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FORMULATION OF SOYA OIL BASED CUTTING FLUID AND PARAMETRIC OPTIMIZATION DURING HARD TURNING OF OHNS STEEL WITH MINIMAL CUTTING FLUID APPLICATION

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ABSTRACT

The vegetable oil-based coolants in machining applications have reached the extra mile in increasing the overall performance. As a proven and tested technology, vegetable oils have been recognized as having superior lubricating properties since the 1960s. During this time, the process of stabilizing coolant emulsions that are based on water-miscible vegetable oils proved to be challenging, which meant that machining lubricant options were limited to mineral oil-based coolants containing various additives. Vegetable oil can be used for the most part in straight oil applications. The most common method of application of cutting fluid is flood or deluge cooling which involves bulk application of cutting fluid in the cutting zone. The copious usage of cutting fluid not only increases the production cost but also creates serious environmental and health hazards. The study highlights the contributions from more than sixty authors on vegetable based oils as emerging environmental friendly cutting fluids. The performance of these oils as emulsions and straight oils for various materials and machining conditions are reported. The study focuses on the evolution of vegetable oils as cutting fluids in manufacturing sector, particularly, metal cutting and metal forming. It is observed that, most of the contributions are directed to develop and commercialize the cutting fluids based on vegetable oils. However, soybean, sunflower and rapeseed seem to possess the relevant properties as a potential cutting fluid. In this present study, an effort was made to reduce the quantity of usage of cutting fluid and to optimize the cutting parameters and to formulate the cutting fluid during hard turning of Oil Hardened Non shrinkable steel (OHNS) with Minimal cutting fluid application (MCFA) using Response Surface Methodology (RSM). Experiments are to be designed using RSM each under different conditions of cutting speed, feed rate and depth of cut using Design expert 10 software.

Keywords: Soya Oil, Oil Hardened Non Shrinkable Steel (OHNS), Response Surface Methodology (RSM), Minitab, Cutting Fluids.

I INTRODUCTION

Hard turning is the method of removing the material from the work piece in order to produce a product with specified dimension and also with proper surface finish. The quality of surfaces of machined components is determined by the surface finish and integrity obtained after machining. Poor surface finish, decrease the fatigue life of machined components. Other than the traditional process, hard turning have advantages like less cycle time, less production cost and a better surface finish[1]. The selection of optimal cutting parameters in machining is a difficult task which involves the development of machining models and optimization algorithm able to optimize these models. Several mathematical model shave been developed to establish the relationship between the cutting performance and the cutting parameters. Optimization of cutting parameters involves the use of optimization algorithms and other numerical optimization techniques. An optimization problem consists of optimizing one or multiple objective functions while satisfying several constraint. In this project a 20runs experiment was performed on a OHNS steel of 45HRC using soya based cutting fluid. Most of the cutting fluids in regular use are petroleum based emulsions which create several environmental problems such as pollution in the shop floor control due to chemical breakdown of the cutting fluid at high cutting temperature, creation of biologically hazardous environment to operators due to bacterial growth, water pollution and soil contamination during final disposal. People exposed to large quantities of cutting fluids may have skin problems and they may inhale or swallow them as particles of cutting fluid. The additives present in the respiratory and digestive system and even cancer due to their toxicity. Handling of cutting fluid may include the pre-treatment and treatment of cutting fluid wastes. The cost of fluid pre-treatment/treatment is sometimes higher than the purchase price of the cutting fluid itself. Enormous usage of cutting fluid in the shop floor increases the presence of oil content in the air which should be kept within the prescribed regulations suggested by occupational safety and health administration. It is found that Europe alone consumes approximately 320,000 tons per year of metal working fluids, out of which at least two thirds need to be disposed. The concept of minimal cutting fluid application (MCFA) presents itself as a possible solution for hard turning[9]. Accordingly, soybean oil based emulsion was prepared by adding important additives. RSM is a mathematical and statistical technique that is useful for modelling and analysis of optimum cutting conditions. The cutting speed (m/min), federate (mm/rev) and depth of cut (mm) were considered as input parameters surface roughness, temperature, tool wear and cutting force were considered as response variables. In order to obtain better surface roughness proper setting of cutting parameters is important, so a model is developed for determining the optimal machine parameters. Response Surface Methodology (RSM) is also used to develop a predictive model. The optimum selection of the process parameters is very important in manufacturing processes as they determine surface quality and dimensional precision. This aims on optimizing the process parameters under the given conditions using RSM.

1.1 Selection Of Cutting Fluid

The cutting fluid used for this research is a soya bean based cutting fluid. It is an emulsion of soya bean oil with oleic acid, ethylene glycol, tri-ethanol amine, petroleum sulfonate and other additives[5]. The emulsion thus processed has high temperature withstanding capacity and can withstand all its properties at extreme working conditions. The physical and chemical properties of vegetable based oils is listed in the table 1.

Table 1: Chemical and Physical characteristics of Vegetable Oils

	Soya Bean	High Oleic Soya Bean	Sun Flower	Rapeseed	Jatropha	Neem	Castor	Coconut
Kinematic Viscosity at 40°C [cSt]	32.9	41.3	40.1	45.6	47.5	68.0	220.6	36.2
Kinematic Viscosity at 100°C [cSt]	8.1	9.0	8.7	10.1	8.0	10.1	19.7	6.7
Viscosity index	219	-	206	216	208	135	220	130
Saponification Value [mgKOHg-1]	189	-	-	180	196.8	166	180	248-265
Total Acid Value [(mgKOHg-1]	0.6	0.1	-	1.4	3.2	23	1.4	-
Iodine Value [mg g-1]	1.44	85.90	-	104	97	66	87	6-8
Pour Point [0°C]	-9.00	-	-12	-12	0.00	9	-27	20
Flash Point [0°C]	240	-	252	240	240	-	250	240

1.2 Selection of Additives

Vegetable oil mainly derived as primarily triglycerides, which are tri-esters of long chain fatty acids combined with glycerol. These oils normally contain 4 to 12 different fatty acids.

Table 2: Composition of cutting fluid

SNo	Name of the constituent	Percentage composition by weight
1.	Petroleum sulfonate (molecular wt= 490 to 520)	15%
2.	Ethylene glycol	1%
3.	Oleic acid	3%
4.	Trirthanol amine	3%
5.	Alcohol ethoxylate	2-6%
6.	Soya bean oil	Rest

These additives posses lubricating nature. Petroleum sulfonate has the property to act as an emulsifier, rust inhibitor, surfactant and EP agent. Petroleum sulfonate of sodium type having composition 15% by weight was considered in this investigation as this has higher molecular weight. Also the performance of sodium sulfonate was acts to be superior compared to potassium, calcium lithium and magnesium sulfonate[3]. Ethylene glycol with composition 1% by weight resists freezing due to its low freezing point and acts as a coupling agent to increase the stability of the emulsion. The use of ethylene glycol not only depresses the freezing point but also elevates the boiling point such that the operating range for the heat transfer fluid is broadened on both ends of the temperature scale. Oleic acid is an unsaturated fatty acid which is used as an emulsifying or solubilizing agent in aerosol products.

1.3 Formulation Of Cutting Fluid

“Soybean” or “Soya” is referred to Glycine max which is found only under cultivation and is a member of the Papilionaceae. The oil content in soybean seed ranges from 15% to 22% depending on environmental conditions during seeds maturity. The major fatty acids are oleic and linoleic. The ratio of soya oil: oleic acid: triethanolamine :ethylene glycol is taken as 2:2:1:1.

Table 3: Properties of Formulated Soya based cutting fluid

SNo	Formulated parameters	Soya oil (Refined)	Formulated oil (with additives)	Emulsion (20% oil)
1.	Ph	4.18	7.74	8.25
2.	Temperature(˚C)	25˚C	32˚C	30˚C
3.	Viscosity(P)@ 2.5rpm	1.94	27.20	0.41
4.	Viscosity(P)@ 5.0rpm	1.12	25.01	0.16
5.	Viscosity(P)@ 50rpm	1.046	23.95	0.17
6	Thermal conductivity(W/Mk)	-	0.174	0.598

This cutting fluid formulation was tried in the present investigation and the specification and composition were considered based on the information available in the literatures. In minimal fluid application, heat transfer is predominantly in the evaporative mode, which is more efficient than the convective heat transfer prevalent in conventional wet turning[12].

Fig1: Measurement of viscosity using viscometer with formulated oil and emulsion

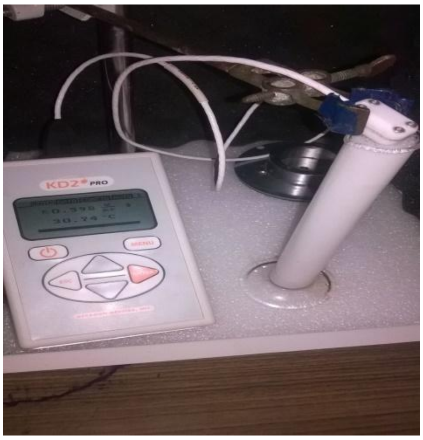

Fig2: Measurement of thermal conductivity with formulated oil and emulsion (20% oil)

The formulated cutting oil with additives is taken for viscosity test using viscometer as Shown in Fig 1 and thermal conductivity respectively which is shown in fig 2.

1.4 Selection of Work Material

Selection of work material OHNS steel rod of 350 mm length and 75 mm diameter with a hardness of 45 HRC was selected as the work material for this investigation. This grade of steel has got a wide range of application in tool and die making industries. It is well known for its high tensile strength and toughness. Tool inserts SNMG 120408 along with a tool holder with a specification PSBNR 2525 M12 as recommended by M/s TaeguTec India (P) Ltd were used for the present investigation[10].

Table 4 composition of work piece material

Carbon	Chromium	Vanadium	Tungsten
0.95	0.5	0.15	0.6

1.5 Experimental Design Using RSM

Design of experiments is a very important tool in engineering for continuous improvement of the performance of manufacturing process. It is essentially a strategy of planning, designing, conducting and analyzing experiments so that valid and reliable conclusions can be drawn in the most effective manner. Statistical experiments are generally carried out to explore, estimate or confirm (JijuAntony, 2003). Experimental design has proved to be very effective for improving the process performance and process capability. Experimental procedures require a structured approach to achieve the most reliable results with minimal wastage of time and money. Experimental design, based on sound statistical principles, can be used to give an over all view of a manufacturing process using a limited number of experiments. The following are the parameters with respective limits as shown in table5.

Table 5:Parameters with limits

Inputs		Limits				
Process Parameters	Units	-1.682	-1	0	1	1.682
Cutting Speed	m/min	77	85	96	107	115
Depthof Cut	Mm	0.5	0.6	0.75	0.88	1
FeedRate	mm/rev	0.05	0.06	0.07	0.09	0.1

A mathematical model of the process can also be developed so that it can help in predicting the results which are expected when parameters are changed. In this present study the optimization of cutting parameters during hard turning of OHNS steel is carried out using response surface methodology (RSM)

Table 6: Order of runs

StdOrder	RunOrder	PtType	Blocks	CS	FR	DOC	Cutting Speed	Feed Rate	DepthofCut
1	8	1	1	-1	-1	-1	85	0.06	0.6
2	15	1	1	1	-1	-1	107	0.06	0.6
3	1	1	1	-1	1	-1	85	0.09	0.6
4	18	1	1	1	1	-1	107	0.09	0.6
5	14	1	1	-1	-1	1	85	0.06	0.88
6	3	1	1	1	-1	1	107	0.06	0.88
7	11	1	1	-1	1	1	85	0.09	0.88
8	17	1	1	1	1	1	107	0.09	0.88
9	13	-1	1	-1.68179	0	0	77	0.07	0.75
10	19	-1	1	1.68179	0	0	115	0.07	0.75
11	16	-1	1	0	-1.68179	0	96	0.05	0.75

12	12	-1	1	0	1.68179	0	96	0.1	0.75
13	7	-1	1	0	0	1.68179	96	0.07	0.5
14	10	-1	1	0	0	1.68179	96	0.07	1
15	2	0	1	0	0	0	96	0.07	0.75
16	6	0	1	0	0	0	96	0.07	0.75
17	9	0	1	0	0	0	96	0.07	0.75
18	5	0	1	0	0	0	96	0.07	0.75
19	4	0	1	0	0	0	96	0.07	0.75
20	20	0	1	0	0	0	96	0.07	0.75

II EXPERIMENTATION USING RSM

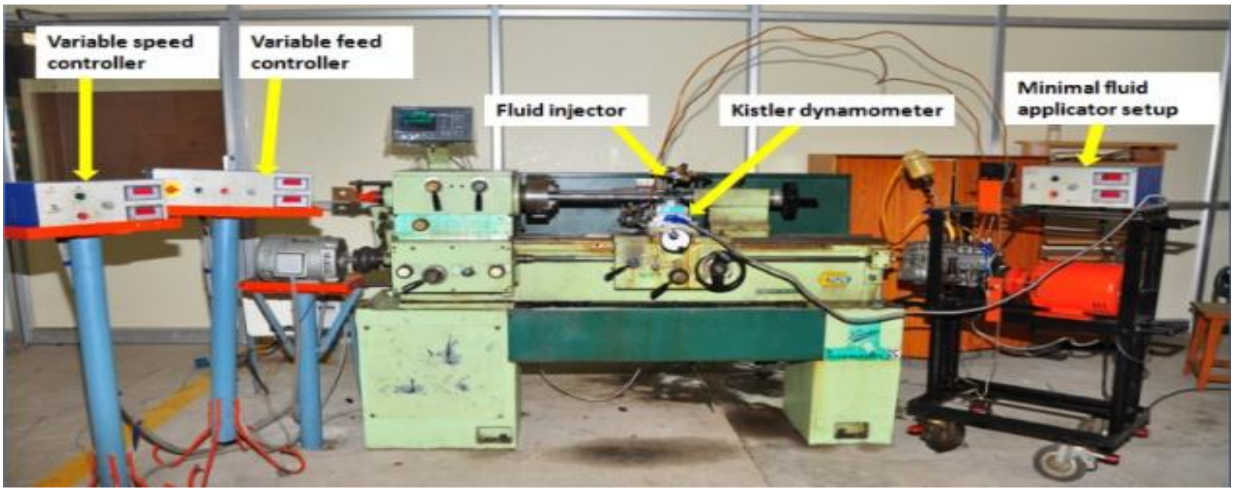

Fig 3 : Lathe With MCFA Setup

The MCFA setup was developed in house at Karunya University by Varadarajan et al [9]. It consists of a P-4 Bosch fuel pump coupled to an infinitely variable electric drive. Although the setup uses two nozzles to project the high velocity steam along the cutting edge ensuring maximum possible interpenetration of both chip-tool and the work-tool interfaces, only the chip-tool nozzle was used for the current study. The MCFA apparatus allowed for the independent variation of pressure at fluid injector, frequency of pulsing and the quantity of application (rate) of fluid application. The cutting parameters were selected and their combinations were determined and set at semi finish turning range based on the results of preliminary experiments and the recommendations of M/sTaegu Tec India (P) Ltd. Table 7 shows the levels of feed rate, cutting speed and depth of cut. During each experiment, surface roughness (Ra). Surface roughness was measured using Mitutoyo (SJ-210) portable surface roughness tester. An emulsion of soya oil based cutting fluid is used for the process.

Table 7: Observations of response parameters

CuttingSpeed (m/min)	FeedRate (mm/rev))	DepthOf Cut (mm)	Surface Roughness (µm)
85	0.06	0.6	1.290
107	0.06	0.6	1.370
85	0.09	0.6	1.400
107	0.09	0.6	1.350
85	0.06	0.88	1.530
107	0.06	0.88	1.700
85	0.09	0.88	1.620
107	0.09	0.88	1.651
77	0.07	0.75	1.560
115	0.07	0.75	1.690
96	0.05	0.75	1.320
96	0.1	0.75	1.230
96	0.07	0.5	1.500
96	0.07	1	1.870
96	0.07	0.75	1.730
96	0.07	0.75	1.710
96	0.07	0.75	1.750
96	0.07	0.75	1.730
96	0.07	0.75	1.770
96	0.07	0.75	1.720

III RESULTS AND DISCUSSIONS

The 20 run experiment was conducted in a turn master by giving the input parameters varied at five levels maximum and minimum coded value and the three levels (-1,0,1) the output parameter surface roughness was measured by using surface roughness tester the values are noted down. The values are taken from the table8, the regression and residual plot was generated by using the Design Expert 10 software respectively.

Regression Analysis:$R_a$versus Cutting Speed, Depth of Cut, Feed Rate

R_a= 1.73587+0.032924*A-1.49093E-003*B+0.12545*C-0.033625*A*B+0.021375*A*C-6.12500E-003*B*C-0.044572*A^2-0.16832*B^2-0.023359*C^2

A,B.C-linear term

A^2, B^2, C^2 -Second order term

A*B,B*C,A*C-interaction term

Table8: Regression Analysis of Surface roughness

Term	Sum of squares	DF	Mean square	F	P
Constant	0.66	9	0.074	54.69	0.0001
Cutting speed	0.015	1	0.015	11.00	0.0078
Feed Rate	3.036E-005	1	3.036E-005	0.023	0.8836
Depth of Cut	0.21	1	0.21	159.67	0.0001
Cutting speed * Feed Rate	9.045E-003	1	9.045E-003	6.72	0.0268
Depth of Cut * Cutting speed	3.655E-003	1	3.655E-003	2.72	0.1304
Feed Rate * Depth of Cut	3.001E-004	1	3.001E-004	0.22	0.6469
Cutting speed * Cutting speed	0.029	1	0.029	21.27	0.0010
Feed Rate * Feed Rate	0.41	1	0.41	303.30	0.0001
Depth of Cut * Depth of Cut	7.863E-003	1	7.863E-003	5.84	0.0363

R-Sq=98.01% R-Sq(adj)=96.22%

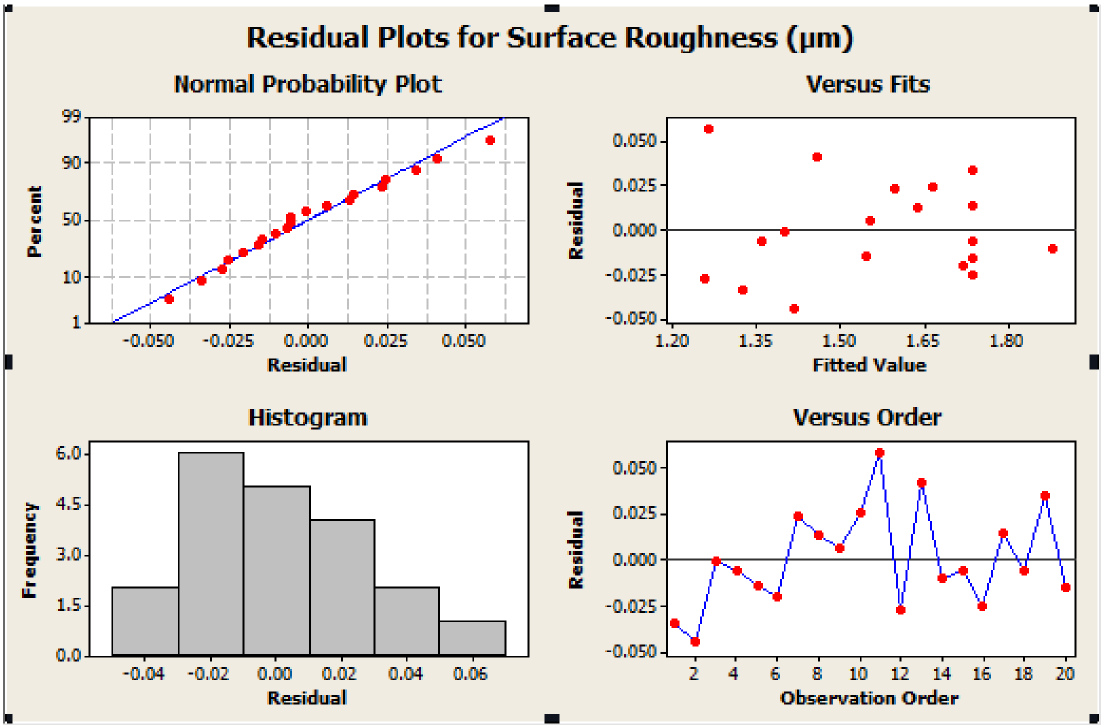

Fig4 : Residual plot for surface roughness (Ra)

3.1 Contour and Surface Plots for Surface Roughness

Contour line for a function of two variables is a curve connecting points where the function has the same particular value. The gradient of the function is always perpendicular to the contour lines. When the lines are close together the magnitude of the gradient is large. A level set is a generalization of a contour line for functions of any number of variables. Contour lines are curved, straight or a mixture of both lines on a map describing the intersection of area or hypothetical surface with one or more horizontal planes. The configuration of these contours allows map readers to infer relative gradient of a parameter and estimate that parameter at specific places.

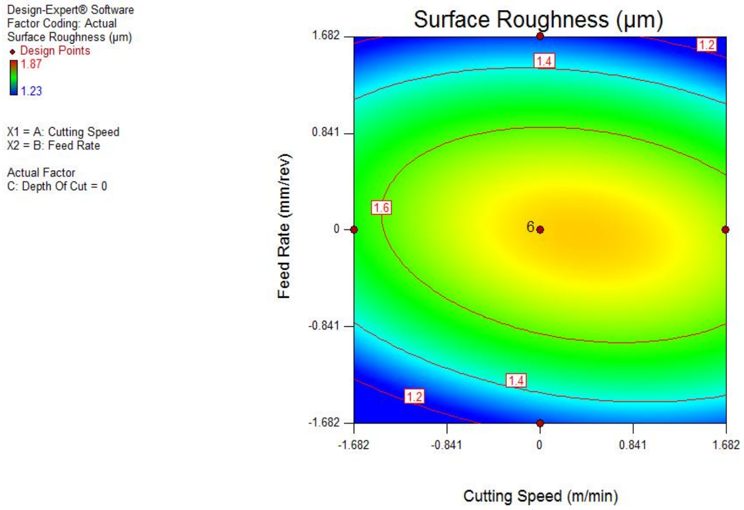

Fig5:Contour plot of surface roughness-Cutting speed and Feed rate

The 3D surface plots are useful for establishing response values and operating condition. As the colour gets darker the response increases. The surface plot shows that the surface roughness increases as the cutting speed, feed rate and depth of cut increases. The surface roughness varies from 1.23µm-1.87µm as shown in fig5-fig9.

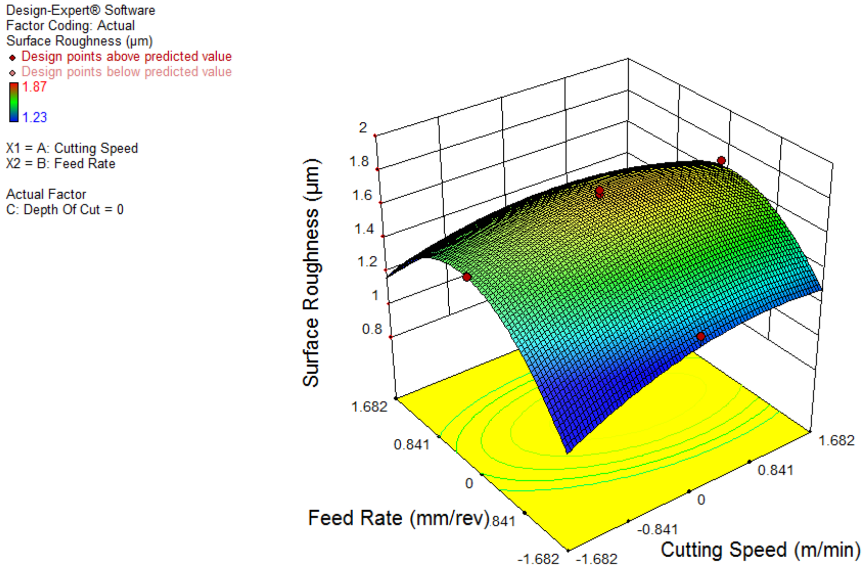

Fig6: Surface plot of Surface roughness-Cutting speed and Feed rate

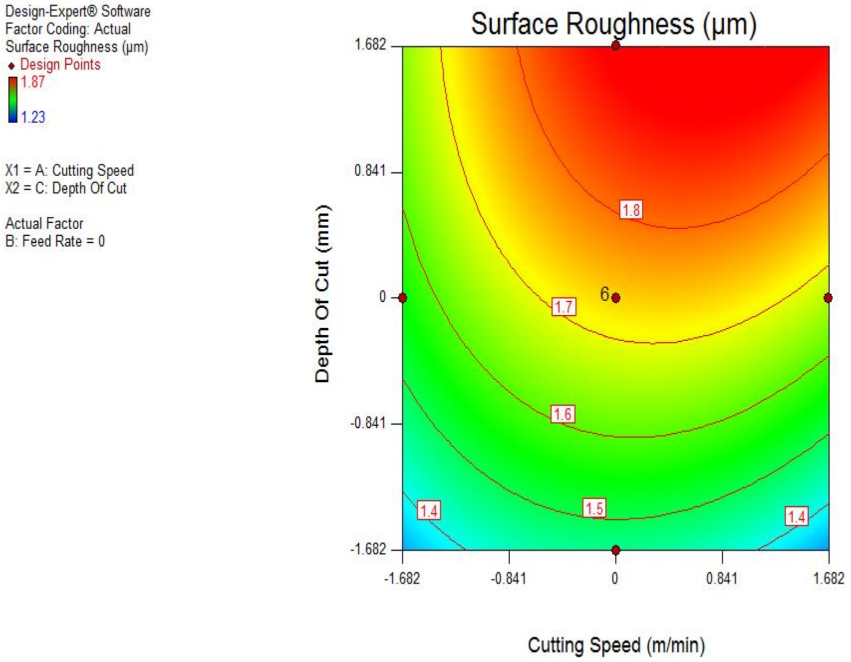

Fig 7: Contour plot of Surface roughness-Cutting speed and Depth of cut.

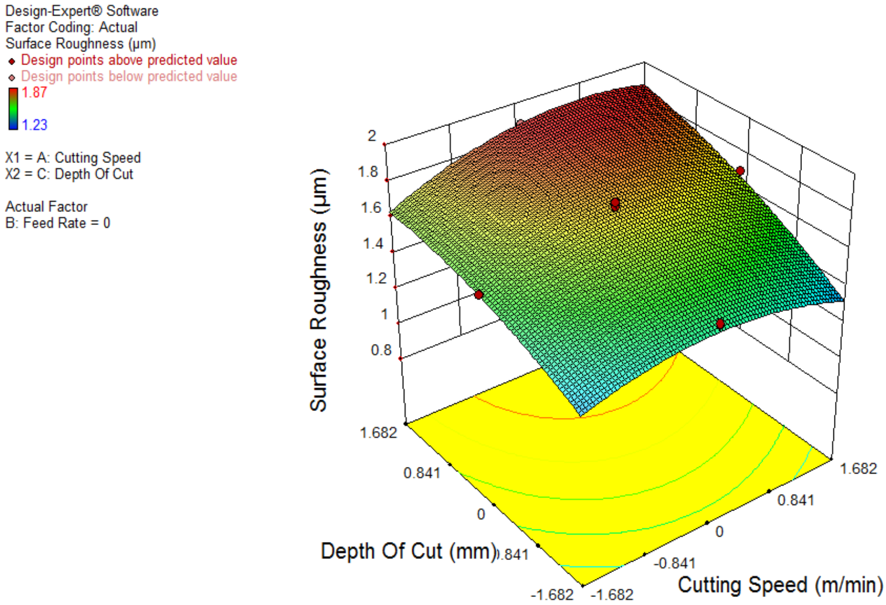

Fig8:Surface plot of Surface roughness-Cutting speed and Depth of cut

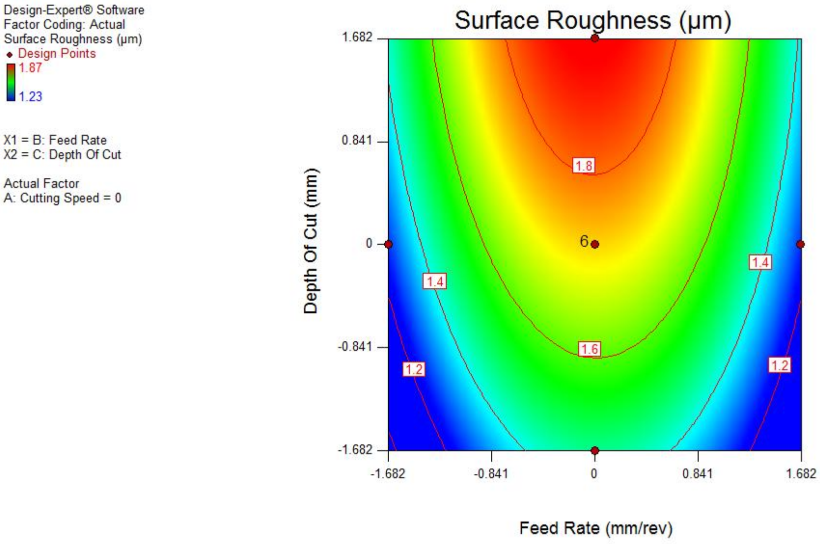

Fig 9: Contour plot of Surface roughness-Feed rate and Depth of cut

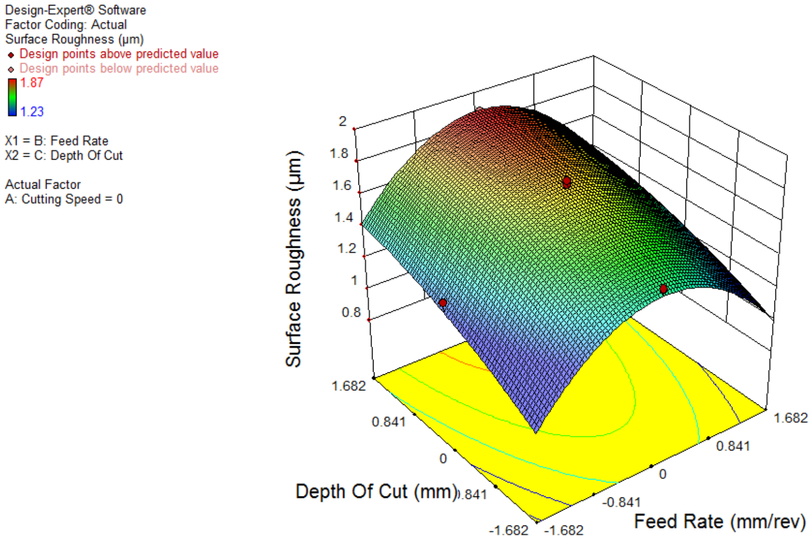

Fig 10: Surface plot of Surface roughness-Feed rate and Depth of cut

IV CONCLUSIONS

Based on this work the following conclusion are drawn for the optimization of the surface roughness during the hard turning of OHNS with soyabean oil based cutting fluid using RSM.

- Minimal cutting fluid application with soya bean oil based cutting fluid improved the cutting performance in terms of surface roughness.
- Hence Soya oil based cutting fluid is the best challenging cutting fluid which can be used in the machining industry.
- In the contour and surface plots, the minimum surface roughness obtained is 1.23µm with cutting speed of 87.1m/min, Feed rate of 0.06125mm/rev and Depth of cut of 0.687mm.
- The optimized cutting parameters for cutting speed ,feed rate and depth of cut are 85m/min, 0.06m/rev, 0.6mm.The desirability of this optimized condition is 89.8%.

- The optimal solution for Surface roughness is 1.27 µm

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