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Role of Air As An Eco-Friendly Coolants in Green Manufacturing

KEYWORDS: Grinding, eco friendly, coolant, surface finish

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ABSTRACT *This paper involves the review for the study of surface finish enhancement of grinding process using cold compressed air. Grinding is metal removal process which employs an abrasive grinding wheel whose cutting elements are grains of abrasive materials of high hardness and high refractoriness. There have been many attempts employed in order to enhance the surface finish for the grinding process using air as an eco friendly coolants. Many research focused the development of eco friendly coolants based on water, oil mist, synthetics coolants etc. The presence of hazardous chemical additives in liquid based coolant causes environmental problems also it is hazardous to the operator and the working environment.*

INTRODUCTION

Machining is the broad term used to describe removal of material from a work piece; it covers several processes, which we usually divide into the following categories:

- Cutting, generally involving single-point or multipoint cutting tools, each with a clearly defined geometry.
- Abrasive processes, such as grinding.
- Nontraditional machining processes, utilizing electrical, chemical, and optimal sources of energy.

Some of the finishing operations which can never be performed by any other processes and it is possible only by grinding is due to the some complicated final shapes or the geometry of the work piece, hardness, manufacturing techniques and so on.[9].

Grinding is a process which utilizes various tiny and hard abrasive particles formed in a binder as a multitude of cutting edges to continuously remove unwanted material on a work piece at very high speeds. The chips produced by grinding are therefore very small, by about two orders of magnitude smaller compared to other cutting operations. A special grinding mode is creep feed where the process is performed at very slow feed velocity and extremely large depth of cut. [8].

Grinding is widely employed machining process used to achieve good geometrical form, dimensional accuracy, surface finish and surface integrity. The grinding process requires higher energy expenditure per unit volume of material removed [1].

Grinding is an essential machining operation. There have been various attempts to improve the performance of the grinding system [2], considering grinding as comprising of the machine, the wheel, the work piece and the coolant. Coolants must lubricate properly to reduce the friction and the amount of heat generated in a grinding system.

Cutting fluids have seen extensive use and have commonly been viewed as a required addition to high productivity and high quality machining operations. Cutting fluid related costs and health concerns associated with exposure to cutting fluid mist and a growing desire to achieve environmental sustainability in manufacturing have caused industry and academia to re-examine the role of these fluids and quantify their benefits [3].

ROLE OF CUTTING FLUID IN GRINDING PROCESS

The main tasks of cooling fluids in a precise grinding

operation are cooling, lubrication and cleaning of crammed chips. In the current technology, soluble coolants those contain chemical additives with synthetic formulations are often used. However, due to very stable nature of the solution, these fluids are environmentally hazardous. [6].

According to Jackson and Hitchiner (2003) , the cutting fluid can lead to cutting instead of plowing by two different ways:

1) Making the wheel sharp: the coolant can act to inhibit glazing and capping of the grits by the decrease of the coefficient of friction.

2) Reducing the coefficient of friction: lowering the coefficient of friction between grit and work piece allows blunter grits to cut, as well as reducing overall forces levels for a given stock removal rate. This brings a double benefit: the energy to be dissipated is lowered, and because cutting is favored, the heat is more easily dissipated.[4].

HARMFUL EFFECTS OF CUTTING FLUIDS

As per as the water soluble fluids are concerned the stability of the emulsion depends on the maintenance of the repulsive charges among the oil droplets dispersed in water. This stability can be broken, leading to the premature disposal of the emulsion, when one of the situations below occurs: The introduction of acids and organic or inorganic salts in the emulsion; the acidulation of the emulsion due to CO_2 absorption during the preparation of the emulsion; the proliferation of microorganisms, such as bacteria and fungi. The bacteria consume the emulsifiers and anti-rust agents, generating acids as a sub product of their metabolism. It causes the breakdown of the emulsion, reduces the pH and decreases in the anti-rust protection.[5]. This are some of listed hazardous of cutting fluids in grinding processes. Many chemical used in cutting fluid composition, such as biocides, anticorrosive, antifoam and others, can have bad effects on man and nature. With the technological evolution, many new synthetic products are exposed in market and for these products there are not adequate toxicological tests, and with hard work to control them, the some Agencies recommend preventive actions.

The Occupational Safety and Health Administration (OSHA) regulated some substances to be controlled in formulations of cutting fluids, such as hanolamine, diethanolamine, hex-

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yleneglycol, morpholine, p-chlorine-m-cresol, alkaline poly chlorines from C10 to C13, nitrodiethanolamine, glycol ether, Stoddard

Solvent, nitrites, polycyclic aromatic hydrocarbons (PAH), chlorinated paraffin oils of short chains, barium composites, oil mist and copper composites [7].

NEED OF ECO-FRIENDLY COOLANTS

Following are some of the conclusion made by T. Nguyen, L.C. Zhang with air as an eco-friendly coolant:

(1) Under low material removal rates, cold air can be used to suppress surface burning with an advantage of reducing grinding forces. The surface hardness was not altered, indicating that thermally induced hardening does not happen. However, the lack of lubrication prevented its applicability for higher material removal rates.
(2) With the addition of a small amount of vegetable oil mist in the cold air stream, larger depths of cut can be performed without burning while keeping the grinding quality comparable to the grinding with coolant.
(3) Grinding chips were of lamellar and leafy shapes, revealing a shearing mechanism of chip formation.
(4) The surface cleaning ability of CAOM is worse than that of coolant, thus causing a slight increase of ground surface roughness.
(5) The residual stress profiles in components ground with CAOM are highly directional, compressive in grinding direction and tensile in transverse grinding direction. This was due to the non-uniformity of the heat flux created by the flow of CAOM.

Much research is going on this scenario of cold air as an eco-friendly coolant due to its inherent properties also it is cryogenic.

THE TAGUCHI SYSTEM

The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Calculate the total loss function and the S/N ratio.
- Analyze the experimental results using the S/N ratio and ANOVA.
- Select the optimal levels of process parameters.[10].

MATHEMATICAL MODELING

A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed mathematical modeling. Mathematical models are used not only in the natural sciences (such as physics, biology, earth science, meteorology) and engineering disciplines (e.g. computer science, artificial intelligence), but also in the social sciences (such as economics, psychology, sociology and political science); physicists, engineers, statisticians, operations research analysts and economists use mathematical models most extensively. A model may help to explain a system and to study the effects of different components, and to make predictions about behavior. Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures. In general, mathematical models may include logical models, as far as logic is taken as a part of mathematics. In many cases, the quality of a scientific field depends on how well the mathematical models developed on the theoretical side agree with results of repeatable experiments. Lack of agreement between theoretical mathematical models and experimental measurements often leads to important advances as better theories are developed.

Grey Relational Analysis (GRA)

The grey means the primitive data with poor, incomplete and uncertain information in the grey systematic theory, the incomplete relation of information among this data is called the gray relation. Grey relational analysis is to compare quantitative analysis to the development between every factor in the grey system dynamically, describes the relation degree among main factor and other factors in the grey system.

In grey relational analysis, black represents having no information and white represents having all information. A grey system has a level of information between black and white. This analysis can be used to represent the grade of correlation between two sequences so that the distance of two factors can be measured discretely. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method. Grey relational analysis is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade. As far as information is concerned, the systems which lack information, such as structure message, operation mechanism and behavior document, are referred to as Grey Systems. For example, the human body, agriculture, economy, etc., are Grey Systems. Usually, on the grounds of existing grey relations, grey elements, grey numbers one can identify which Grey System is, where "grey" means poor, incomplete, uncertain, etc. The goal of Grey System and its applications is to bridge the gap existing between social science and natural science. Thus, one can say that the Grey System theory is interdisciplinary, cutting across a variety of specialized fields.

Projects which have been successfully completed with the Grey System theory and its applications are as follows:

- Regional economic planning;
- To forecast yields of grain for some provinces;
- To analyze agricultural economy;
- To make satisfactory planning of irrigation;
- To build models available for biological protection;
- To control the water level for boilers by grey prediction control;
- To estimate the economic effect;
- To build a diagnosis model available for medicine;
- To forecast weather.

Regression Analysis

In statistics, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modelling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. In restricted

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circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables. The performance of regression analysis methods in practice depends on the form of the data generating process, and how it relates to the regression approach being used.

The general purpose of multiple linear regressions is to seek for the linear relationship between a dependent variable and several independent variables. Multiple regressions allow researchers to examine the e ect of more than one independent variables on response at the same time.

The model is specified as;

$$y = \beta 0 + \beta 1\ x1 + \beta 2\ x2 + \cdots + \beta mxm + \varepsilon, \quad \ldots\ldots (1)$$

Where

y is the dependent variable

xj, j = 1, 2, ... , m, represent m different independent variables

β0 is the intercept (value when all the independent variables are 0)

βj, j = 1, 2, ... , m, represent the corresponding regression coefficients

ε is the random error, usually assumed to be normally distributed with mean zero and variance σ2

[1] Regression Model for Surface Roughness
y = 0.38822 + 0.0062381x1 + -0.0093425x2 + -0.0093165x3 + 0.00021988x4 ………………..….(2)

[2] Regression Model for Material Removal Rate
y = -65.993 + -0.9x1 + 2.9587x2 + 3.5257x3 + 0.64445x4 ..…….................(3)

ANALYSIS OF VARIANCE (ANNOVA MODELS)
ANNOVA procedures separate the variation observable in a response variable into two basic components: variation due to assignable causes and to random variation.

Table no: 01 Factors and Level combinations

Sr. No.	Factor		Level		
			1	2	3
1	A	Air Temperature (^{0}C)	5	10	20
2	B	Air Velocity (m/sec)	3.5	5	6.5
3	C	Cutting Speed (m / min.)	15	20	25
4	D	Depth of Cut (μm)	50	100	200

Figure 1: Experimental setup (Surface grinding machine)

Figure 2: Surface Roughness tester.

From the factor and level combinations i.e. 3^4 experiments it is found that the L_9 orthogonal array is the best suitable options (refer table 2).

Table no: 02 Test combinations for L_9.

Test	Factor						A1		A2			A3			
	A	B	C	D			B1	B2	B3	B1	B2	B3	B1	B2	B3
T1	1	1	1	1	C1	D1	■								
T2	1	2	2	2		D2						■			
T3	1	3	3	3		D3								■	
T4	2	1	2	3	C2	D1									■
T5	2	2	3	1		D2		■							
T6	2	3	1	2		D3				■					
T7	3	1	3	2	C3	D1					■				
T8	3	2	1	3		D2							■		
T9	3	3	2	1		D3			■						

Table no. 03: Results

Test	Response					
	Surface Roughness (μm)					MRR (mm^3/min)
	Soluble Oil as Coolant	Cold Air as Coolant				
		1st	2nd	3rd	4th	
T_1	1.89	0.28	0.28	0.29	0.27	27
T_2	1.63	0.21	0.21	0.19	0.18	72
T_3	1.43	0.17	0.17	0.18	0.18	180
T_4	1.86	0.26	0.26	0.23	0.23	144
T_5	1.64	0.19	0.18	0.19	0.19	45
T_6	1.93	0.27	0.29	0.26	0.28	54
T_7	1.97	0.29	0.28	0.23	0.27	90
T_8	2.27	0.38	0.31	0.35	0.37	108
T_9	2.18	0.32	0.31	0.30	0.29	36

Table no 04: Normalized Results for Material Removal Rate

Test	Normalized Response				
	Surface Roughness				MRR
	1st	2nd	3rd	4th	
T_1	0.607	0.607	0.586	0.630	0.15
T_2	0.810	0.810	0.895	0.944	0.4
T_3	1.000	1.000	0.944	0.944	1
T_4	0.654	0.654	0.739	0.739	0.8
T_5	0.895	0.944	0.895	0.895	0.25
T_6	0.630	0.586	0.654	0.607	0.3
T_7	0.586	0.607	0.739	0.630	0.5
T_8	0.447	0.548	0.486	0.459	0.6
T_9	0.531	0.548	0.567	0.586	0.2

The large value of normalized results can indicate the better performance characteristic and the best-normalized results will be equal to one.

Table 5: The Grey Relational Coefficient and Grade

	$\Delta_{0,1}(k)$	$\Delta_{0,2}(k)$	$\gamma_1(k)$	$\gamma_2(k)$	γ
T_1	0.414	0.85	0.480897	0.412921	0.446909
T_2	0.190	0.6	0.710962	0.591946	0.651454
T_3	0.056	0	1	1	1
T_4	0.346	0.2	0.533153	0.443902	0.488528

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T_5	0.105	0.75	0.869732	0.724138	0.796935
T_6	0.414	0.7	0.480897	0.42728	0.454089
T_7	0.414	0.5	0.480897	0.400394	0.440646
T_8	0.553	0.4	0.400353	0.333333	0.366843
T_9	0.469	0.8	0.445426	0.370861	0.408144

Table 06: Factor and Level Combinations

Sr. No.	Factor		Grey Relational Grade			Max - Min	Rank
			1	2	3		
1	A	Air Temperature (^{0}C)	0.699	0.579	0.405	0.294	1
2	B	Air Velocity (m/ sec)	0.458	0.605	0.620	0.162	3
3	C	Cutting Speed (m / min.)	0.422	0.516	0.745	0.323	2
4	D	Depth of Cut (µm)	0.551	0.515	0.618	0.103	4

Total mean grey relational grade = 0.56

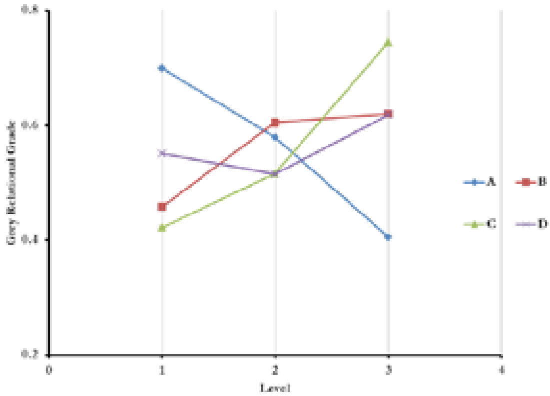

Figure 03 Grey Relational Grade for Various Factor and Level Combination

From the figure03 above comparing the grey relational grade, it is observed that the factor and level combination $A_1B_3C_3D_3$gives optimum response i.e. test no3.

A_1: Air Temperature (5^{0}C)

$B_{3:}$ Air Velocity (6.5 m/sec)

C_3: Cutting Speed (25 m/min)

D_3: Depth of Cut (200 µm)

Table 07 : ANOVA Table

Source	DoF	SS	V	F	P(%)
A	2	0.043704	0.021852	307.7748	36.29995
B	2	0.016026	0.008013	112.8593	13.31099
C	2	0.055202	0.027601	388.7466	45.85003
D	2	0.005465	0.002732	38.48489	4.539032
e	18				
Total	26				100

The degree of freedom for the numerator is four and for the denominator nineteen.

Verification Run.

Test No. 3 shows optimum value of surface finish i.e the predicted value of the surface finish is 0.16 µm.

As per 95% CI = 0.18 ± 0.0083 µm

As per 99% CI = 0.18 ± 0.0103 µm

To validate the predicted results obtained from Grey Relational Analysis method, it is necessary to conduct the verification run.

After conducting the experiment for optimum combination obtained i.e. $A_1B_3C_3D_3$(Air Temperature 5^{0}C, Air Velocity 6.7 m/sec, Cutting Speed 25 m/min and depth of cut 200 µm) the value of surface roughness is0.175 µm, which shows close correlation with predicted value.

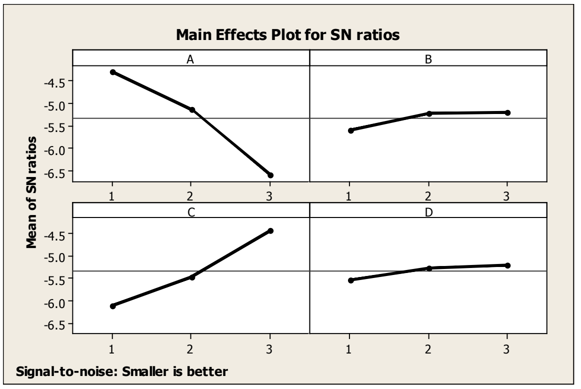

Figure 04 S/N ratio plot for surface roughness obtained by using air as coolantA1B3C3D3 Optimum Combination gives surface roughness 1.43 µm.

Conclusions:-

From the experimental study it is clearly observed that the use of air improves the surface finish and material removal rate. The optimum combination factor and level that gives the 0.175 µm surface finish and 180 mm3/min material removal rate is A1B3C3D3. So from this we can conclude that air can be used as an eco-friendly coolant in the grinding operation.

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