Parametric optimization of bearing steel turning process using MCDM hybrid technique

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Abstract - The sustainable metal cutting process mainly focuses on the appropriate utilization of cutting tool and coolant. For the sustainable process, minimum quantity lubrication system externally attached with CNC (computer numerical control) machines to direct the cutting fluid at metal cutting interface. In the view of biodegradability, Nanofluids is prepared by adding nanoparticles to vegetable oil and supplied at machining zone via minimum quantity lubrication system. The key objective of the current investigation is to study the effect of dry, flood, vegetable oil and Cu (copper) and Zn (zinc) Nanofluids cooling condition during bearing steel turning process. The multi objective parametric optimization is performed using multi criteria decision making hybrid technique. For the experimental investigation, surface roughness and machining temperature selected as response parameters. Investigation concluded that Cu and Zn Nanofluids cooling conditions noticed as the significant as compared to dry, flood and vegetable oil. For Cu Nanofluids minimum quantity lubrication cooling condition, surface roughness and machining temperature decreased effectively.

Keywords: Minimum quantity lubrication, Multi criteria decision making, Nanofluid, Turning.

1. INTRODUCTION

In the machining process, heat is generated at the cutting zone to lessen the effect of generated heat cutting fluid is applied at the cutting zone. Traditionally, a large amount of cutting fluid is applied onto the cutting zone and the projected result of reducing the heat affected zone is positive. However, the contact between workers and injurious gases increased to a greater extent. Because of continuous working with harmful environments shop workers develop skin disorders and lung cancer. There were also concerns about the cost of purchasing disposal and handling of cutting fluid. To tackle the challenges identified owing to the conventional cooling system, the minimum quantity lubrication (MQL) technology was used during the metal cutting process. In terms of machine product quality and tool life, MQL achieves excellent results. MQL has been recognized as an alternative eco-friendly approach in metal cutting Industries because of the low consumption of cutting fluid. When compared to a flood system the MQL system used 10000 times the minimum amount of cutting fluid during every metal cutting process. During the metal cutting process, the nanotechnology domain was merged with it to improve the performance of a MQL system. The nanometer size particles are correctly added to the base cutting fluid and the rate of heat transfer cutting fluid is effectively raised.

Several researches show the utilization of cutting fluids with turning operation on tools and notified different Outcome. [1] A.A Junankar et al. Performance evaluation of cu nanofluid in bearing steel MQL based turning operation. Feed rate noticed as a significant input parameter followed by depth cut and cutting speed. Surface roughness is reduced by 51% vegetable oil. Its helps to decrease the cutting zone temperature by 21% vegetable oil. [2] S.T. Prashantha Kumar et al. Investigate the effect of nano cutting fluid and cutting parameters under MQL on roughness in turning of DSS-2205. Among three nanofluids the copper oxide nanofluids gives better surface roughness followed by Silicon Carbide and Aluminum oxide. [3] Rabinaray et. al. A brief study on effects of nano cutting fluids in hard turning of AISI 4340 Steel. Selection of flow rate, pressure and type of Nano cutting fluid with the proper set of input variables provide desired machining output. Improvement of efficiency of Nano fluid. [4] Usha et al. Optimization of parameters in turning using herbal based nano-cutting fluid with MQL. Intersection of MQL flow rate with volume concentration, Speed, Feed rate, DOC, volume concentration Speed with Speed, Feed rate, DOC, Speed with Feed rate and feed rate with DOC are identified as significant terms.[5] Yıldırım et. al. Investigation of hard turning performance of eco-friendly cooling strategies: Cryogenic cooling and nanofluid based MQL. Machined surface nanofluid gave better results, cryogenic cooling gave better results in tool-chip interface temperature, tool life, chip morphology and tool wear. Thermal conductivity of the nanofluid is high. [6] Garg et. at. Study of effect of nanofluid concentration on response characteristics of machining process for cleaner production. The feed rate and drill diameter are most critical for obtaining higher MRR and lower values of torque and thrust force, thus enabling cleaner production and environment. [7] Chaudhari et. Al. The best choice is that heat transfer should better at moderate viscosity value for good machining results. reduction in cutting forces, cutting zone temperature and workpiece surface morphology and tool life improved largely in Nanofluid MQL. The thermal conductivity of Al2O3 and CuO nanofluids increases with increment of nanoparticle vol. % concentration. The rate of thermal conductivity increment of CuO nanofluid is observed the higher compared to Al2O3 nanofluid even at same concentration. [8] Ondin et. at. Investigation of the influence of MWCNTs mixed nanofluid on the machinability characteristics of PH 13-8 Mo stainless steel. [9] Junankar et. al. Optimization of bearing steel turning parameters under CuO and ZnO nanofluid-MQL using MCDM hybrid approach. CuO nanofluid noted as the effective cooling condition on comparing with ZnO nanofluid. [10] Venkatesan et. al. Ability study and multi-response optimisation of cutting force surface roughness and to remain on CNC turned inconel 617 superalloy using Al2O3 nanofluids in coconut oil. Surface roughness and cutting velocity increased cutting force decreased. [11] paras et. al. Study of hybrid nanofluid of titanium oxide (TiO2) and Montmorillonite clay nanoparticles for a milling of AISI 4340 Steel. that reduced friction between the cutting inserts and the workpiece [12] Sadiq et. al. Enhance Enhancement of thermophysical and lubricating properties of silicon carbide nano lubricants for machining operation [13] Walker et. at. The MQL Handbook (Minimum Quantity Lubrication). 80% reduction of maintenance and cleaning work, better surface quality, shorter processing times. [14] Kumara et. al. An Investigation on Turning AISI 1018 Steel with Hybrid Biodegradable Nanofluid/MQL Incorporated with Combinations of CuO-Al2O3 Nanoparticles The results reported that with biodegradable hybrid nanofluids with CuO and Al2O3 (50:50) combination reduction of 13.72% in surface roughness. [15] Martin P. Lautenschlaegera,et.al. Effects of lubrication on friction and heat transfer in machining processes on the nanoscale: a molecular dynamics approach. The simulation results show that even in the presence of the working fluid, the tip of the cutting tool and the workpiece are mostly in direct contact during the machining process, i.e. the initially present fluid molecules are squeezed out of the contact zone.

After detailed research, it is got to know that the study of Minimum Quantity Lubrication with Pure form of metals- Cu and Zn is not available. Very less studies are available on pure form of metals which encourage us to know more regarding pure metals with MQL technique on turning process. Different optimization approaches were used for parametric optimization in previous study; however there were very few investigations on multi response parametric optimization. This encourages us to focus on a comparison of copper and zinc for the bearing steel turning process. Product surface quality and machining temperature were chosen as response criteria in the context of machining productivity. The entropy weighted method weighted aggregates sum product assessment was used in the multi criteria decision making hybrid approach (EWM-WASPAS).

2. EXPERIMENTATION

A bearing Steel round bar is employed as a work material for the experimentation setup (80mm length and 20mm diameter). A Spectro analysis using an AMETEK SPECTROMAX was used to determine the detailed bearing Steel composition, and the results are provided in the table. The investigation was carried out using a CNC lathe (computer numerical control). CNC was connected to the MQL system. The MQL system was oriented in the direction of the cutting tool feed and nozzle. Cu, Zn nanoparticles were used to make the nanofluid, which was mixed with vegetable oil. Three parameters with three levels were chosen during the experiment. The experiment was designed using a L9 orthogonal array, and it can be used in both Cu and Zn nanofluid machining environments. During the investigation, a total of 18 experiments were carried out. The table no.1 below shows the detailed results.

Fig.1. Experimentation Setup with MQL System

Table no.1. Experimentation parameters

Parameters	Particulars
Work material	Bearing Steel – (Length- 80 mm and Diameter– 20 mm)
Tool	Insert DNMG110408E
Base Fluid	Vegetable Oil
Machining Environment	Cu Nanofluid + MQL (5 bar, 125 ml/hr) Zn Nanofluid + MQL (5 bar, 125 ml/hr)
Machining Parameters	Cutting Speed (130,160,190) (m/min) Feed Rate (0.2, 0.3, 0.4) (mm/rev) Depth of Cut (0.1, 0.15, 0.2) (mm)
Response Parameters	Surface Roughness (Measuring Device –Mitutoyo Surftest) Machining Temperature (Measuring Device – IR Thermometer)
Design of Experiment	L9 Orthogonal Array
Total Experiments	18

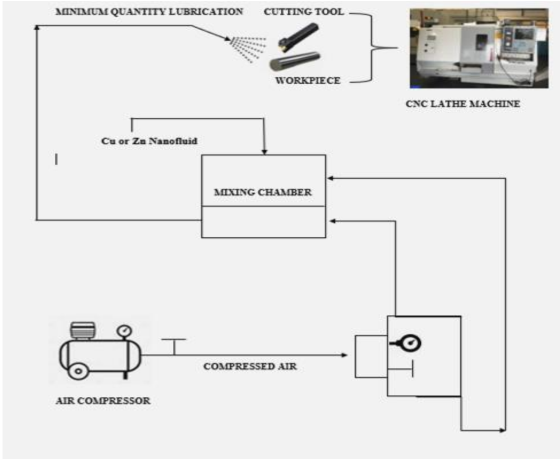

Fig.2. Experimentation Methodology

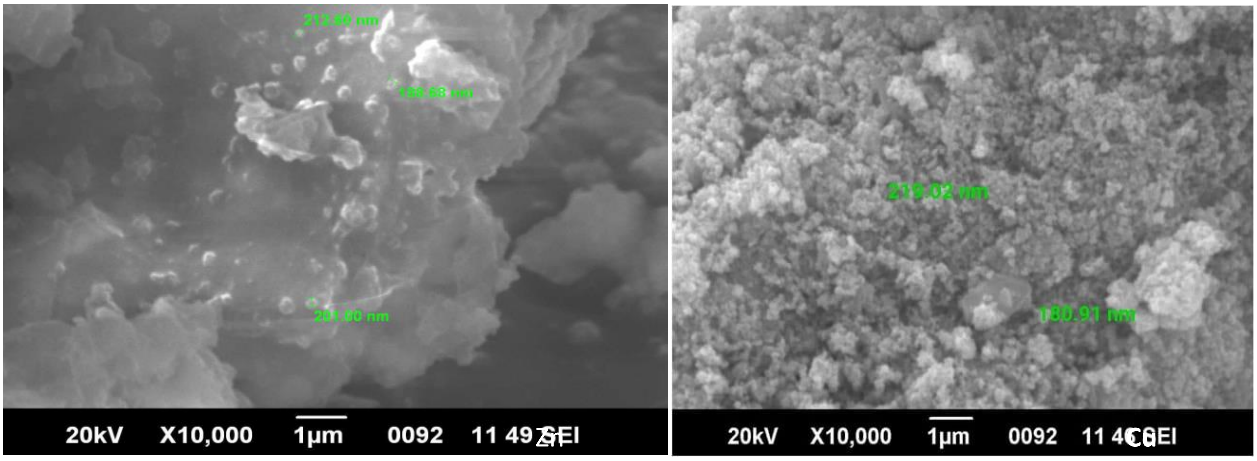

Fig.3. SEM Images of a) Zn and b) Cu Nanoparticles.

3. RESULT AND DISCUSSION

The best machining condition is determined using a hybrid approach of multi criteria decision making (MCDM). The MCDM hybrid methodology has two parts: a) the entropy weights method (EWM) and b) the weighted aggregated sum product assessment (WASPAS) method. Evaluation EWM was used to calculate the weights for on the basis of the weights, determine the best response settings the machining condition has been established.

1 Entropy weight method

Shannon and Weaver proposed this method for determining response parameter weights. To determine the response weights, use the EWM technique based on probability theory and the procedures below.

Step 1: Give your response

The experiments are built around specified evaluation criteria for the response characteristics listed in Table 2.

Step 2: Create a Decision Matrix

Eq. 1 shows the decision matrix (1). Each experiment is assigned to a row of the decision matrix, and each response is assigned to a column. Table 2 shows a decision matrix based on response parameters.

$$DM = \begin{bmatrix} q_{11} & q_{12} & q_{1j} & q_{1m} \\ q_{21} & q_{22} & q_{2j} & q_{2m} \\ q_{i1} & q_{i2} & q_{ij} & q_{im} \\ .. & .. & .. & .. \\ q_{n1} & q_{n2} & q_{nj} & q_{nm} \end{bmatrix} \ldots (1)$$

Step 3: Normalization

The favorable and non-beneficial reactions are used to standardize the collected data of response variables. Non-beneficial reaction was chosen and stated by Eq. 2 for the surface roughness and machining temperature (2).

$$NDM_{ij} = \frac{Minq_{ij}}{q_{ij}} \qquad \ldots. (2)$$

Step 4: Probability and Entropy

The probability (Prij) and entropy (Enj) of responses estimated with the help of Eqs. (3) and (4) respectively. The values shown in Table 3.

$$Pr_{ij} = \frac{NDM_{ij}}{\Sigma_{i=1}^{n} NDM_{ij}} \qquad \ldots. (3)$$

$$En_j = -Y\Sigma_{i=1}^{n} Pr_{ij} log_e(Pr_{ij}) \quad .... (4)$$

Where

$Y = \frac{1}{log_e(n)}$ n = no. of experiments

Step 5: Divergence and Entropy Weights

Eqs. (5) And (6) were used to calculate the divergence (Divj) and entropy (Ewj) for the jth response (6). Table 3. shows the results.

$$Div_j = |1 - n| \quad ..... (5)$$

$$Ew_j = \frac{Div_j}{\Sigma_{i=1}^{m} Div_j} \quad ...... (6)$$

2. Weighted aggregated sum product assessment

Zavadskas invented the weighted aggregated sum product assessment (WASPAS) technique, which is based on two techniques: the weighted sum method (WSM) and the weighted product method (WPM) (WPM). The WASPAS technique is described in the following steps.

Step 1: Create a Decision Matrix

Prepare the decision matrix as indicated in Table 2 with reference to the recorded values of the response parameters.

Step 2: Normalization

Using the minimization criteria provided in Eq. (7) the collected data for surface roughness and machining temperature were reduced. Table 2. shows the normalized response parameters.

$$x_{ij} = \frac{x_{ij}}{x_{ij}} \quad ..... (7)$$

Step 3: Total Relative Importance for WSM

Eq. (8) utilized to appraise the full relative significance $(Q_i^{(1)})$ by using WSM.

$$Q_i^{(1)} = \Sigma_{i=1}^{n} x_{ij}.W_j \quad ... (8)$$

Step: 4.Total Relative Importance for WPM

Eq. (9) utilized to gauge the entire relative significance $(Q_i^{(2)})$ by using WPM.

$$Q_i^{(2)} = \prod_{j=1}^{n} x_{ij}^{wj} \quad .... (9)$$

Step 5: Final Relative Importance

Last relative significance (Qi) calculated to upgrade the ranking accuracy and assessed utilizing Eq. (10). The ultimate FRI is appeared in Table 4.

$$Q_i = \lambda.Q_i^1 + (1-\lambda)Q_i^2 \quad .... (10)$$

Table no.2 Recorded Response Parameters

Expt. No.	Machining Environment	Surface Roughness (SR) (nm)	Machining Temperature (MT) (°C)
1	Cu NF+ MQL	2.80	28.50
2	Cu NF+ MQL	3.12	29.60
3	Cu NF+ MQL	2.13	31.40
4	Cu NF+ MQL	2.95	29.40
5	Cu NF+ MQL	2.00	28.90
6	Cu NF+ MQL	2.55	30.20
7	Cu NF+ MQL	3.01	29.95
8	Cu NF+ MQL	2.45	30.50
9	Cu NF+ MQL	2.75	30.30
10	Zn NF + MQL	3.10	32.30
11	Zn NF + MQL	2.63	32.10
12	Zn NF + MQL	2.98	29.20
13	Zn NF + MQL	3.20	30.10
14	Zn NF + MQL	2.67	31.30
15	Zn NF + MQL	2.12	30.50
16	Zn NF + MQL	2.80	30.90
17	Zn NF + MQL	3.15	31.20
18	Zn NF + MQL	2.85	31.60

Table no.3 Weight Determination

Expt. No.	For Dry Machining Environment									
	Normalization		Total Probability		Entropy		Divergence		Weights	
	SR	MT	SR	MT	SR	MT	SR	MT	SR	MT
1	0.7601	1.0000	0.1165	0.1163	0.986494	0.999814	0.0135	0.0002	0.9864	0.0136
2	0.9606	0.9757	0.1472	0.1135						
3	0.5471	0.9463	0.0839	0.1100						
4	0.5363	0.9823	0.0822	0.1142						
5	0.9004	0.9589	0.1380	0.1115						

6	0.5214	0.9329	0.0799	0.1085						
7	0.6649	0.9257	0.1019	0.1076						
8	1.0000	0.9426	0.1533	0.1096						
9	0.6338	0.9353	0.0971	0.1088						
For Flood Machining Environment										
10	0.8805	1.0000	0.1508	0.1179	0.982628	0.999610	0.0174	0.0004	0.9781	0.0219
11	1.0000	0.9757	0.1713	0.1151						
12	0.5200	0.9199	0.0891	0.1085						
13	0.5623	0.9415	0.0963	0.1110						
14	0.5755	0.9829	0.0986	0.1159						
15	0.4804	0.8973	0.0823	0.1058						
16	0.4692	0.8894	0.0804	0.1049						
17	0.8095	0.9549	0.1387	0.1126						
18	0.5403	0.9178	0.0926	0.1082						
Expt. No.	For Cu Nanofluid + MQL Machining Environment									
	Normalization		Total Probability		Entropy		Divergence		Weights	
	SR	MT	SR	MT	SR	MT	SR	MT	SR	MT
1	0.5130	1.0000	0.1026	0.1177	0.982862	0.999667	0.0171	0.0003	0.9810	0.0190
2	0.4020	0.9236	0.0804	0.1087						
3	0.5302	0.8951	0.1061	0.1053						
4	0.5097	0.9091	0.1020	0.1070						
5	1.0000	0.9477	0.2001	0.1115						
6	0.4317	0.9966	0.0864	0.1173						
7	0.5467	0.9416	0.1094	0.1108						
8	0.5524	0.9295	0.1105	0.1094						
9	0.5130	0.9539	0.1026	0.1123						
For Zn Nanofluid + MQL Machining Environment										
10	0.8636	1.0000	0.1437	0.1216	0.972960	0.999421	0.0270	0.0006	0.9791	0.0209
11	0.5429	0.9439	0.0903	0.1148						
12	0.5135	0.8938	0.0854	0.1087						
13	1.0000	0.9018	0.1663	0.1096						
14	0.6107	0.8783	0.1016	0.1068						
15	0.9500	0.9266	0.1580	0.1127						
16	0.7917	0.8901	0.1317	0.1009						
17	0.3420	0.9323	0.0569	0.1134						
18	0.3977	0.9182	0.0661	0.116						

In this Experimentation observed that under the Cu nanofluid – MQL machining environment is very effective resulted. For the Cu nanofluid and the Zn nanofluid the machining environment, lowest surface roughness and the machining temperature are reported. The weights are determined for response parameters for each machining environment. For Cu nanofluid, 0.9810 and 0.0190 weights are determined for surface roughness and the machining temperature respectively. Similarly, for the Zn nanofluid 0.9791 and 0.0209 weights are determined for surface roughness and machining temperature respectively. On the basis of determined weights, TRI estimated by WSM and WPM method. Final relative importance estimated using both TRI values and finally rank is calculated by selecting the higher value of FRI. Therefore, it is observed that the experiment no 5 for Cu nanofluid while in the experiment no 13 observed as optimum for Zn nanofluid machining environment. In the surface roughness and the machining temperature observed the noteworthy minimization due to the formation of layer of nanoparticles on the developed micro cracks on the machined component. The friction at machining zone declined with the nanoparticle layer formation on surface area of the work material. (Table5).

Expt. No.	For Cu Nanofluid + MQL Machining Environment					
	TRI for WSM (Q^1)		TRI for WPM (Q^2)		FRI	Rank
	SR	MT	SR	MT	Q	
1	0.5032	0.0190	0.5195	1.0000	0.5209	5
2	0.3944	0.0175	0.4091	0.9985	0.4102	9
3	0.5201	0.0170	0.5366	0.9979	0.5363	4
4	0.5000	0.0173	0.5162	0.9982	0.5163	7
5	0.9810	0.0180	1.0000	0.9990	0.9990	1
6	0.4235	0.0189	0.4386	0.9999	0.4405	8
7	0.5363	0.0179	0.5530	0.9989	0.5533	3
8	0.5420	0.0177	0.5587	0.9986	0.5588	2

9	0.5032	0.0181	0.5195	0.9991	0.5202	6
For Zn Nanofluid + MQL Machining Environment						
10	0.8456	0.0209	0.8663	1.0000	0.8664	3
11	0.5315	0.0197	0.5498	0.9988	0.5502	6
12	0.5028	0.0187	0.5207	0.9977	0.5205	7
13	0.9791	0.0188	1.0000	0.9978	0.9979	1
14	0.5980	0.0184	0.6170	0.9973	0.6158	5
15	0.9301	0.0194	0.9510	0.9984	0.9495	2
16	0.7751	0.0173	0.7955	0.9961	0.7925	4
17	0.3349	0.0195	0.3498	0.9985	0.3518	9
18	0.3894	0.0192	0.4054	0.9982	0.4066	8

Table no.4 Rank Estimation

Expt. No.	For Dry Machining Environment					
	TRI for WSM (Q^1)		TRI for WPM (Q^2)		FRI	Rank
	SR	MT	SR	MT	Q	
1	0.7498	0.0136	0.7630	1.0000	0.7632	4
2	0.9476	0.0133	0.9612	0.9997	0.9608	2
3	0.5396	0.0129	0.5516	0.9993	0.5518	7
4	0.5290	0.0134	0.5408	0.9998	0.5415	8
5	0.8881	0.0130	0.9017	0.9994	0.9012	3
6	0.5143	0.0127	0.5260	0.9991	0.5262	9
7	0.6558	0.0126	0.6686	0.9990	0.6681	5
8	0.9864	0.0128	1.0000	0.9992	0.9992	1
9	0.6251	0.0127	0.6377	0.9991	0.6375	6
For Flood Machining Environment						
10	0.8612	0.0219	0.8829	1.0000	0.8830	2
11	0.9781	0.0214	1.0000	0.9995	0.9995	1
12	0.5086	0.0201	0.5275	0.9982	0.5276	7
13	0.5500	0.0206	0.5695	0.9987	0.5697	5
14	0.5629	0.0215	0.5825	0.9996	0.5834	4
15	0.4699	0.0197	0.4882	0.9976	0.4883	8
16	0.4589	0.0195	0.4771	0.9974	0.4771	9
17	0.7918	0.0209	0.8133	0.9990	0.8126	3
18	0.5285	0.0201	0.5477	0.9981	0.5476	6

Table no.5 Effecting Machining Parameters According to FRI

Dry Machining Environment					
Machining Parameters	Level 1	Level 2	Level 3	Δ	Rank
Cutting Speed	0.7586	0.6563	0.7683	0.1120	2
Feed Rate	0.6576	0.9537	0.5718	0.3819	1
Depth of Cut	0.7629	0.7133	0.7070	0.0558	3
Flood Machining Environment					
Machining Parameters	Level 1	Level 2	Level 3	Δ	Rank
Cutting Speed	0.8034	0.5471	0.6124	0.2562	2
Feed Rate	0.6433	0.7985	0.5212	0.2773	1
Depth of Cut	0.7280	0.7056	0.5294	0.1986	3
For Cu Nanofluid + MQL Machining Environment					
Machining Parameters	Level 1	Level 2	Level 3	Δ	Rank
Cutting Speed	0.4891	0.6519	0.5441	0.1628	2
Feed Rate	0.5302	0.6560	0.4990	0.1570	3
Depth of Cut	0.5067	0.4822	0.6962	0.2140	1
For Zn Nanofluid + MQL Machining Environment					
Machining Parameters	Level 1	Level 2	Level 3	Δ	Rank
Cutting Speed	0.6457	0.8544	0.5170	0.3374	2
Feed Rate	0.8856	0.5059	0.6255	0.3797	1
Depth of Cut	0.7226	0.6516	0.6429	0.0796	3

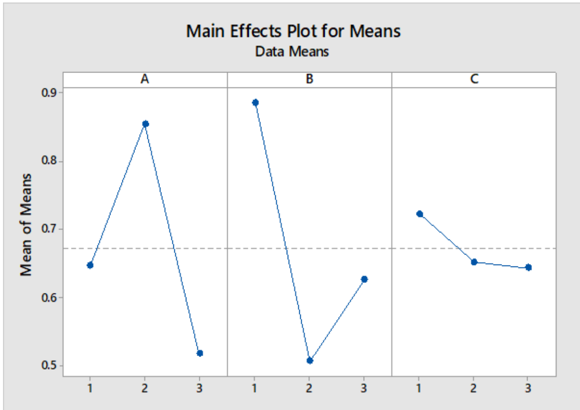

Fig. 4. Main Effect Plot for Zn nanofluid + MQL Machining Environment

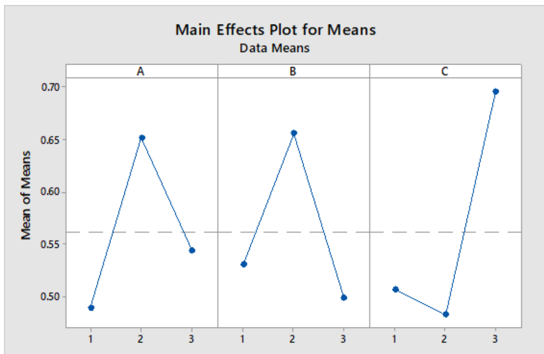

Fig. 5. Main Effect Plot for Cu nanofluid + MQL Machining Environment

4. CONCLUSION

During turning process on Bearing steel, it is observed that MQL machining with Cu and Zn are better than the dry, flood techniques. The Hybrid approach of Multi criteria Decision Making utilized and hence we noted some Outcomes-

1. For Cu Nanofluid with MQL machining environment- Temperature of cutting speed noted less than the dry and flood machining environment.
2. Also, the surface roughness noticed to be less than the Dry and Flood Machining environment.
3. For Zn nanofluid with MQL machining environment- Surface roughness is less than the dry and flood machining environment.
4. Comparing Cu and Zn, it is observed that Cu Nanofluid minimizes the surface roughness by 32% comparing to Cu nanofluid.
5. Temperature is reducing by 15% in Cu Nanofluid Environment as compared to Zn.

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