, mechanical, magnetic and thermal properties. Metallic or non-metallic particles of nanometre dimensions can be produced by modern nanotechnology. “Nanofluid” is the name conceived to describe a fluid in which suspending nanoparticles with average sizes below 100 nm in traditional host liquids such as water, oil, ethylene glycol and organic liquids. To create visually appealing parts that can be used right away without requiring post-treatment, ALSI304 stainless rods must be spun using MQL brass nano-coolant. In spite of the availability of numerous complex manufacturing methods, including additive manufacturing and smart manufacturing, subtractive manufacturing-which is widely available and reasonably priced-remains the fastest and most dependable method of production [1]. It is necessary to develop technical know-how to optimize the subtractive manufacturing process by interacting with input parameters in order to strike a balance between innovation and technological accessibility. The wide range of operating conditions, including coolant, lubrication, vibration, friction, cutting parameters, operator, and materials, that frequently affect the quality, quantity, and aesthetic of the component mean that choosing the appropriate cutting input parameters in the operation of subtractive manufacturing has remained a significant challenge. Optimizing cutting parameters for turning processes can result in the right amount, low cost, quick cycle time, safety, sustainability, and environmental friendliness in addition to other benefits [2].

1.1 Machining Process

Machining is the largest and most widely used manufacturing process for creating new goods from chemicals, raw materials, or finished goods. The biggest and most popular manufacturing technique for turning raw materials, chemicals, or products into new ones is machining. It is a controlled material removal process used to reduce and shape a material to the appropriate final dimensions. Subtractive manufacturing refers to a variety of controlled machining and material removal techniques that begin with solid blocks, bars, or rods of plastic, metal, or other materials that are melded by eliminating material. In the subtractive manufacturing process, the machining operations need to balance cutting parameters like spindle speed, cutting fluid, depth of cut, feed rate, and cutting force in order to prolong tool life, reduce cycle time, produce quality products, consume energy efficiently, increase productivity, maintain safety, and be environmentally friendly [3]. Examples of machining procedures include cutting, drilling, milling, turning, abrasive processes, and contemporary machining (using lasers, chemicals, heat, and other cutting-edge technologies. Researchers adopted work pieces, cutting tools, jigs and fixtures, and other operational systems as cutting parameters. The application of a suitable machining techniques offers a good number of benefits, such as lower processing costs, increased dimension accuracy, compatible surface quality, the promotion of internal and external geometric features, high material removal rates, improved material properties, and the ability to produce parts in the most cost-effective manner.

1.2 Machining Difficult-to-Cut Metals

Metals that are challenging to cut make desirable building materials for industrial processes in the automotive, aerospace, medical, food and beverage processing equipment, nuclear power plants, marine, and petrochemical industries. Additionally, utilized for water pipes and fixtures in homes and apartments. as a result of their exceptional qualities, which include high wear resistance, outstanding fatigue performance, high strength, height, weight, resistance to corrosion, high-temperature resistance, and toughness. As a result, they are frequently utilized in mechanical applications such as general transportation, energy production, and manufacturing; nevertheless, other characteristics including high hardness and low heat conductivity have an adverse impact on tool life, energy usage, and surface quality [4]. The right choice of machining parameters, including feed rate, depth of cut, tool material, and efficient coolant, is crucial to improving machinability, productivity, and lowering overall machining costs. The machining of metals that are difficult to cut still has a number of issues, particularly with titanium alloy, stainless steel, in cornel, nickel base alloy, ceramic, polymer, and composite materials. This is despite the fact that numerous studies have been conducted with the aim of defining the ideal machining parameter and choosing the better effective coolant [5]. Due to their other characteristics, such as their high strength, high hardness, and low heat conductivity, difficult-to-cut metal is known to have issues with poor machinability, short tool life, and poor surface polish during machining. While low-carbon steel and polymer showed high elongation rates and ductility among other types of hard-to-cut metals. However, the geometrical area, surface quality, and clip forms are their key areas of concern. Composite materials are homogeneous materials because they combine two or more materials with distinct qualities. They continue to be difficult to reduce in terms of parameter needs [6]. There are many different types of hard-to-cut materials that need to be machined, but it can be challenging to discover the cutting input parameters that will produce the appropriate output response [7]. The ability to control the cutting parameters and obtain the required outcomes varies depending on the working material. While some material cutting criteria, such as those for difficult-to-cut materials, call for specialized knowledge, others are straightforward and simple [8].

1.3 Cutting Fluids Sustainability for Machining Difficult-to-Cut Metals

Cutting fluids are widely utilized in many industries, but machining uses them the most. Reducing production time, cost, fuel usage, and other linked boosting processes is the basic idea behind manufacturing. Cutting fluids are crucial in achieving this goal [9]. Cutting fluids must be used extensively when machining metal that is challenging to cut. This is due to the fact that during their machining, excessive heat and cutting force are produced at the cutting edge, which raises the temperature of the cutting tool, shortening its lifespan, producing a poor surface quality, and resulting in high energy consumption. Cutting fluids' efficient cooling capabilities control the unwelcomely high temperature of the cutting tool and chip, hence minimizing friction, wear, and tear on the workstation [10, 11].

Cutting tool wear interferes with the efficiency of machining, extending production times and driving up product costs. Although other cutting factors, such as cutting force and temperature, have an impact on the condition of cutting tools, they are the most significant. As a result, it is necessary to create methods for lowering the friction and temperature that are related to metals. Cutting fluid application is one of these procedures that is crucial. Fluids' cooling properties prevent the workpiece from thermally expanding, which results in longer tool life and a better surface for the completed product. Fluids were crucial in metal cutting processes because of these benefits. In order to determine the suitability of a chosen, identified nanomaterial in terms of cutting tool life, energy usage, surface quality, material removal rate, the temperature of the cutting zone, and production rates, the act of managing cooling and lubrication, two important agents for machining difficult-to-cut metals, needs to be investigated and analysed [12]. The tool coating also helps to regulate the heat produced during machining. A detailed analysis of the interactions between the input elements for the cutting parameters is necessary to balance the effects of the rate of material removal, temperature, and surface roughness [13].

Sustainability is the capacity of a process, system, or service to operate effectively without harming the environment. Due to the fact that sustainability requires using a variety of methods and tactics to conserve natural resources and safeguard the environment, it is currently crucial to incorporate sustainable practices into manufacturing operations. The use of cutting fluids, which has an impact on the environment, is one of the main difficulties with sustainable machining. Near Dry Machining (NDM), Minimum Quantity Lubrication (MQL), Cryogenic Cooling (CC), High-Pressure Coolant (HPC), Compressed Air Cooling (CAC), and Nano Cutting Fluids Lubrications (NCFL) are just a few of the cutting-edge solutions that have been developed to help solve this issue. The issues of machinability and sustainability in the machining process are now being addressed by these techniques. MQL has certain advantages over other sophisticated techniques of this kind, including a sufficient supply of cutting fluid, consideration of the creation of cutting force, temperature, and good surface quality [14, 15]

However, industries prefer difficult-to-cut materials because to their superior physical, mechanical, and chemical qualities at high temperatures (toughness and ductility, strong resistance to corrosion, and resistance to thermal distortion). Due to its unique and exceptional qualities, AISI 304 SS is especially in demand in the chemical, marine, and aerospace industries. To preserve high strength at high temperatures and chemical reactions, improvements are suggested in the domain of machining hard-to-cut materials with poor machinability due to low heat conductivity. As seen in Figure 1 and Figure 2, there is a separate machining procedure. However, as it is simpler and less expensive than the unconventional technique, the standard method—also known as the subtractive machining method—will be used for this investigation. The machined surface of the work material and tool life are the factors that influence the machinability of hard-to-cut metals. Metals that are challenging to cut can be efficiently machined with the help of the right selection of cutting tool materials, cutting settings, and circumstances, as well as the functional behavior of machined specimens. In order to increase productivity, cut costs, be more environmentally friendly, and increase safety, this study aims to offer novel techniques for machining hard-to-cut materials without sacrificing dimensional and geometrical accuracy or the quality of the machined surface in terms of roughness, finish, subsurface quality, or hardness. According to Figure 1 and 2, stainless steel falls within the group of hard to cut materials. Generally speaking, the largest category of steels used worldwide is the AISI 300 series of austenitic stainless steels [16, 17].

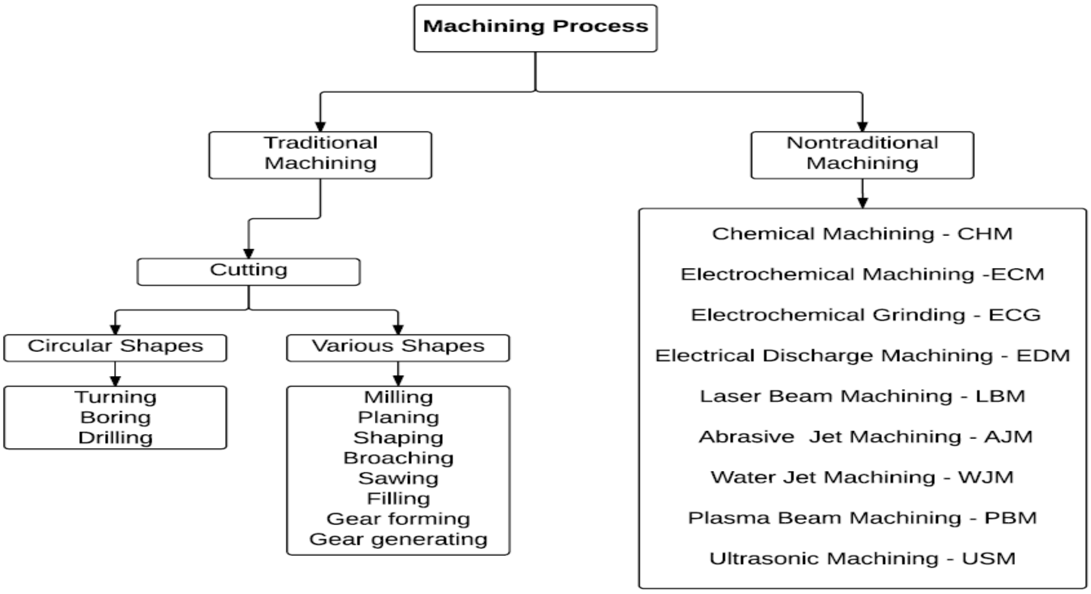

Figure 1: Machining process [18]

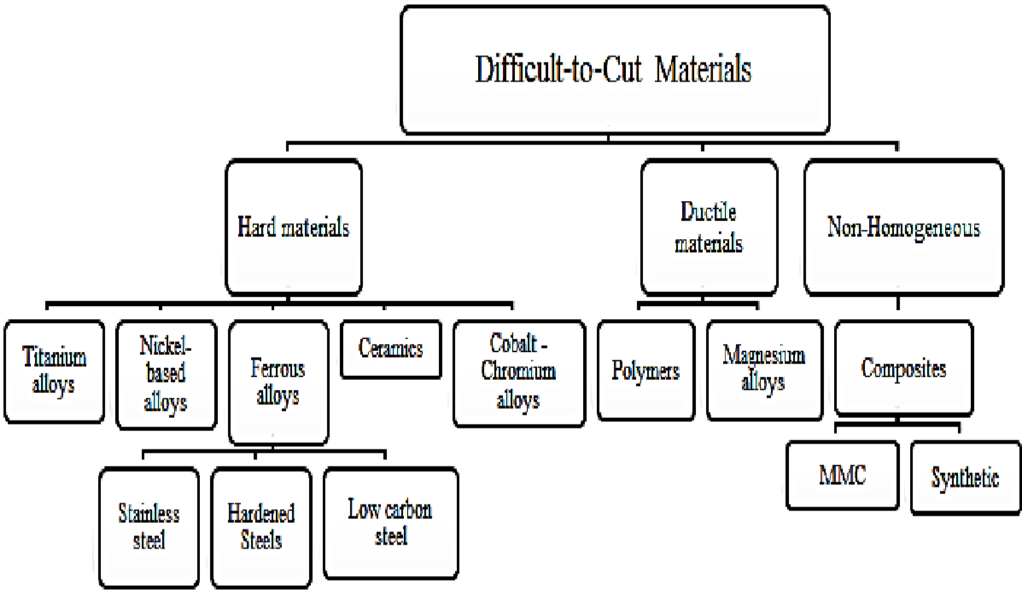

Figure 2: Difficult to cut metals [19]

Despite having much higher corrosion resistance than carbon and low alloy steels, these steels are more challenging to machine due to their poor heat conductivity, propensity for built-up edges, and high work hardening qualities. High tool wear and poor surface finish are frequent issues [20]. Due to friction at the tool-chip interface and plastic deformation that occurs at the primary shear plane, temperature builds at the chip-tool interface during metal cutting operations. The wear and life of the tool as well as the material's surface integrity are both impacted by this temperature increase. The turning operation is deemed to be the most advantageous when discussing the metal cutting or metal removal procedure because of how simple it is to conduct, how affordable it is, and how effectively it produces results. Manufacturing sectors should now concentrate on improving the turning process by speeding up metal removal and reducing cutting pressures to reduce power consumption [21].

1.4 Minimum Quantity Lubrication, MQL

The basic objective of minimum quantity lubrication (MQL) is to profit from cutting fluids without being harmed by their negative effects. It uses a small amount of high-pressure cutting fluid that is applied directly to the cutting zone rather than being drained away as is the case with flood cooling. This phenomenon is also known as "spatter lubrication," "micro lubrication," or "near dry machining" since MQL uses a much smaller amount of cutting fluid. Using a base fluid like water, oil, ethylene glycol, or organic liquid, bio-fluid and dispersing metallic or non-metallic nanoparticles or nanofibers with a unit size of less than 100 nanometre, a nano coolant is created [22]. Nano-additives can be non-metallic, mixed metallic, carbon, or ceramic nano-particles. The three types of hard to cut materials/metals include non-homogenous materials, hard materials, and ductile materials. Difficult-to-cut materials have been extensively used in a variety of technical applications, including automotive and aeronautical design, due to their beneficial properties, such as a high strength-to-weight ratio and better capacities to resist induced corrosion [23].

The process of cooling and lubricating the cutting zone during any machining operation by using Nano fluid in place of the typically utilized cutting fluids is known as nano lubrication. A specified quantity of nanoparticles with a size of a few nanometres are added to the cutting fluid to create nanofluids. Depending on the cutting fluid employed, the nanoparticles may have a tendency to settle down or float due to their various specific densities. The cutting fluid is then fully blended with the nanoparticles using an ultrasonic vibrator for around 48 hours. Due to their extremely small size, nanoparticles have a high surface area to volume ratio. Their ability to dissipate heat is greatly enhanced by their vast surface area. Nanoparticles have outstanding heat-dissipating properties as a result. It is possible to improve the cooling and lubricating capabilities of cutting fluids by adding various kinds of nanoparticles. Some of the nanoparticles that can be employed in the cutting fluids for cooling and lubricating purposes are: molybdenum disulfide nanoparticles, aluminium oxide nanoparticles, graphite nanoparticles, carbon nanotubes and silver nanoparticles [24].

1.5 Machining AISI 304 SS Alloys

AISI 304 alloys is widely used in the aerospace, automotive, and biomedical industries because of their outstanding properties, which include high tensile strength and toughness, and exceptional corrosion resistance. On the other hand, AISI 304 SS has a reputation for being a challenging metal to cut because of problems that arise during the machining process. The machinability of the material can be increased by employing moderate cutting speeds, high feed rates, a large amount of cutting fluid, and sharp cutting fluids. Cutting forces were examined during AISI 1045 in contrast to dry cutting [25]. MQL also offers decreased cutting fluid usage, extended tool life, and enhanced process performance. The machinability of hard-to-cut materials was improved by using a new cooling and lubrication technique known as minimal quantity lubricant (MQL), using the right amount of cutting fluid and compressed air [26, 27]. The cryogenic technique is regarded as another useful option for enhancing machinability and dissipating the generated heat at the cutting zone because it affects the properties of the cutting tool as well as the workpiece by using a super cold medium of liquefied gasses at temperatures lower than 120°C [28].

Less than 100 nanometres is the maximum diameter of a nanoparticle. In a number of industries, including engine cooling, engine transmission oil, diesel-electric generator jacket water coolant, boiler exhaust flue gas recovery, building heating and cooling, electronics cooling, welding cooling, nuclear systems cooling, and solar water heating, nanotechnology is used or is thought to be used. Nanofluids are used in manufacturing (drilling, turning, milling, and grinding), refrigeration (home refrigerators, chillers), defence, and space. High-powered lasers, microwave tubes, biological uses, lubrication, and thermal storage Numerous studies have been done on the enhanced heat transfer properties of nano fluids, notably in terms of convective and thermal conductivity. In a range of reviews on thermal and theological aspects in the literature, several academics have outlined various methods of heat transfer, including boiling. Graphene-suspended cooling performed on par with cryogenic cooling, if not better, and it was much simpler to use in the testing. The addition of different nanoparticles to a conventional coolant considerably increased its thermal conductivity. Wide variations in particle forms, sizes, and materials can provide a variety of thermal characteristics [29].

However, there are basically two methods for producing nanofluids; the two-step method is the method that is most frequently employed for synthesis. The metals to be used in this method are first ground into dry powder-like nanometre-sized particles, which are then used to generate the nanoparticles. The nano-sized powder is then dispersed into the base fluid using ultrasonic equipment. However, it has been found that nanoparticles have a propensity to assemble in groups due to their large surface area and surface activity. This makes it difficult to produce a stable nanofluid. A single-step technique that involves creating nanoparticles and dispersing them throughout the base fluid is used to lessen this effect [30].

A brand-new material called nanofluid is created from synthetic copper and zinc powder. It is used in many applications, including as photovoltaic, touch screens, and biosensors, and has exceptional mechanical, electrical, thermal, and optical properties. Brass has a layered structure like to that of graphite, but in graphite oxide, the plane of carbon atoms is heavily embellished by oxygen-containing groups, increasing interlayer distance and making the atomic-thick layers hydrophilic. One of brass's most prominent qualities is its excellent heat conductivity, which may reach 50,000 degrees Fahrenheit. Because of this exceptional property, brass is a good heat-transmitting medium that can be utilized as a cutting fluid in the machining of challenging materials like titanium. In tribological interactions between copper-zinc and stainless steel, the brass had a lower friction coefficient than water without brass powder and experienced less friction. Brass colloidal suspensions allowed for reductions in cutting temperature of up to 58%, lubrication improvements of up to 58.73%, and cutting force reductions of up to 26%. Again, the cutting temperature was lowered by 50% when using brass colloidal solutions. Brass-suspended coolant produced results comparable to, if not superior to, cryogenic cooling, but it was much simpler to use in the testing [31].

Table 1: Physical properties for **AISI** 304 stainless steel (**AISI 304 SS**) alloys

Property	Value
Density	8.00 g/cm3
Melting Point	1450 °C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.72 x 10-6 Ω.m
Thermal Conductivity	16.2 W/m.K
Thermal Expansion	17.2 x 10-6 /K

Chromium serves as the primary alloying component other than ferrous in stainless steel. When oxygen is present, chromium surrounds the metal and creates a thin coating to protect it from the environment. The physical properties of AISI 304 stainless steel are presented in Table 1 [31]. Excellent forming qualities are present in the grade. Without undergoing any intermediary heat-softening procedures, it can be drawn. It retains its qualities well, particularly its hardness at cryogenic temperatures. In the majority of situations, corrosion resistance can be restored without post-weld annealing. Wherever little carbide precipitation is required, the low carbon 304L grade can be employed. The grade is simple to clean and sterilize and gives good resistance to the majority of oxidizing acids. Compared to carbon steel, AISI 304 SS is less machinable. If slower speeds and high feed rates are used along with cutting fluids, it can be easily machined. Stress corrosion cracking can occur with AISI 304 SS. In chloride and salty environments, it exhibits less corrosion. The product's structural rigidity is compromised by chloride ions' localized pitting corrosion. Some of the applications are found in food processing equipment, particularly in beer brewing, milk processing, and winemaking, fasteners and flange manufacturing, architectural applications such as roofing and cladding, doors and windows, automotive and aerospace components, heat exchangers [32].

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The materials used to carry out this research work are metal particles namely copper and zinc metal; brass nanoparticles, distilled water, beaker while the equipment is lathe machine, 40-macron sieve, hot-plate stirrer, hydrometer, digital beam balance and viscometer.

2.2 Methods

The locally-sourced brass alloy was separated, cut to chips and milled into a nano size 40 nanometre using top-down method to create the optimum structure with the required qualities. The pebbles were added in ratio 3:1. That is, 3 grams of pebbles were added for every gram of brass chip. A mesh of 100 microns was used to crush-up particles for hours and sieved through a 40-micron mesh to obtain the necessary nano-sized particle as presented in Figure 3.

The quantity of Brass nanoparticles required for the preparation of Nanofluids is calculated using equation 1 [32].

$$\%\ \text{volume concentration} = \frac{\left[\frac{W_{Br}}{\rho_{Br}}\right]}{\left[\frac{W_{Br}}{\rho_{Br}} + \frac{W_{bf}}{\rho_{bf}}\right]} = \frac{\left[\frac{W_{Br}}{8730}\right]}{\left[\frac{W_{Br}}{8730} + \frac{200}{1000}\right]} \quad (1)$$

The quantity of Brass nanoparticles required to prepare Nanofluids of different percentage volume concentrations in 200 ml of base fluid is presented in Table 2 and its physical property is as showed in Table 3.

Figure 3: Produced nano powder

Table 2. Volume concentrations of brass nanoparticles with corresponding weight

Weight of Brass Nanoparticles (g)	Volume Concentration (%)
20	1.1
30	1.6
40	2.2
50	2.7
60	3.3
70	3.8
80	4.3

Table 3. Physical properties of Austenitic stainless steel AISI 304

Physical Properties	Magnitude
Density	8000
Poisson's Ratio	0.27–0.30
Elastic Modulus (GPa)	193
Tensile Strength (Mpa)	515
Yield Strength (Mpa)	205
Vickers Hardness	260
Thermal Conductivity (W/(mK))	16.3

The nanofluids were created using a two-step process. The hot plate stirrer (Stuart UC152) is used to evenly distribute the nano-sized powder into the base fluid (distilled water). The particles were stirred mechanically and passed over ultrasonic machine to transport the nanoparticle in the base fluid. This breaks up any particle agglomerations created during mixing for stable fluid. Similarly, the stability of brass was done by a sonication process to decrease nanoparticle clumping. The mass of the brass particle at various weights 2 grams, 3 grams, 4 grams, 5 grams, and 6 grams were carried out using electronic analyser scale as shown in Figure 3. The base fluid for the various masses of the brass particle was thereafter put into distilled water in a constant volume of 200ml. Two grams of brass particles were added to distilled water in a beaker and set on the hot plate stirrer. The magnetic bar was inserted into the beaker containing distilled water and speed was set to 60^0C temperature at constant 300 rev/min respectively. After being powered by an energy source for 60 minutes, the hot plate stirrer was applied while particles from the fluid were filtered as illustrated in Figure 4 and Figure 5.

As AISI 304 hardened steel is the material of choice for machining application. Two different machining operating mode conditions using AISI hardened steel bar turning were used to examine the impact of dispersed brass nanoparticles in the distilled water on the machining quality performance. Stainless steel bars of initial diameter 40 mm and length 300 m were used as the experimental workpiece. All the machining process was carried out on a heavy-duty lathe machine using uncoiled carbide cutting tool insert on a tool holder for the entire machining procedure. The machining process was carried out using the MQL method at different levels of cutting speed, feed rate, depth of cutting and % volume concentration of brass nanoparticles. The analysis of the quality of machining behaviour results are used to select the condition values. Concentration of Brass nanoparticles varying 2 vol.%, 5 vol.%, to 8 vol.% for the both running conditions for comparative analysis. In each run of running mode, machining was carried out ranging 60 seconds to 360 seconds. After, the final surface roughness was measured using Surface Profilometer.

The MQL flow rate through nozzle was set to 15ml/h at air pressure 4 bar. Nozzle distance was 50 mm from the cutting edge of the tool at an angle 10^0 from the longitudinal axis at nozzle heat diameter 1.5mm. Metal removal rate (MRR) of the workpiece before and after cutting was calculated using Equation 2

$$\text{MRR} = \frac{\text{Volume of material removed}}{\text{Time taken in min}} \tag{2}$$

The surface roughness (µm) value of the square block is quantified in µm by using a surface roughness tester SJ-210. The surface finish is evaluated three times on each machined surface perpendicular to the cut.

The experiment involved a turning process is carried out on a cylindrical job of stainless steel (AISI 304) as shown in Figure 6.

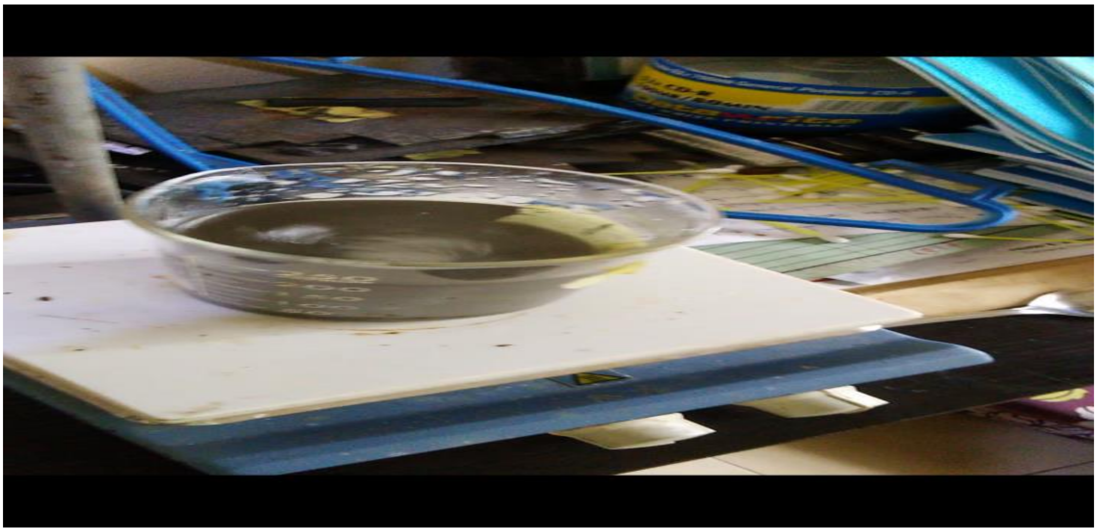

Figure 4: Ultrasonic sonication of brass nano-fluid

Figure 5: Brass nano fluid Filtration

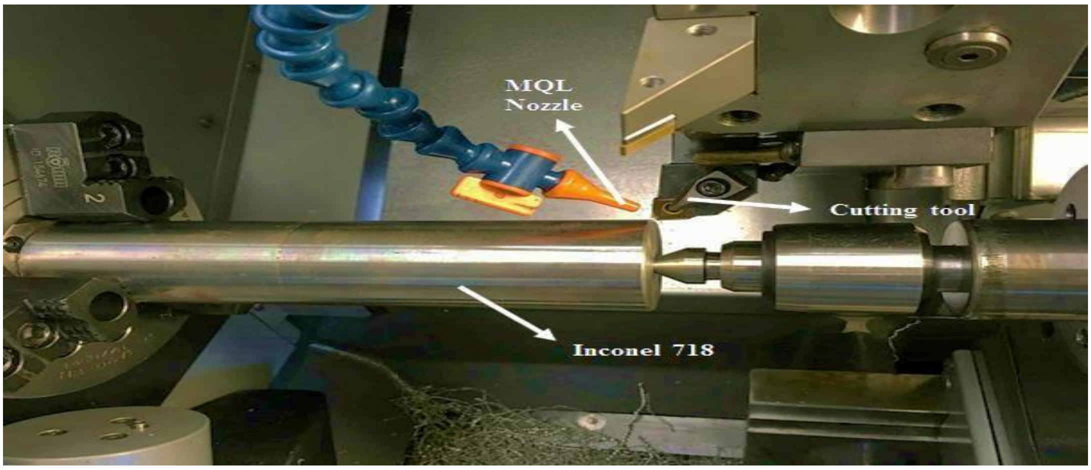

Figure 6: Experimental setup for turning AISI 304SS

3. RESULTS AND DISCUSSIONS

The results of material removal rate and surface roughness values of the turning operation samples of AISI 304 stainless steel are presented below in Table 4 to Table 10. Table 4 reveals the smaller the value, the better the finest surface roughness of material.

Table 4: Experimental results of surface roughness for average value

Job No	Surface Roughness Ra (µm)	Surface Roughness Ra (µm)	Surface Roughness Ra (µm)	Average Surface Roughness Ra (µm)
1	3.52	3.55	3.54	3.54
2	2.96	2.98	3.01	2.98
3	3.27	2.98	3.51	3.25
4	2.88	3.01	2.72	2.87
5	2.88	3.12	3.04	3.01
6	3.14	2.97	3.24	3.12

Table 5: Operational output for conventional oil and CU-Zn40 particles

Run No	Spindle Speed Vc (m/min)	Feed rate (mm/rev)	Depth of Cut (mm)	Concentrationof CU-Zn40 (wt%)	MRR (g/sec)	T ^{0}C	Ra (µm)
1	100	0.15	0.50	2	0.014	32	3.51
2	100	0.15	0.50	2	0.038	37	2.95
3	100	0.15	0.50	2	0.027	33	3.25
4	100	0.20	1.00	4	0.076	40	2.83
5	100	0.20	1.00	4	0.096	35	3.00
6	100	0.20	1.00	4	0.070	32	2.92
7	100	0.25	1.50	6	0.123	38	2.88
8	100	0.25	1.50	6	0.121	36	2.80
9	100	0.25	1.50	6	0.130	32	2.78
10	140	0.15	1.00	4	0.088	33	2.90
11	140	0.15	1.00	4	0.078	31	2.72
12	140	0.15	1.00	4	0.092	39	2.78
13	140	0.20	1.50	6	0.165	36	2.76
14	140	0.20	1.50	6	0.132	38	2.44
15	140	0.20	1.50	6	0.147	41	2.68
16	140	0.25	0.50	2	0.082	30	2.72
17	140	0.25	0.50	2	0.042	41	3.00
18	140	0.25	0.50	2	0.031	32	2.76
19	180	0.15	1.50	6	0.097	35	1.82
20	180	0.15	1.50	6	0.095	40	1.56
21	180	0.15	1.50	6	0.064	33	1.60
22	180	0.20	0.50	2	0.086	38	1.88
23	180	0.20	0.50	2	0.035	40	1.54
24	180	0.20	0.50	2	0.072	33	1.55
25	180	0.25	1.00	4	0.052	35	1.14
26	180	0.25	1.00	4	0.042	38	1.14
27	180	0.25	1.00	4	0.038	28	.098

The results showed that the material removal rate falls between 0.085 and 0.29 g/sec, the temperature between 34 and 49°C, and the surface roughness between 1.19 and 3.22 µm. The variation in the responses showed that the combination of the selection of input cutting parameters has a significant impact on the machining operations. The impact of feed rate and depth of cut proved to be the most noticeable. Increasing the feed rate from 0.15 to 0.25 mm/rev and the depth of cut from 1.5 to 2.5 increased the material removal rate from 0.085 to 0.29 g/sec, the temperature from 34 to 49°C and the surface roughness from 2.94 to 3.05 µm at a uniform spindle speed of 100 m/min. The depth of cut exhibited the highest level of significance for temperature compared to the two other factors considered.

Table 6 showed the response of utilizing the Taguchi method for optimizing turning process on machining parameters basis. It was observed from the table that the larger, the better the material removal rate.

Table 6. Signal-to-Noise ratios response

Level	Spindle speed (m/min)	Feed rate (mm/rev)	Depth cut (mm)
1	-30.90	-30.85	-30.95
2	-31.08	-31.39	-30.82
3	-31.05	-30.80	-31.27
Delta	0.17	0.59	0.46
Rank	3	1	2

The Taguchi analysis showed various data obtained by spindle speed Vc (m/min), feed rate (mm/rev) and depth of Cut (mm) of AISI 304 stainless steel machining.

Table 7. Means Machining parameter response

Level	Spindle speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	35.00	34.78	35.11
2	35.67	37.00	34.56
3	35.56	34.44	36.56
Delta	0.67	2.56	2.00
Rank	3	1	2

3.1 Material Removal Rate and Surface Roughness

The material removal rate, cutting zone temperature, and surface roughness values of the turning operation samples of AISI 304 SS are shown in Table 8 based on the 20 experimental runs. The temperature ranges from 34 to 49°C, the rate of material removal is 0.085-0.29 g/sec, and the surface roughness is from 1.19 to 3.22 m.

Table 8: Experimental responses of material removal rate and surface roughness at different levels

Run	Spindle speed (S) m/min	Feed rate (F) mm/rev	Depth of cut (D) Mm	Response 1 g/sec	Response 2 °C	Response 3 µm
S/No	Initial Value			Responses		
1	100	0.15	0.5	0.085	34	2.94
2	180	0.15	0.5	0.084	36	1.55
3	100	0.25	0.5	0.23	46	2.78
4	180	0.25	0.5	0.123	38	1.75
5	100	0.15	1.5	0.15	41	3.22
6	180	0.15	1.5	0.14	40	1.56
7	100	0.25	1.5	0.29	49	3.05
8	180	0.25	1.5	0.185	39	1.23
9	100	0.2	1	0.24	47	2.89
10	180	0.2	1	0.122	34	2.46
11	140	0.15	1	0.10	35	1.56
12	140	0.25	1	0.12	36	1.96
13	140	0.2	1.5	0.12	34	1.22
14	140	0.2	2.0	0.155	37	1.26
15	140	0.2	1	0.15	37	1.19

Run	Spindle speed (S) m/min	Feed rate (F) mm/rev	Depth of cut (D) Mm	Response 1 g/sec	Response 2 ^{0}C	Response 3 µm
S/No	Initial Value			Responses		
16	140	0.2	1	0.15	37	1.21
17	140	0.2	1	0.15	37	1.20
18	140	0.2	1	0.15	37	1.20
19	140	0.2	1	0.15	37	1.22
20	140	0.2	1	0.15	37	1.22

The range of responses demonstrate that the combination of the input cutting parameter selection has a substantial influence on the machining processes. The run number 7 showed that the feed rate and depth of cut had the most obvious effects. At a constant spindle speed of 100 m/min, raising the feed rate from 0.15 to 0.25 mm/rev and the depth of cut from 1.5 to 2.5 increased the material removal rate from 0.085 to 0.29 g/sec, the temperature from 34 to 49 m, and the surface roughness from 2.94 to 3.05 m. This might be as a result of the vibration that the increased feed rate and depth of cut have on the cutting tool. Similarly, it was discovered that the rate of material removal, temperature, and surface roughness, were 1.12 g/sec, 34 ^{0}C, and 1.22 m correspondingly, when the spindle speed was increased to 140 m/min during the turning operation at the feed rate of 0.2 mm/rev. The material removal rate was greatly improved, the cutting zone maintained at the lowest temperature, and the most aesthetically pleasing surface quality of 1.22 mm thanks to the increase in spindle speed from 100 to 140 mm/rev. This demonstrated how spindle speed affects turning operations. Table 9 shows that improving spindle speed did not result in better reactions even when the feed rate and depth of cut were decreased. In addition, Table 9 reveals that the depth of cut is the most important cutting parameter. The responses were nearly uniform at fixed input parameters for spindle speed, feed rate, and depth of cut. The values of the reactions were widening, though, when the feed rate and spindle speed were maintained constant while the depth of cut varied.

Table 9. Means Tests Response

Level	Spindle speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	2.991	2.566	2.573
2	2.751	2.400	2.170
3	1.370	2.146	2.369
Delta	1.621	0.419	0.404
Rank	1	2	3

The Taguchi technique emphasizes the significance of analysing response variation using the signal-to-noise (S/N) ratio to minimize variance in quality characteristics caused by uncontrollable parameters. Table 9 shows the impact of the parameters spindle speed on the metal removal rate values. Up to 180 m/min, it has an increased effect with a diminishing effect aftermath. The ideal spindle speed at level 3 was found 180 m/min. **T**he parameter input rate increases the feed rate and growth. The best feed rate was 0.25 mm/rev at level 3. The cutting parameter depth on metal removal rate values increases with best cut level 1.0 mm at level 2.

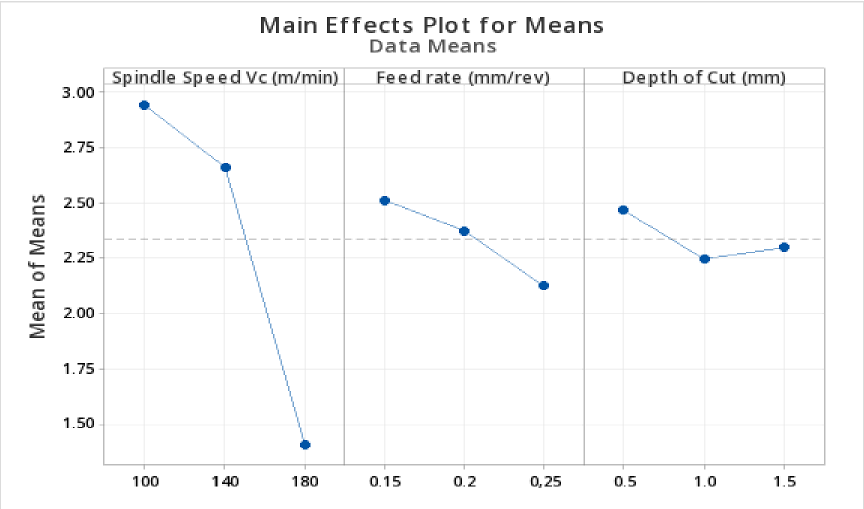

Figure 7: Analysis of surface roughness mean of means against spindle speed, feed rate and depth of cut

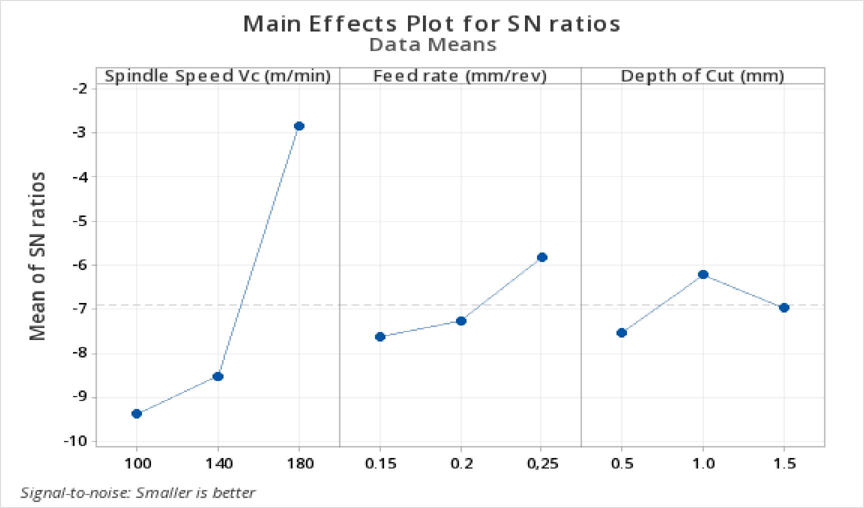

Figure 8: Taguchi analysis of surface roughness against spindle speed, feed rate and depth of cut

The effect of parameters spindle speed on the metal removal rate values is showed in Figure 7 and Figure 8 for S/N ratio. The surface roughness effect is increasing with increase in spindle speed up to 180 m/min, beyond that it decreases with optimum spindle speed at level 3.

The effect of parameters depth of cut on the metal removal rate values is shown in Figure 9 and Figure 10 for S/N ratio. Its effect is increasing with increase in depth of cut. So, the optimum depth of cut is level 21(0 mm)

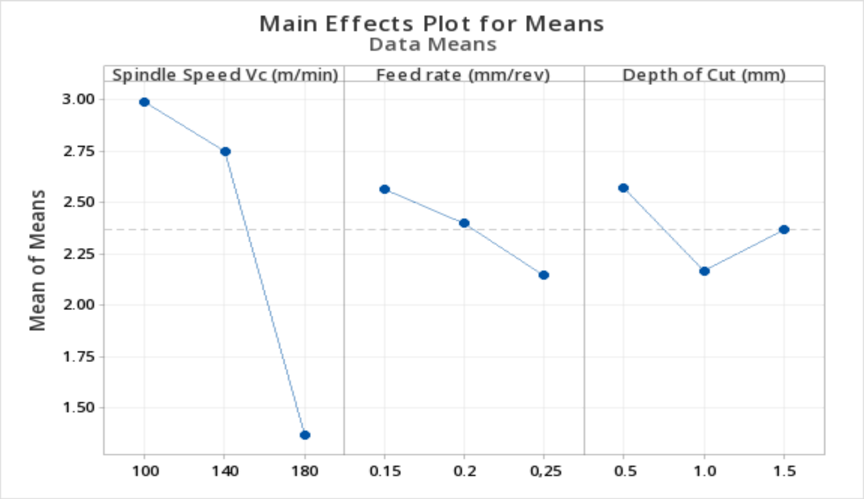

Figure 9: Analysis of surface roughness mean of means against spindle speed, feed rate and depth of cut

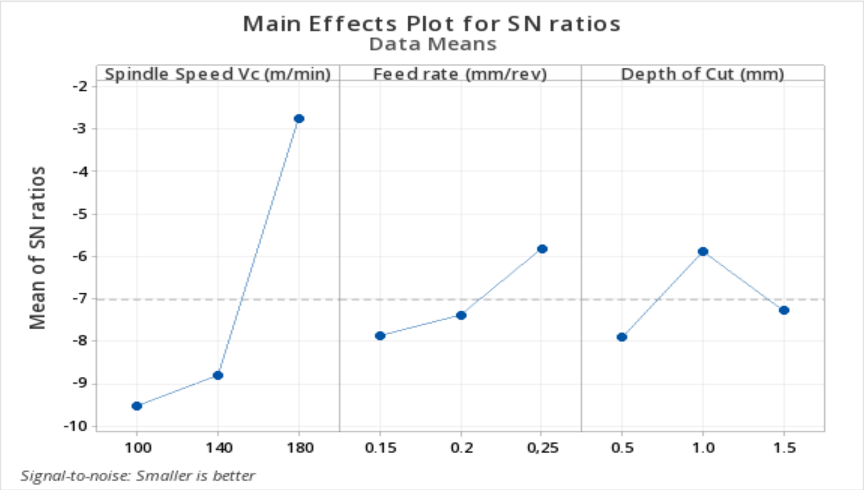

Figure 10: Taguchi Analysis of Mean of SN ratios against Spindle Speed, Feed rate and Depth of Cut

4. CONCLUSION

The present work is carried out in real time and the results are calculated as per the standard method and previous researchers' suggestions. Various issues related to cutting fluid used during the machining of hard metals and new cutting fluid technologies have been resolved. Locally-sourced brass alloy was used and cut to the requisite nano size of 40 nanometre. Due to its affordability and availability, brass was chosen as the alloy of the study. The rate of material removal ranged 0.085 to 0.29 g/sec, and the surface roughness is from 1.19 to 3.22 m was efficiently machined. The following conclusions were made:

i. Nano additive improves the surface roughness finish of machined part and the addition of brass nano particle with cutting fluid provides better surface finish when compared to other base fluid.
ii. Optimizing the additive ratio of nano particle is an essential to have better outcomes and it is identified in the range of 2-10g with 200 ml of cutting fluid in this present work.
iii. Addition of Brass alloy concentration improves the material removal rate, reduce the temperature and the cutting zone and provides a guaranteed finish product.

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