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Research Article

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# Machining of AZ91D Magnesium Alloy with Novel Nano Minimum Quantity Lubrication Condition

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## Abstract

The purpose of this research is to evaluate the effects of a novel minimum quantity lubrication (MQL) technique and nano-MQL (N-MQL) during the cutting of AZ91D alloy on the surface of the machined area. Two groups were taken for the study, i.e., control group and the experimental group. The number of samples is calculated using a sample calculator. 12 samples were taken for each group. In the control group, the machining operation is carried out on AZ91D with MQL. In the experimental group using the novel N-MQL technique. The effect of the novel N-MQ technique on surface roughness is studied. Statistical testing was performed using SPSS (Statistical Package for the Social Sciences), and sample size was determined by setting the alpha level at 0.05 and the G-power at 80%. The average roughness for group 1 was 0.166833 m, compared to 0.94 m for group 2. Group 1 is MQL with AZ91D machining, and group 2 with N-MQL cutting. It investigated how the innovative MQL approach worked and influenced surface roughness. T-test analysis shows that there is a significant difference between groups 1 and 2 (significant at $p = 0.001$, or $p < 0.05$) in their mean variance of roughness. Surface quality significantly improves with the N-MQL method in relation to MQL and paved the way for green machining.

## Keywords

Surface roughness, Magnesium alloy, Nanoparticles, Minimum quantity lubrication, CNC machining, Green manufacturing

## Introduction

The industry's lightest structural metal was magnesium. It has a few intriguing characteristics [1]. While it is as robust as metal, it is as lightweight as plastic. Alloys made from it have a high specific strength, low density, and high stiffness, and they can be recycled [2]. Magnesium alloys are frequently used in the aircraft, power, and automotive sectors [3]. Aluminum or iron could be used as alternatives for structural and mechanical applications [4]. Magnesium alloys have numerous applications due to their desirable qualities. Its hardness-to-weight ratio is higher, it has a high damping capacity, and it is easy to recycle when compared primarily to properties of developed materials.

Manufacturing components from magnesium alloy via machining is essential for achieving both low-cost and low-impact results. should be done in a cool, dry place. Adhesion, however, is a problem at slower cutting speeds, especially on the main flank face. By increasing the cutting speed, the blade's cutting edge can be lengthened to include the minor flank face and eventually the rake face of the major cutting edge. At varying cutting speeds, there was little to no difference in the Al7075-T6 workpiece's surface quality or chip morphology.

Cutting fluids, as the author explains, plays a crucial part in any cutting operation by ensuring proper cooling and lubrication [5]. Cutting fluids made from minerals are commonly used in manufacturing, but they pose serious risks to human and environmental health [6]. A sustainable cooling/lubrication system that helps the environment and makes light alloys easier to machine is necessary, as explained by the authors [7]. A high temperature in the cutting zone and a lack of control over the final product's geometry and shape are two potential outcomes of this scenario [8]. Cutting magnesium alloy to a fine finish is risky because the powdery chips that accumulate can catch fire [8]. That's why it's so important to study how different cooling rates affect the cutting process parameters in the machining of magnesium alloy. Finish face milling is a good example of why and how tool temperatures can fluctuate [7].

The research shows that there have been relatively few investigations into how novel N-MQL affects the surface roughness of AZ91D alloy. The experimental and depth theoretical knowledge about various machining operations, MQL technique, tool wear measurement techniques, metals and alloys motivated us to carry out this research work. This study is related to the machining of Z91D alloy under MQL conditions and N-MQL.

## Materials and Method

The Saveetha Institute of Medical and Technical Sciences Chennai, Saveetha Engineering Industries performed the machining procedures and surface roughness tests required for this research project. It is focused on surface roughness testing and CNC Vertical Milling Machine YCM EV1020A (Figure 1). A control group is the machining operation that uses MQL lubrication. An experimental group is a machining operation that employs the unique novel N-MQL technique, in which compressed lubricant is applied to the machining zone with nanoparticles mixed. A sample calculator is used to determine the sample count. The total number of samples taken was 24 (N = 2), with 12 samples being taken for each of the groups (N = 12). However, high cutting speeds can cause higher cutting temperatures or chip ignition. Understanding how surface roughness influences the machining of magnesium alloy is, therefore, essential. In this study, we utilized a commercially available magnesium alloy, AZ91D. The workpiece of magnesium alloy 10*10*1 cm in size was utilized.

It contained (in order of predominance) Mg (4.5 - 5.3%), Al (0.0.20%), Zn (0.28%), Mn (0.5%), Si (0.0.05%), Cu (0.008%), Ni (0.001%), and Fe (0.001%). To examine the microconstituents and intermetallic phases of the AZ91D magnesium alloy, the metallographic specimen's surface was ground progressively using a scanning electron microscope (SEM-JEOL Model No. 5600LV). For the experimental group, machining processes are finished using a setup with little lubrication. A clean production approach is near-dry machining, which uses the least amount of lubricant possible. N-MQL requires significantly less cutting fluid to be sprayed into the cutting zone. The typical flow rate for most machining operations is between 10 and 100 ml/h. Figure 2 depicts the surface roughness tester that was used in this investigation.

**Figure 1:** Vertical CNC milling machine YCM XV1020A.

**Figure 2:** Surface roughness tester SJ-410.

Surface roughness is the dependent variable, while cutting speed, feed rate, depth of cut, nanoparticles, and castor oil are the independent variables. SPSS software calculates the significance for the 24 samples from the experimental and control groups. For two groups of work items, surface roughness versus trial number graphs were used in the analysis, along with total surface roughness.

### Statistical analysis

SPSS V.26 was used to find the statistically significant difference between the test and control groups. For all 24 samples of surface roughness of magnesium alloy that were machined under the MQL and N-MQL were studied. The significant value, mean, and standard deviation for MQL and N-MQL machining techniques are studied using SPSS with a 95% confidence interval (CI). X-axis is marked with cutting environments [9, 10]. The Y-axis represents surface roughness. Feed rate, flank wear, temperature, cutting speed, nanoparticles, depth of cut, and castor oil are the independent variables. Surface roughness vs trail number graphs for two groups of workpieces were used for the analysis.

## Results

The surface roughness of the samples from the control group and experimental group was measured using surface roughness measurement equipment. The surface roughness N value in table 1 is 12 when compared to the MQL and N-MQL groups. The N-MQL value is 0.94833, and the mean surface roughness value, MQL, is 0.166833. A vertical CNC machine is shown in figure 1. The results show that MQL ma-

**Figure 3:** Magnesium alloy after drying, MQL machining.

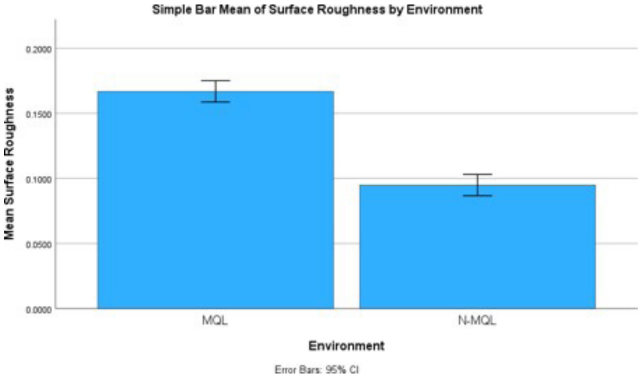

**Figure 4:** Mean surface roughness comparing MQL range is 0.1700 and N-MQL range is 0.0999 the environment error bars: 95% CI. MQL is higher than N-MQL with +/-1 standard deviation.

chining's surface finish has improved over N-MQL machining. The surface roughness tester was employed in figure 2, the workpiece in figure 3 and mean surface roughness comparing MQL in figure 4.

## Discussion

In this context, surface roughness is the dependent variable, and the independent variables are cutting speed, feed rate, flank wear, temperature, depth of cut, nanoparticles, and castor oil. SPSS is used to calculate the significance of each of the 12 samples taken from the experimental and control groups (Table 2). Surface roughness vs trial number graphs for two groups of work pieces were used in the analysis, along with all surface roughness [11]. The input variables chosen for this study were cutting speed, environment, and feed. Tool wear, chip morphology and surface roughness, are reactions that are seen. Surface roughness was seen to have decreased by 95% under MQL (Table 3). MQL reduces the cutting temperature, it improves chip-tool interaction and maintains the sharpness of the cutting edges, making it superior to dry and traditional machining with flood cutting fluid supply [12, 13].

The percentage weight ratio of the nanoparticles, the castor oil's viscosity, compressor pressure, and nozzle diameter are the variables affecting this study. The irregularity of the workpieces created by the hand lay-up approach and the impossibility of uniform distribution in manual manufacturing are the study's limitations. It is possible to research the effects of various nanoparticles, castor oils, and mineral oils. The same research can be done with nanoparticles of various sizes and

**Table 1:** Comparing surface roughness of MQL and N-MQL.

| Group | | N | Mean | Std. deviation | Std. error mean |
|---|---|---|---|---|---|
| Surface roughness | MQL | 12 | 0.166833 | 0.128829 | 0.0037190 |
| | N-MQL | 12 | 0.94833 | 0.128829 | 0.0037190 |

**Table 2:** Descriptive table displaying the mean and standard deviation of dry machining surface roughness, cutting speed, feed rate, and machining with MQL setup.

| S. No. | Environment | Cutting speed | Feed rate | Surface roughness |
|---|---|---|---|---|
| 1 | MQL | 45 | 0.8 | 1.8 |
| 2 | MQL | 45 | 1 | 1.85 |
| 3 | MQL | 45 | 1.2 | 1.97 |
| 4 | MQL | 60 | 0.8 | 1.71 |
| 5 | MQL | 60 | 1 | 1.76 |
| 6 | MQL | 60 | 1.2 | 1.88 |
| 7 | MQL | 75 | 0.8 | 1.62 |
| 8 | MQL | 75 | 1 | 1.67 |
| 9 | MQL | 75 | 1.2 | 1.79 |
| 10 | MQL | 90 | 0.8 | 1.53 |
| 11 | MQL | 90 | 1 | 1.58 |
| 12 | MQL | 90 | 1.2 | 1.7 |
| 13 | N-MQL | 45 | 0.8 | 1.08 |
| 14 | N-MQL | 45 | 1 | 1.13 |
| 15 | N-MQL | 45 | 1.2 | 1.25 |
| 16 | N-MQL | 60 | 0.8 | 0.99 |
| 17 | N-MQL | 60 | 1 | 1.04 |
| 18 | N-MQL | 60 | 1.2 | 1.16 |
| 19 | N-MQL | 75 | 0.8 | 0.9 |
| 20 | N-MQL | 75 | 1 | 0.95 |
| 21 | N-MQL | 75 | 1.2 | 1.07 |
| 22 | N-MQL | 90 | 0.8 | 0.81 |
| 23 | N-MQL | 90 | 1 | 0.86 |
| 24 | N-MQL | 90 | 1.2 | 0.98 |

**Table 3:** The surface roughness comparing equal variances of MQL and N-MQL.

| | | Levene's test for equality of variances | | T-test for equality of means | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Significance | | Mean difference | Std. error difference | 95% CI of the difference | |
| | | | | | | One-sided p | Two-sided p | | | Lower | Upper |
| Surface Roughness | Equal variance assumed | 0.000 | 0.001 | 13.690 | 22 | <0.001 | <0.001 | 0.0720 | 0.0052 | 0.0610 | 0.0829 |
| | Equal variance not assumed | | | 13.690 | 22 | <0.001 | <0.001 | 0.0720 | 0.0052 | 0.0610 | 0.0829 |

volume fractions.

## Conclusion

The purpose of the research was to examine how a specific MQL strategy affected surface roughness while milling magnesium alloy. The surface roughness of the new MQL machining process is compared to that of the N-MQL method. T-test analysis of the mean/average surface roughness of the MQL, N-MQ showed a statistically significant difference between the material groups (t = 13.690, p = 0.001). Surface roughness values are decreased when compared to MQL thanks to the ball-bearing effect of the oil's nanoparticles.

## Acknowledgements

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## Conflict of Interest

None.

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