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Multiresponse Optimization of Surface Grinding Operation of En19 Alloy Steel Using Grey Relational Analysis (GRA)

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Abstract:- Conventional grinding fluid is widely used in grinding process, which results in high consumption and impacting the environment. Minimum Quantity Lubrication (MQL) is alternative source for the Conventional grinding process. In this study, Water based nanofluid applied to grinding process with MQL approach for its excellent convection heat transfer and thermal conductivity properties. The grinding characteristics of hardened steel can be investigated. Water based nanofluid MQL grinding can significantly reduce the grinding temperature, decrease the grinding forces and gives better surface finish than conventional grinding process. The process parameters considered are Nanofluid Type, Nanofluid Concentration, Depth of Cut & feed rate and multiple responses are surface roughness, Temperature, Grinding Wheel Wear & Material Removal Rate. CuO 2% concentration has the better surface roughness. Analysis of Variance (ANOVA) is done to find out significant process parameter at 95% confidence level. ANOVA shows that Nanofluid Type has significant factor, because its p-value less than 0.05. The use of GRA converts the multi response variable to a single response Grey relational grade and simplifies the optimization procedure.

Keywords:- Conventional Grinding, Gray Relational Analysis, MQL, Nanofluid Concentration, Surface Roughness.

I. INTRODUCTION

Grinding is a process of surface finishing using abrasive materials. It is mainly used in manufacturing industries where close tolerances and smooth surface finish is prime requirement. During the process of grinding, due to surface contact between the tool (grinding wheel) and the work piece, large amount of heat is generated at the interface of wheel and the surface of the work piece. This heat generated is removed by proper cooling arrangement of the work piece surface. Improper cooling and lubrication may lead to thermal stresses in the work piece which may cause change in microstructure of the surface, distortion and surface irregularities [1]. When coolant comes in contact with the hot wheel-work piece interface, the onset of nucleate boiling increases the rate of heat transfer between the wheel-work piece interface and the coolant. The further increase in temperature creates a vapor film between the work piece surface and the coolant which reduces the rate of heat transfer between the coolant and the work piece; as a result of this surface of the work piece burns [1]. This discussion shows that a large amount of coolants are required during the process of grinding. This adds to the initial cost of the product.

To reduce the expenses on the coolants without affecting the quality of the product, Nano-fluids are being used now days as coolants in various manufacturing processes. Nano-fluid coolants are available both in solid as well as liquid (water based) phases. Due to their very high thermal conductivities, a small amount of Nano-fluid coolants can replace the traditional coolants. This method of lubrication is also known as Minimum Quantity Lubrication (MQL). MQL gives similar results as that of flood cooling as the coolant in MQL does not evaporate due to the heat generated during grinding process [2]. Due to emerging of nanotechnology, high thermal conducting fluids called 'Nano-fluids' has emerged. Nano-fluids are engineered colloidal suspension of Nano-particles (10-100 nm) in base fluids. An applicability of the fluids as coolants is mainly due to the enhanced thermo-physical properties of fluids due to the Nano particles inclusion.

II. EXPERIMENTAL PROCEDURE

2.1Experimental Setup

The grinding experiments were conducted on Blohm Pvt. Ltd. (Germany) made Hydraulic Reciprocating Surface Grinder as shown in fig.1. A vitreous bond CBN grinding wheel with 50µm average abrasive size was used. The initial diameter and the width of wheel were 200mm and 13.75 mm, respectively. The work-piece material was EN-19 with a carbon content of 0.35-0.45% and hardness of 35 Rockwell C. The width and length of the work-piece surface for grinding are 9mm and 50mm, respectively. The experimentation also consists MQL setup. In this system, nozzle with pipe is used to transport liquid and air at workpeice grinding surface. For MQL grinding, the flow rate was set to 2.5ml/min for all grinding fluids including water-based nanofluids. The surface grinding parameters were used for the experimentation work as : depth of cut, minimum as 5 µm & maximum as 10µm and feed rate minimum as 1000mm/rev & maximum as 2500mm/rev. Before every test, the grinding wheel was dressed at 10µm down feed, 500 mm/min traverse speed. The normal and tangential grinding forces measured by using dynamometer. The grinding temperatures measured by the METRAVI MT-5 Infrared Thermometer, which range has Distance: Spot = 12:1.

Fig.1 Surface Grinding M/c Setup

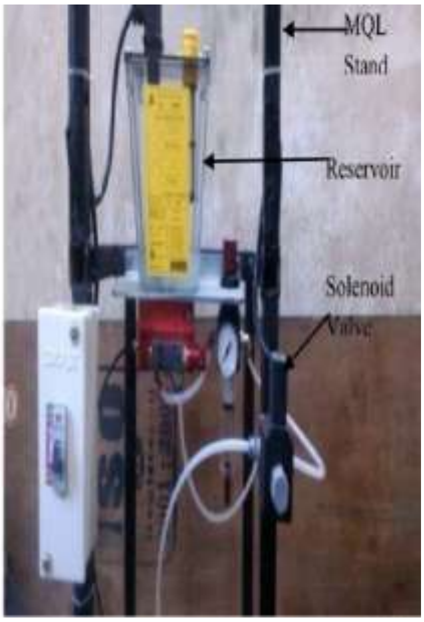
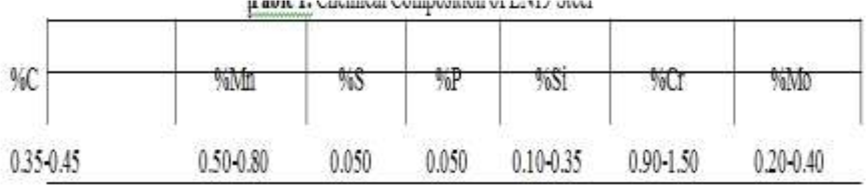


Fig.2 MQL Setup

2.2 Work piece Material

Rectangular bar of 9mm width, 15mm height and 50mm length made of EN-19 steel which is a high carbon alloy steel renowned for its good ductility & shock resistant & its resistance to wear properties is chosen as work piece. It is suitable for gears, pinions, shafts, spindles. It is now widely used in the oil & gas industry. The chemical compositions of EN-19 steel are shown in TABLE 1.

Table 1. Chemical Composition of EN19 Steel



%C	%Mn	%S	%P	%Si	%Cr	%Mo
0.35-0.45	0.50-0.80	0.050	0.050	0.10-0.35	0.90-1.50	0.20-0.40

Fig.3 EN19 Workpiece Specimen

2.2 Process Parameters & Levels

Table 2. Process Parameters

	Process parameter	Level 1	Level 2	Level 3
A	Nanofluid Type	Al_2O_3	CuO	--
B	Nanofluid Concentration (%)	2	4	6
C	Depth of Cut (µm)	5	10	--
D	Feed Rate (mm/rev)	1000	2500	--

In this experimentation four process parameters viz. nanofluid type, nanofluid concentration, depth of cut and feed rate are used & full factorial orthogonal array is used. From the review of previous study, the feasible range for the machining parameters defined by varying the nanofluid concentration 2 – 6 %, feed rate min. – max. (mm/min) and depth of cut min – max (mm). For the experimentation selection of process parameter & levels as shown in TABLE 2 [3].

2.3 Design of Experiment

Design of experiment is used to determine optimal value of process parameter to improve performance of manufacturing process. In this experimentation four process parameters viz. nanofluid type, nanofluid concentration, depth of cut and feed rate are used & full factorial orthogonal array is used. The experimental layout for the process parameters is shown in TABLE 3.

Table 3. Experimental Layout of Full Factorial with Experimental Results

Expt. No.	Nanofluid Type	Nanofluid Concentration (%)	Depth of Cut (mm)	Feed Rate (mm/min)	Ra (µm)	Tempt. (°c)	GWW (µm)	MRR (gm/min)
1	1	1	1	1	0.18	32.962	20	3
2	1	1	1	2	0.27	43.892	40	4.5
3	1	1	2	1	0.11	45.43	60	5
4	1	1	2	2	0.36	50.202	40	6.5
5	1	2	1	1	0.14	33.444	30	2.5
6	1	2	1	2	0.3	38.292	30	3.5
7	1	2	2	1	0.24	40.008	60	5
8	1	2	2	2	0.25	58.314	50	6.5
9	1	3	1	1	0.23	37.612	50	2
10	1	3	1	2	0.3	46.496	15	3
11	1	3	2	1	0.15	42.836	40	3.5
12	1	3	2	2	0.41	51.628	40	6
13	2	1	1	1	0.07	39.334	40	2
14	2	1	1	2	0.14	51.296	40	4
15	2	1	2	1	0.15	49.442	30	3.5
16	2	1	2	2	0.14	55.838	40	4.5
17	2	2	1	1	0.16	46.064	30	2
18	2	2	1	2	0.18	52.026	30	3.5
19	2	2	2	1	0.12	53.172	60	4
20	2	2	2	2	0.25	62.684	40	5
21	2	3	1	1	0.18	45.282	50	3
22	2	3	1	2	0.2	52.49	20	3
23	2	3	2	1	0.21	54.16	50	4.5
24	2	3	2	2	0.31	62.038	30	5.5

III. GREY RELATIONAL ANALYSIS (GRA)

Grey relational analysis converts multiple response optimizations into optimization of a single response Grey relational grade. The steps involved in optimization of grey relation analysis are as follows:

1) Normalizing experimental results

In grey relational generation, the normalized data i.e. surface finish, Temperature, grinding wheel wear corresponding to lower-the-better (LB) criterion can be expressed as:

() □ ()

() = max () □ () (1)

MRR should follow higher-the-better criterion (HB), which can be expressed as:

() □ min ()

() = max () □ min () (2)

Here $x_i(k)$ is the value after grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. An ideal sequence is $x_0(k)$ (k=1,2,3,.......,24) for the responses. The definition of grey relational grade in the course of grey relational analysis is to reveal the degree of relation between the 24 sequences $x_0(k)$ & $x_i(k)$, (1,2,3,.......,24).

2) Calculate the grey relational coefficient**()** as:

□ + ψΔ

() = (k) + ψΔ (3)

Here, □ = ǁ **(") □()** ǁ = difference of absolute value x0(k) and xi(k); ψ is the distinguishing

coefficient 0 ≤ψ≤1; □ = **∀$%∀&** ǁ **() □'()** ǁ = the smallest value of Δ0i ; and □ = **∀$ %∀&** ǁ **() □ ·()** ǁ =the largest value of Δ_{0i} [4].

3) The grey relational grade γ_i calculated as by averaging grey relational coefficients.

1

(= ‾)() (4)

"*+

4) To find significant parameter which affects the process, for this do ANOVA for process parameter along with response as grey relational grade.

5) Select the optimal level of machining parameter.

6) Conduct confirmation test to verify optimal process parameter.

Table 4. Normalized data (Grey relational generation) & Estimation of Δ_{0i} for each responses

Expt. No.	Ra (µm)	Tempt. (°c)	GWW (µm)	MRR (gm/min)	Ra (µm)	Tempt. (°c)	GWW (µm)	MRR (gm/min)
1	0.676	1	0.889	0.222	0.324	0	0.111	0.778
2	0.412	0.632	0.444	0.556	0.588	0.368	0.556	0.444
3	0.882	0.581	0	0.667	0.118	0.419	1	0.333
4	0.147	0.420	0.444	1	0.856	0.580	0.556	0
5	0.794	0.984	0.667	0.111	0.206	0.016	0.333	0.889
6	0.324	0.821	0.667	0.333	0.676	0.179	0.333	0.667
7	0.5	0.763	0	0.667	0.5	0.237	1	0.333
8	0.471	0.147	0.222	1	0.529	0.853	0.778	0
9	0.529	0.844	0.222	0	0.471	0.156	0.778	1
10	0.324	0.545	1	0.222	0.676	0.455	0	0.778
11	0.765	0.668	0.444	0.333	0.235	0.332	0.556	0.667

12	0	0.372	0.444	0.889	1	0.628	0.556	0.111
13	1	0.786	0.444	0	0	0.214	0.556	1
14	0.794	0.383	0.444	0.444	0.206	0.617	0.556	0.556
15	0.765	0.446	0.667	0.333	0.235	0.554	0.333	0.667
16	0.794	0.230	0.444	0.556	0.206	0.770	0.556	0.444
17	0.735	0.560	0.667	0	0.261	0.441	0.333	1
18	0.676	0.359	0.667	0.333	0.324	0.641	0.333	0.667
19	0.853	0.320	0	0.444	0.147	0.680	1	0.556
20	0.471	0	0.444	0.667	0.529	1	0.556	0.333
21	0.676	0.585	0.222	0.222	0.324	0.415	0.778	0.778
22	0.618	0.343	0.889	0.222	0.382	0.657	0.111	0.778
23	0.588	0.287	0.222	0.556	0.412	0.713	0.778	0.444
24	0.294	0.022	0.667	0.778	0.706	0.978	0.333	0.222

Table 5. Grey relational coefficient (ψ=0.5) & Overall grey relational grade

Expt. No.	Ra (μm)	Tempt. (°c)	GWW (μm)	MRR (gm/min)	Overall Grey Relational Grade
1	0.607	1	0.818	0.391	0.704157
2	0.459	0.576	0.474	0.529	0.509691
3	0.810	0.544	0.333	0.6	0.57166
4	0.370	0.463	0.474	1	0.576549
5	0.708	0.969	0.6	0.36	0.65923
6	0.425	0.736	0.6	0.429	0.547398
7	0.5	0.678	0.333	0.6	0.527925
8	0.489	0.370	0.391	1	0.561644
9	0.515	0.767	0.391	0.333	0.500366
10	0.425	0.523	1	0.391	0.584918
11	0.68	0.601	0.474	0.429	0.545766
12	0.333	0.443	0.474	0.818	0.517114
13	1	0.700	0.474	0.333	0.62673
14	0.708	0.448	0.474	0.474	0.525847
15	0.68	0.474	0.6	0.429	0.545686
16	0.708	0.394	0.474	0.529	0.526308
17	0.654	0.532	0.6	0.333	0.529658
18	0.607	0.438	0.6	0.429	0.518442
19	0.773	0.424	0.333	0.477	0.500871
20	0.486	0.333	0.474	0.6	0.473183
21	0.607	0.547	0.391	0.3917	0.484123
22	0.567	0.432	0.818	0.3917	0.552074
23	0.548	0.412	0.391	0.5297	0.470308
24	0.415	0.338	0.6	0.6927	0.511294

Table 6. Mean of the overall grey relational grade

Process Parameter	Grey Relational Grade				
	Level 1	Level 2	Level 3	Delta	Rank
Nanofluid Type	0.567201	0.522044	--	0.045158	2
Nanofluid Concentration	0.573328	0.539794	0.520745	0.052583	1
Depth Of Cut	0.561886	0.527359	--	0.034527	3
Feed Rate	0.55554	0.533705	--	0.021835	4
Mean of overall grey relational grade = 0.038526					

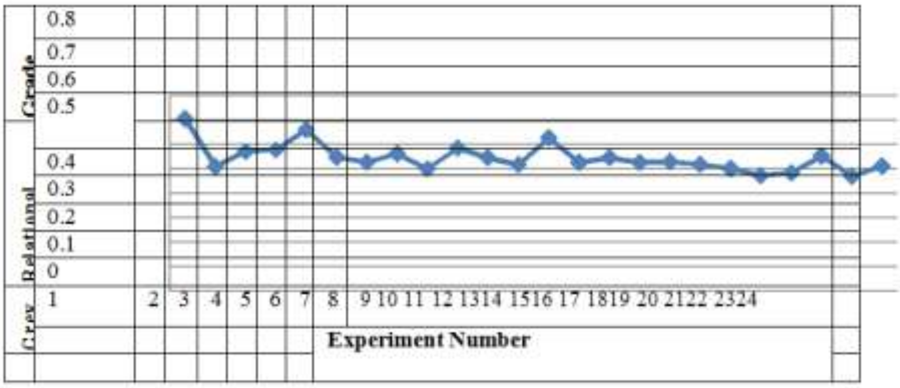


Fig. 4 Grey Relational Grade Vs Experiment Number

Higher grey relational grade value indicates optimal level of machining parameter. Fig. 4 indicates experiment 1 has higher grey relational grade value. From TABLE 6, nanofluid concentration has strongest effect on multi performance characteristics followed by nanofluid type, depth of cut & feed rate.

Main effect plot for GR Grade in fig. 5 indicates that nano fluid type AL_2O_3 has high GR Grdae than CuO. In Nano fluid concentration 2% has high GR Grade. GR Grade decreases from 2% to 4% to 6%. GR Grade for depth of cut is high at 5 µm& it decreased at 10 µm. Similarly GR Grade for feed rate is high at 1000mm/min & it decreased at maximum as 2500mm/min.

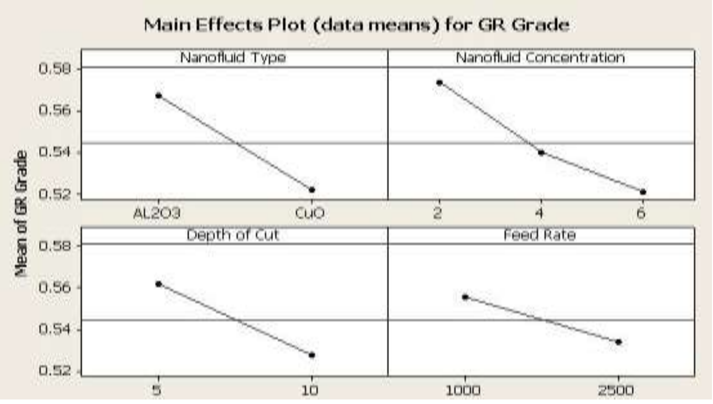


Fig. 5 Main Effect Plot for GR Grade

IV. ANALYSIS OF VARIANCE (ANOVA)

Analysis of Variance (ANOVA) is done to find out significant process parameter at 95% confidence level, p-value for this factor is less than 0.5.

Table 7. ANOVA for Overall Grey Relational Grade

Source	DOF	Sum of Square	Mean of Square	F-Value	P-Value	% Contribution
Nanofluid Type	2	0.012235	0.012235	5.71	0.028	16.95
Nanofluid Concentration	1	0.011340	0.005670	2.64	0.098	15.71
Depth of Cut	1	0.007153	0.007153	3.34	0.084	9.90
Feed Rate	1	0.002861	0.002861	1.33	0.263	3.96
Error	18	0.038592	0.002144			
Total	23	0.072180				

CONCLUSIONS

The experimental investigation of EN 19 alloy steel by using surface grinding operation is done. The following conclusions are made which are

1) Main effect plot for GR Grade indicates that nanofluid type AL_2O_3 has high GR Grdae than CuO.
2) ANOVA shows that Nanofluid Type has significant factor, because its p-value less than 0.05.
3) CuO 2% concentration has better surface roughness than AL_2O_3.
4) Percentage contribution of nanofluid type is 16.95%, nanofluid concentration is 15.71%, depth of cut 9.90%, feed rate is 3.96%.

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