Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI: 10.21474/IJAR01/3915
DOI URL: http://dx.doi.org/10.21474/IJAR01/3915

RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION OF MACHINABILITY CHARACTERISTICS UNDER MINIMUM QUANTITY LUBRICATION USING GRAPHENE BASED NANO-CUTTING FLUID.

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Manuscript Info

Manuscript History

Received: 12 February 2017
Final Accepted: 10 March 2017
Published: April 2017

Key words:-
Cutting zone temperature, graphene, minimum quantity lubrication, response surface methodology, surface roughness, flank wear.

Abstract

Minimum quantity lubrication (MQL) has proved to be a sustainable method which can replace flood cooling for the application of cutting fluid in the metal cutting operation. Addition of nanoparticles in the cutting fluid may enhance the cooling and lubricating properties of the base fluid. Present work deals with the experimental investigation of the effect of addition of graphene nanoparticles in the cutting fluid under MQL on machinability characteristics such as tool flank wear, surface roughness and cutting zone temperature. Response surface methodology (RSM) was utilized for the experimental design. The concentration of graphene nanoparticles in the base fluid, cutting velocity, feed rate and depth of cut were taken as cutting parameters. Regression analyses was employed to estimate flank wear, surface roughness and cutting temperature. ANOVA was applied to examine the influence of cutting parameters on cutting temperature, flank wear and surface roughness. Results showed that higher concentration of graphene nanoparticles played a significant role in reducing flank wear of cutting tool even at higher magnitude of cutting velocity and feed rate which has an immense potential of boosting the productivity of machining process. Minimum surface roughness was also obtained at higher concentration of graphene nanoparticles along with higher magnitude of cutting velocity and lower magnitude of feed rate and depth of cut. In case of cutting zone temperature higher concentration of graphene platelets was effective in reducing cutting zone temperature along with lower magnitude of cutting velocity, feed rate and depth of cut. Finally, the optimization of output responses was done in order to provide the ranges for best cutting conditions.

Introduction:-

Today metal cutting is one of the most prominent operation in the production industry. Machining involves withdrawal of excess material from the workpiece by forcing of the cutting tool against the workpiece in order to obtain desired shape, size and surface finish of the workpiece. When ferrous materials are machined the cutting temperature increases with cutting velocity which results in softening of cutting tool leading to rapid wear and failure of the cutting tool (Bruni et al., 2006). Since high cutting speed is preferable for obtaining higher productivity so the generated heat has to be dissipated continuously around the cutting zone to maintain the sharpness of the cutting edge of the tool. If the temperature continues to rise then after a certain point of time tool becomes blunt

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which in turn results in immoderate power consumption and inferior surface finish, therefore it is necessary to remove generated heat for the enhancement of tool life as well as the surface finish.

Cutting fluids have been frequently used to take care of the heat produced during the machining process. Cooling and lubrication properties of a cutting fluid plays a critical role in machining. Task of a cutting fluid is to minimize the friction between tool and workpiece interface thereby reducing the cutting temperature around the cutting zone, to conduct the heat generated during cutting operation away from the cutting zone, to prevent the built-up edge formation by decreasing the adhesion between chip and tool, to contribute in cleaning the cutting zone by washing away the chips from the cutting region and to prevent the oxidation of newly finished surface by forming a protective film over it. However, toxicity effect of mineral, synthetic and semi-synthetic cutting fluids vandalizes the ecosystem (Birova et al., 2002). When cutting fluids evaporate and dispersed as a vaporand microparticles, they give rise to serious health hazards like lung cancer, respiratory diseases, dermatological and genetic diseases (Bennett, 1983). Apart from these detrimental effects cutting fluids also holds up to 15-20% of the entire worth of the manufactured workpiece. In recent years researchers have been focusing mainly on minimum quantity lubrication (MQL) technique because of its economical and eco-friendly qualities. MQL also meets the requirements of green machining.

In minimum quantity lubrication, a very small quantity of lubricant is blend with high pressure air to form an oil mist which is sprayed in the cutting zone with the help of a nozzle (Varadharajan et al., 2002). MQL framework comprises of an atomizer, cutting fluid sump, nozzle and so on. The atomization of lubricant is carried out in an atomizer where high-pressure air is utilized to atomize the lubricant. The atomizer acts as an ejector. Atomized lubricant is then provided to the cutting zone by the air in a low-pressure circulation system. Cutting fluid is kept in the oil sump under a stable hydro powered load from where it is sucked by the partial vacuum created by venturi impact in the blending chamber. The air going via blending chamber atomizes the lubricant stream into oil mist. At the point where this oil mist is showered in the machining zone as fog, it fills in as a coolant and in addition a lubricant and infiltrates profound into the tool-workpiece interface (A.K. Sharma et al. 2016).

Many research works have been carried out using conventional cutting fluids under MQL technique and most of them concluded that it is more efficient than flood lubrication. Tiwari et al. (2012) found a rise in thermal conductivity, viscosity and density of the cutting fluid due to increment in volume concentration of nanoparticles and due to this increment the heat dissipation potential of cutting fluid was enhanced and cutting zone temperature was reduced. Peng et al. (2009) stipulated four techniques regarding the reduction of wear and friction by the addition of nano-sized particles into the cutting fluid. They are as per the following:- (1) Tiny spherical nanoparticles which will probably roll between two frictional surfaces and convert the sliding friction into a coalition of rolling and sliding friction; (2) Nanoparticles are prone to mesh with friction sets to generate a surface preventive layer; (3) Nanoparticles settle down into the voids of the contact surfaces to create a physical tribo-layer that makes up for the loss of mass which is called “mending effect”; (4) Large number of nanoparticles are capable to sustain compressive force evenly thereby reducing the compressive stress concentrations associated with high contact pressure. Fig. 1 shows the lubrication techniques between two frictional surfaces when nanoparticles enriched cutting fluid is used during machining.

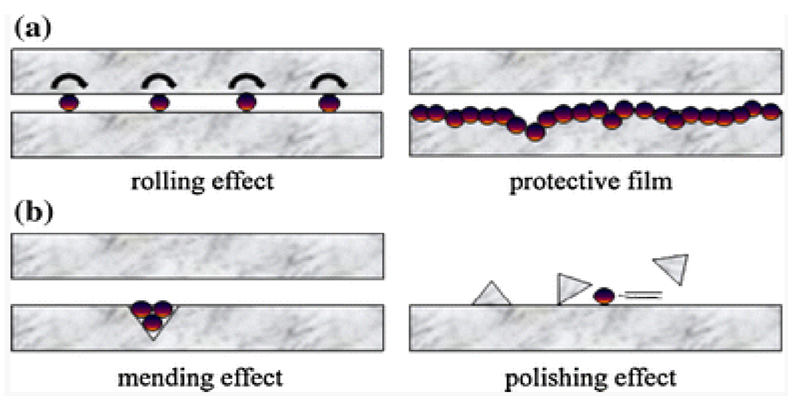


Fig. 1:- Lubrication mechanisms during machining with nanoparticles enhanced cutting fluid. (Lee et al. 2009).

Vamsi Krishna et al. (2010) explored the impact of the insertion of nanoboric acid in SAE-40 and coconut oil while turning with carbide tool and observed a remarkable decrement in flank wear, temperature and surface roughness. M. Amrita et al. (2014) made an attempt to study the impact of inclusion of functionalized nanographite, nanoboric acid and nanomolybdenum disulfide in emulsifier oil while turning of AISI 1040 steel with cemented carbide tool and concluded that the application of MQL significantly lessened tool wear, cutting temperature, cutting forces and surface roughness in juxtaposition of dry and wet machining. M.M.S Prasad and R.R Srikant (2013) found that an increase in the concentration of nanographite in water soluble oil while turning of AISI 1040 steel adopting MQL diminished cutting temperature, surface roughness, cutting forces and tool wear. Sayuti et al. (2014) used SiO_2 nano-lubricant in mineral oil while turning of AISI 4140 steel with coated carbide inserts adopting MQL and concluded that minimum tool wear was achieved with nanoparticle concentration of 0.5%wt, air pressure of 2 bar and nozzle orientation angle of 60^o whereas better surface finish was obtained with 0.5%wt silicon dioxide (SiO_2) concentration, less air pressure and nozzle orientation angle of 30^o. Kyung-Hee Park et al. (2011) investigated the impact of the inclusion of nanographene in vegetable oil while ball milling of AISI 1045 steel with TiAlN-coated carbide insert and observed that the use of MQL reduced central wear, flank wear and chipping at the cutting edge of the tool. Dinesh Setti et al. (2012) utilized water-based Al_2O_3 nanofluid during grinding of Ti-6Al-4V alloy and observed that the implementation of MQL lessened grinding forces and enhanced surface quality significantly. Sharma et al. (2015) evaluated the impact of nanofluids while turning of AISI D2 steel adopting MQL and observed that the nanofluid lessened surface roughness and cutting forces. Samuel et al. (2011) explored the influence of the addition of graphene platelets into the semisynthetic metalworking fluids during microturning and concluded that the addition of graphene platelets improved cooling and lubricating efficiencies due to increase in wettability of cutting fluid and sliding of graphene sheets within platelets respectively. Amrita et al. (2013) employed nanographite in water soluble oil during turning of AISI1040 and found that nanofluid under MQL showed better machining performance than MQL with conventional cutting fluid, dry machining and wet machining. Very small work has been done so far on nanoparticle enhanced cutting fluids in turning operation with MQL application. The motivation behind this investigation is to explore the impact of different concentrations of graphene-based nano cutting fluid along with cutting speed, feed rate and depth of cut with the help of response surface methodology (RSM) originated design of experiment on different machinability characteristics such as tool wear, cutting temperature, and surface roughness in the course of turning operation adopting minimum quantity lubrication technique.

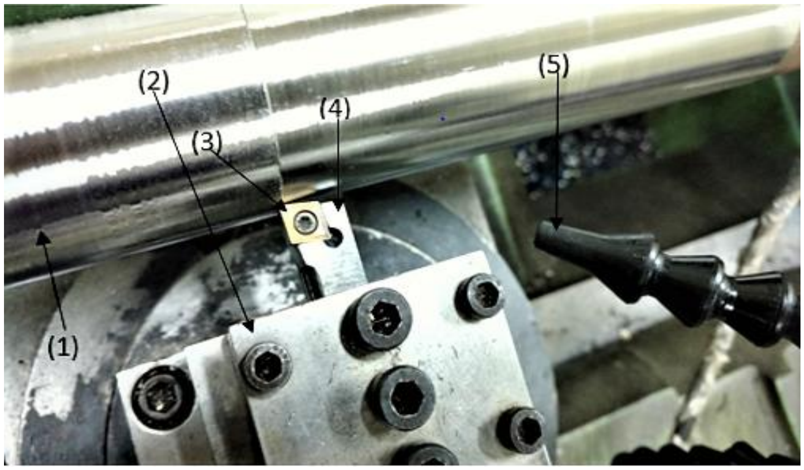
Experimental Details:-

The experiment involved turning operation which was accomplished on AISI 304 stainless steel with tungsten carbide tool insert having a standard designation as CCMT09T304-TN2000. The tool holder is codified as WIDAX SCLCR1212F09 D 3J.The workpiece had an initial diameter of 66.08mm. All the experimental runs were done on a high-speed precision lathe machine (Model: NH22) with 11 kW spindle power manufactured by Hindustan machine tools (HMT). Experimental setup also includes dynamometer, charge amplifier, data acquisition system, tachometer, k-type thermocouple and MQL setup. Fig.2 shows the experimental setup on which turning operation was performed.

(a)

(1) Air Compressor (2) Control Panel (3) MQL Setup (4) High-speed precision lathe machine (5) PC attached with thermocouple

(b)



(1) Workpiece (2) Tool post (3) Cutting tool (4) Tool holder (5) Discharge nozzle

Fig 2:- (a) and (b) Various components of experimental setup involved during machining and measurement of output responses.

2.1 Preparation of nano-cutting fluid:-

First of all base fluid was prepared by mixing water and servo-cut-s oil. The concentration of servo-cut-s oil in water was 5% (v/v). After preparing base fluid graphene nanoparticles (30-40nm) was added to the base fluid and mixed rigorously to evade sedimentation of graphene nanoparticles due to the difference in specific gravity. Three samples of nano-cutting fluid were made having different concentrations (0.2%, 0.6%, and 1% w/w) of graphene nanoparticles. After that ultra-sonication of these samples was done in order to obtain a uniform dispersion of nanoparticles in the base fluid.

2.2 Design of experiment

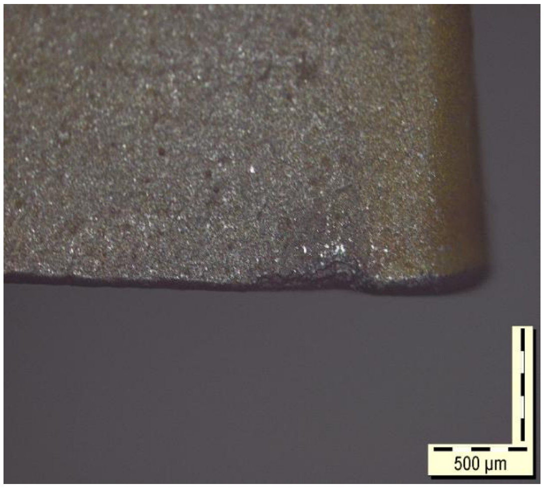
Experimental design is done before the commencement of any experiment in order to obtain significant output responses in a lesser number of experimental runs. In this investigation, the design of experiment was done on the basis of response surface methodology (RSM) using Box- Behnken design. Table 1 shows the different magnitudes of input turning factors used during machining.

Table 1:- Magnitudes of turning factors used in design of experiment

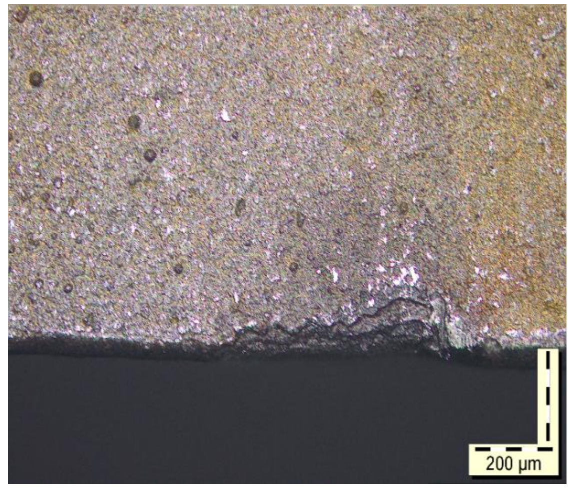
S. No.	Turning factors	Unit	Level 1	Level 2	Level 3
1	Cutting Speed	m/min	40	90	140
2	Feed	mm/rev	0.08	0.12	0.16
3	Depth of Cut	mm	0.6	1.0	1.4
4	Concentration of nanoparticles	%(w/w)	0.2	0.6	1.0

Results and Discussion:-

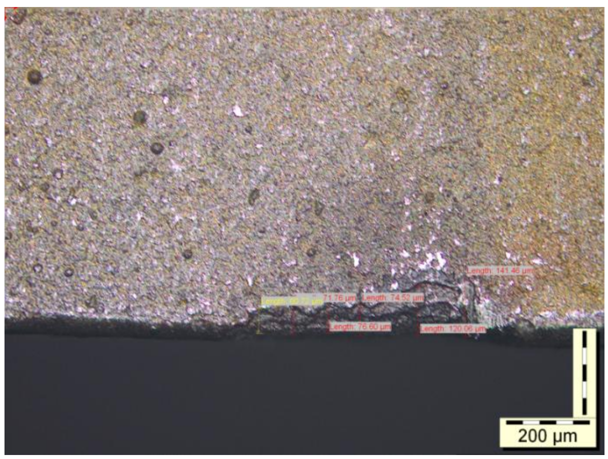
During machining output responses which were evaluated are tool wear, cutting zone temperature and surface roughness. The temperature evaluation was carried out by the assistance of a k-type thermocouple. The surface roughness of the workpiece after each turning run was recorded using Mitutoyo Surftest SJ-210. The measuring device was mounted on the workpiece and then the surface roughness for every length of cut was recorded. Flank wear of cutting tool was computed with the help of Olympus metallurgical microscope BX51M which is shown in Fig. 3.



(a) Image of flank wear taken with the help of Olympus metallurgical microscope at 5X magnification.



(b) Image of flank wear taken with the help of Olympus metallurgical microscope at 10X magnification.



(c)Measurement of tool wear at six different positions on the flank surface

Fig. 3:- (a) (b) and (c) Tool wear measurement with the help of Olympus metallurgical microscope BX51M

After measuring various output responses, response surface methodology was employed to analyze the influence of the concentration of graphene nanoparticles along with cutting velocity, feed and depth of cut on output responses like tool flank wear, cutting zone temperature, surface roughness during machining. The relationship between turning factors and output responses were modeled by quadratic regression.

Tool flank wear:-

ANOVA was implemented to investigate whether the cutting parameters have a significant impact on the tool flank wear or not. If the P value of a particular cutting parameter in ANOVA table is less than 0.05 then it implies that cutting parameter has a significant influence on the flank wear.

Table 2:- ANOVA result for flank wear

Source	Sum of Squares	Degree of Freedom	Mean Sum of Squares	F- Value	P-Value
Model	13833.59	14	988.11	10.37	0.0001
A-Velocity (V)	4691.26	1	4691.26	49.24	0.0001
B-Feed (f)	2035.44	1	2035.44	21.37	0.0006
C-Depth of cut (d)	731.45	1	731.45	7.68	0.0169
D-Concentration(C)	1124.16	1	1124.16	11.80	0.0049
AB	940.40	1	940.40	9.87	0.0085
AC	18.74	1	18.74	0.20	0.6653
AD	698.97	1	698.97	7.34	0.0190
BC	625.85	1	625.85	6.57	0.0249
BD	227.53	1	227.53	2.39	0.1482
CD	82.79	1	82.79	0.87	0.3696
A^2	5.49	1	5.49	0.058	0.8143
B^2	39.19	1	39.19	0.41	0.5333
C^2	2072.97	1	2072.97	21.76	0.0005
D^2	70.13	1	70.13	0.74	0.4077
Residual	1143.23	12	95.27		
Lack of Fit	999.51	10	99.95	1.39	0.4892
Pure Error	143.72	2	71.86		
Cor. Total	14976.82	26			

Model Summary:	Std. Dev.	R-Squared	Adj. R-Squared	Pred. R-Squared
	9.76	0.9237	0.8346	0.5940

Regression equation was formulated to estimate the value of tool flank wear (W) by inserting the values of various cutting parameters is given by equation (1):

$$W = 197.254 + (0.7398 \times V) + (272.041 \times f) - (313.413 \times d) + (93.0907 \times C) - (7.6665 \times V \times f) + (0.1082 \times V \times d) - (0.6609 \times V \times C) + (781.781 \times f \times d) - (471.375 \times f \times C) - (28.4344 \times d \times C) + (0.0004 \times V^2) - (1694.2 \times f^2) + (123.219 \times d^2) + (22.6642 \times C^2) \quad (1)$$

3.1.1 Influence of cutting conditions on tool flank wear under MQL through RSM based contour and surface plots

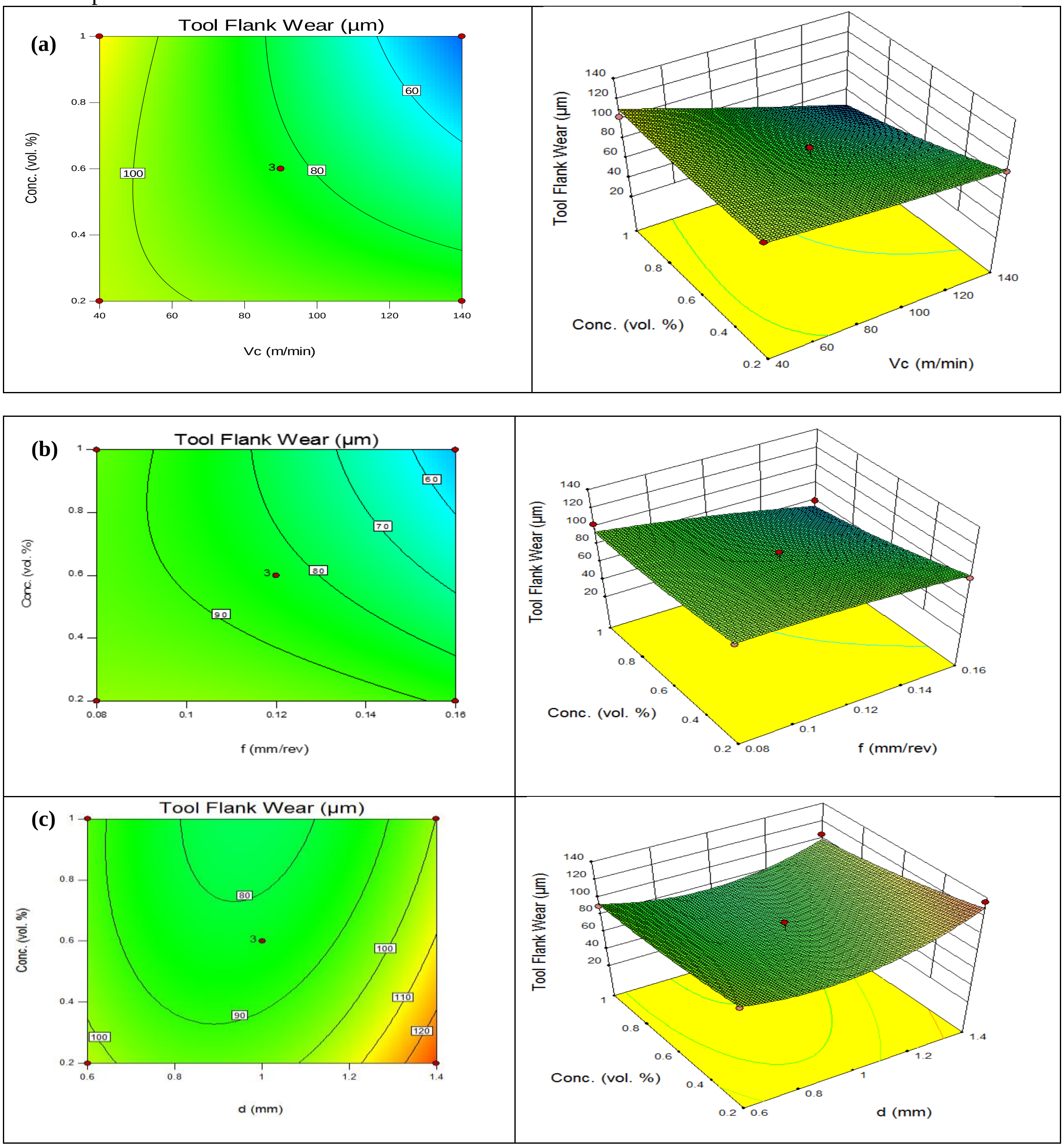


Fig. 4:- (a) (b) and (c) Contour and surface plots of tool flank wear with respect to various cutting parameters.

In Fig. 4(a) contour and surface plot shows that there is not much influence of the concentration of graphene nanoparticles on the tool flank wear at the lower magnitude of the cutting velocity but as the cutting velocity is increased with the concentration of graphene nanoparticles significant reduction in flank wear is observed. The minimum flank wear is attained at highest magnitude of cutting velocity and concentration of graphene nanoparticles. The same trend as that of concentration vs cutting velocity is followed in Fig. 4(b) where the minimum flank wear of the cutting tool is attained at highest magnitude of feed rate and concentration of graphene nanoparticles in nanofluid under MQL during machining. In the contour and surface plot shown in Fig. 4(c) tool wear initially tends to decrease as the depth of cut and graphene nanoparticles concentration tends to increase and after attaining a minimum value at the high magnitude of graphene concentration and middle magnitude of depth of cut, tool wear tends to increase further with the increase in depth of cut. At the high magnitude of depth of cut maximum flank wear takes place at the lower graphene concentration but as the concentration is increased the reduction of flank wear takes place. So higher concentration of graphene nanoparticles plays a significant role in reducing flank wear of cutting tool due to its excellent lubrication property which results from exfoliation mechanism. In sheet like nanoparticle including graphene there is weak interlayer van der walls force due to which two adjacent layers are exfoliated easily under the shear force. Sliding movement between adjacent layers will result in lower friction which in turn reduces the flank wear of the cutting tool W. Dai et al. (2016).

3.2 Surface Roughness:-

ANOVA was employed to investigate whether the cutting parameters have a significant impact on the surface roughness or not. If the P value of a particular cutting parameter in ANOVA table is less than 0.05 then it implies that cutting parameter has a significant influence on the surface roughness of the workpiece.

Table 3:- ANOVA result for surface roughness

Source	**Sum of Squares**	**Degree of Freedom**	**Mean Sum of Squares**	**F-Value**	**P-Value**
Model	1.37	14	0.098	9.49	0.0002
A-Velocity(V)	0.23	1	0.23	21.88	0.0005
B-Feed(f)	0.31	1	0.31	29.69	0.0001
C-Depth of cut(d)	0.33	1	0.33	32.09	0.0001
D-Concentration(C)	0.100	1	0.100	9.67	0.0090
AB	0.00090	1	0.000900	0.087	0.7729
AC	0.056	1	0.056	5.44	0.0380
AD	0.00716	1	0.007157	0.69	0.4215
BC	0.00004	1	0.000043	0.00	0.9494
BD	0.00608	1	0.006084	0.59	0.4577
CD	0.00456	1	0.004556	0.44	0.5192
A^2	0.068	1	0.068	6.57	0.0248
B^2	0.24	1	0.24	22.85	0.0004
C^2	0.00222	1	0.002221	0.21	0.6512
D^2	0.00010	1	0.000102	0.01	0.9224
Residual	0.12	12	0.010		
Lack of Fit	0.11	10	0.011	1.47	0.4722
Pure Error	0.015	2	0.007437		
Cor. Total	1.50	26			

Model Summary:	Std. Dev.	R-Squared	Adj. R-Squared	Pred. R-Squared
	0.10	0.9172	0.8205	0.5578

Regression equation was formulated to estimate the value of surface roughness (Ra) by inserting the values of various cutting parameters is given by equation (2):

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$$\mathrm{Ra} = 4.1137 - (0.0164 \times \mathrm{V}) - (29.9039 \times \mathrm{f}) - (0.0138 \times \mathrm{d}) - (0.57409 \times \mathrm{C}) + (0.0075 \times \mathrm{V} \times \mathrm{f}) + (0.0059 \times \mathrm{V} \times \mathrm{d}) - (0.00211 \times \mathrm{V} \times \mathrm{C}) + (0.2057 \times \mathrm{f} \times \mathrm{d}) + (2.4375 \times \mathrm{f} \times \mathrm{C}) + (0.21093 \times \mathrm{d} \times \mathrm{C}) + (4.5135 \times \mathrm{V}^2) + (131.49 \times \mathrm{f}^2) - (0.1275 \times \mathrm{d}^2) + (0.0273 \times \mathrm{C}^2) \qquad (2)$$

3.2.1 Influence of cutting conditions on surface roughness under MQL through RSM based contour and surface plots

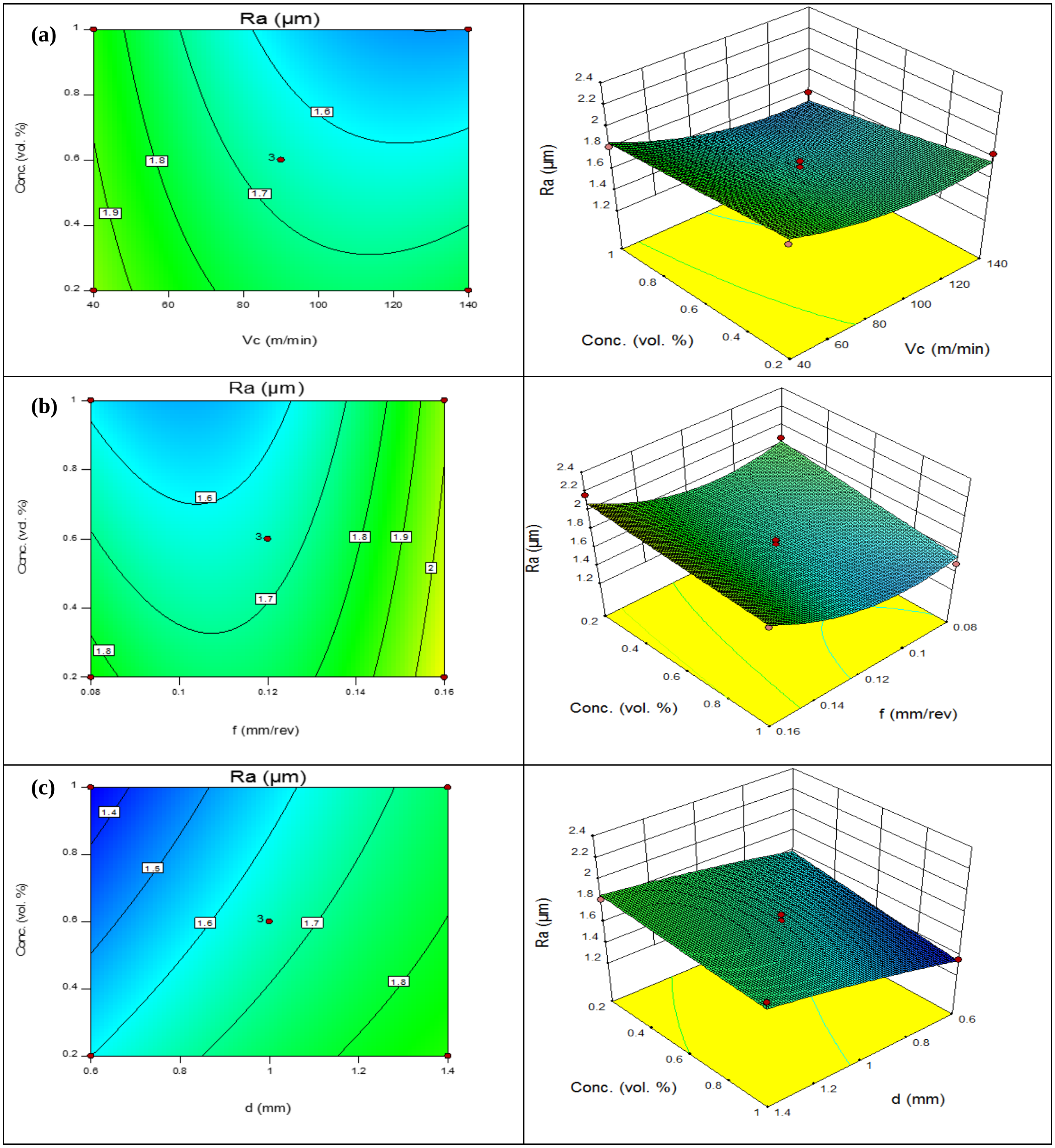

Fig. 5:- (a)(b)and(c) Contour and surface plots of surface roughness of work piece with respect to various cutting parameters.

In the contour and surface plots which are shown in Fig. 5(a) there is not much refinement in the surface finish with the increase in the concentration of graphene nanoparticles at a lower magnitude of cutting velocity but as we further increase the cutting velocity with the increment in the graphene concentration there is a significant reduction in surface roughness of the workpiece. The best surface finish is obtained at highest magnitudes of cutting speed and graphene nanoparticle concentration. In Fig. 5(b) the minimum value of surface roughness is attained at the lower magnitude of feed rate with a high magnitude of graphene concentration and when feed rate magnitude has further increased the value of surface roughness increases with the lower concentration of graphene nanoparticles but decreases slightly when the magnitude of graphene concentration approach towards its higher value. There is a significant decrement in surface roughness or we can say that minimum value of surface roughness is attained at the lower magnitude of depth of cut with a higher magnitude of concentration of the graphene nanoparticles but as the depth of cut is further increased the surface roughness increases with the lower magnitude of graphene concentration as shown in Fig. 5(c). Again higher concentration of graphene nanoparticles plays a significant role in reducing surface roughness of the workpiece which can be attributed to the exfoliation of graphene platelets which helps in reducing friction between tool-workpiece interface thereby maintaining the sharp cutting edge of the cutting tool which is helpful in providing superior surface finish.

Cutting Zone Temperature:-

ANOVA was employed to investigate whether the cutting parameters have a significant impact on the cutting zone temperature or not. If the P value of a particular cutting parameter in ANOVA table is less than 0.05 then it implies that cutting parameter has a significant influence on the cutting temperature.

Table 4:- ANOVA result for cutting temperature

Source	Sum of Squares	Degree of Freedom	Mean Sum of Squares	F-Value	P-Value
Model	4276.32	14	305.45	13.18	0.0001
A-Velocity(V)	250.25	1	250.25	10.80	0.0065
B-Feed(f)	1094.62	1	1094.62	47.24	0.0001
C-Depth of cut(d)	1778.77	1	1778.77	76.76	0.0001
D-Concentration(C)	132.73	1	132.73	5.73	0.0339
AB	2.40	1	2.40	0.10	0.7530
AC	73.10	1	73.10	3.15	0.1010
AD	60.84	1	60.84	2.63	0.1311
BC	16.40	1	16.40	0.71	0.4166
BD	360.81	1	360.81	15.57	0.0019
CD	0.72	1	0.72	0.031	0.8628
A^2	157.47	1	157.47	6.80	0.0229
B^2	1.00	1	1.00	0.043	0.8391
C^2	31.92	1	31.92	1.38	0.2633
D^2	154.37	1	154.37	6.66	0.0241
Residual	278.07	12	23.17		
Lack of Fit	205.97	10	20.60	0.57	0.7771
Pure Error	72.11	2	36.05		
Cor. Total	4554.39	26			

Model Summary:	Std. Dev.	R-Squared	Adj. R-Squared	Pred. R-Squared
	4.81	0.9389	0.86777	0.7039

Regression equation was formulated to estimate the value of cutting zone temperature (T) by inserting the values of various cutting parameters is given by equation (3):

$$T = -20.3065 + (0.1053 \times V) + (498.365 \times f) + (28.1844 \times d) + (24.3021 \times C) + (0.3875 \times V \times f) + (0.2137 \times V \times d) + (0.195 \times V \times C) + (126.562 \times f \times d) - (593.594 \times f \times C) - (2.6562 \times d \times C) - (0.0021 \times V^2) - (270.313 \times f^2) - (15.2891 \times d^2) + (33.625 \times C^2) \quad (3)$$

3.3.1 Influence of cutting conditions on cutting zone temperature under MQL through RSM based contour and surface plots

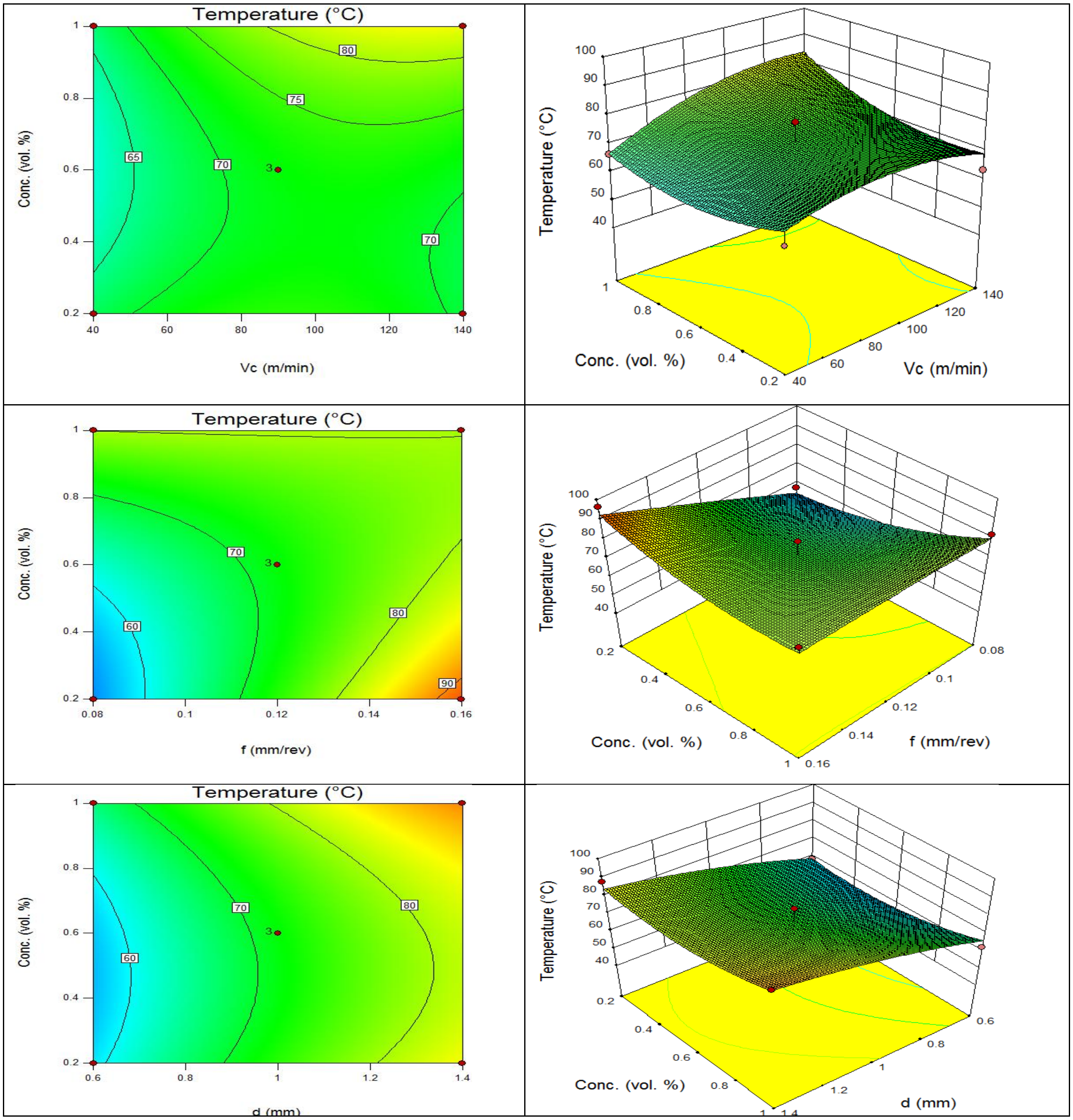

Fig. 6:- (a) (b) and (c) Contour and surface plots of cutting zone temperature with respect to the various cutting parameter.

In the contour and surface plots which are shown in Fig. 6(a) minimum cutting temperature is observed at the lower magnitude of cutting velocity with a higher magnitude of graphene nanoparticle concentration and as we proceed towards a higher magnitude of cutting velocity there is a slight increment in cutting temperature with a higher concentration of graphene nanoparticles. In Fig. 6(b) minimum cutting temperature is noticed at lower magnitude of feed rate with lower magnitude of graphene concentration but as we proceed towards higher magnitude of feed rate the cutting temperature tends to decrease with higher magnitude of graphene nanoparticle concentration. In Fig. 6(c) minimum cutting temperature is observed at the lower magnitude of depth of cut with a middle magnitude of graphene nanoparticles concentration and as we move towards higher magnitude of depth of cut there is not much effect of the concentration of graphene nanoparticles on the cutting zone temperature. Hence overall higher concentration of graphene nanoparticles in the base fluid is effective in reducing the cutting zone temperature which can be attributed to both improved lubrication as well as improved thermal conductivity of graphene enriched cutting fluid. Apart from these increased wettability of nanofluid also plays a critical role in reducing cutting zone temperature. The contact angle of the nanofluid on the tool surface decreases with the increase in the concentration of graphene nanoparticle and due to this larger surface area of the droplet remains in contact of the tool surface providing enhanced cooling by evaporation of the water phase. Increased wettability also helps graphene platelets in the cutting fluid to penetrate into the tool-workpiece interface which decreases the coefficient of friction thereby reducing the heat generation as a result of lowered friction between tool-workpiece interface J. Samuel et al. (2011).

3.4 Optimization of cutting conditions:-

In order to obtain optimal cutting conditions during turning of AISI 304 stainless steel the machinability characteristics such as tool flank wear, surface roughness and cutting zone temperature should be minimized. The goals and the parameter range elucidated for the optimization process are given in Table 5.

Table 5:- Goals and parameter range for optimization of the cutting condition.

Condition	**Goal**	**Lower limit**	**Upper limit**
Cutting velocity, V	Is in range	40	140
Feed, f	Is in range	0.08	0.16
Depth of cut, d	Is in range	0.6	1.4
Concentration of graphene, C	Is in range	0.2	1.0
Flank wear (µm)	Minimize	35.67	135.2
Surface roughness (µm)	Minimize	1.357	2.32
Cutting temperature (°C)	Minimize	47.7	96.4

Table 6 demonstrates the RSM optimization results in order of decreasing desirability magnitude. The optimized tool flank wear, surface roughness and cutting zone temperature are (35.67-37.83) µm, (1.357-1.402) µm and (60.44-62.08) °C respectively.

Table 6:- Response optimization for flank wear, surface roughness and cutting temperature.

S. No.	**V (m/min)**	**f (mm/rev)**	**D (mm)**	**C %(w/w)**	**Flank wear (µm)**	**Surface roughness (µm)**	**Cutting temperature (°C)**	**Desirability**
1	140	0.142	0.600	0.899	35.67	1.382	61.37	0.888
2	140	0.140	0.600	0.925	36.37	1.357	62.08	0.888
3	139.99	0.141	0.600	0.862	37.83	1.390	60.44	0.887
4	140	0.142	0.600	0.881	35.67	1.395	60.94	0.887
5	139.61	0.141	0.600	0.923	35.71	1.367	62.08	0.886
6	139.93	0.142	0.603	0.887	35.67	1.392	61.26	0.886
7	139.99	0.143	0.604	0.873	35.67	1.402	60.97	0.885
8	139.25	0.142	0.600	0.905	35.67	1.384	61.63	0.885

Conclusion:-

In this paper response surface methodology (RSM) was employed to investigate the influence of concentration of graphene nanoparticles in cutting fluid along with the process parameters such as cutting velocity, feed rate and depth of cut on tool flank wear, surface roughness and cutting zone temperature during turning of AISI 304 stainless steel under minimum quantity lubrication technique. In turning experiment different cutting velocity, feed rate and depth of cut as cutting parameters and different concentration of graphene-based nanofluid were utilized. Regression models for flank wear of cutting tool, surface roughness and cutting zone temperature was obtained using RSM while investigating the influences of turning factors on various machinability characteristics.

After investigating the influence of cutting conditions on different response outputs under MQL it can be concluded that higher concentration of graphene nanoparticles in the base fluid is helpful in achieving minimum flank wear of cutting tool even at higher magnitude of cutting velocity and feed rate which can play a critical role in improving the productivity of the machining process. In the case of surface roughness, a higher concentration of graphene nanoparticles in the base fluid along with the higher magnitude of cutting velocity but lower magnitudes of feed rate and depth of cut is required to accomplish the best surface finish of the workpiece during machining. It was observed that higher concentration of graphene nanoparticles along with lower magnitudes of cutting velocity, feed rate and depth of cut is helpful in reducing the cutting zone temperature. Overall higher concentration of graphene nanoparticles plays a critical role in reducing all the three response outputs. Finally the optimization of cutting condition was done in which cutting velocity, feed rate, depth of cut and concentration of 140 m/min, 0.142 mm/rev, 0.6 mm and 0.89%(w/w) gave minimum flank wear, surface roughness and cutting temperature of 35.67 µm, 1.382 µm and 61.37 ^{o}C respectively with composite desirability of 0.888.

Acknowledgement:-
I am deeply indebted to Dr. Amit Rai Dixit, Associate Professor, Indian Institute of Technology (ISM) Dhanbad for his active guidance throughout the completion of the paper.

References:-
1. Bruni, C., Forcellese, A., Gabrielli, F., Simoncini, M. (2006): Effect of the lubrication-cooling technique, insert technology and machine bed material on the work part surface finish and tool wear in finish turning of AISI 420B. Int. J. Mach. Tools Manuf., 46(12-13): 1547-1554.
2. Birova A., Pavlovicova, A., Cvenros, J. (2002): Lubricating oils based on chemically modified vegetable oils. Journal of synthetic lubrication, 18: 291-299.
3. Bennett, E.O. (1983): Water based cutting fluids and human health. Tribology international, 16(3): 133-136.
4. Varadarajan, A.S., Philip, P.K., Ramamoorthy, B. (2002): Investigations on hard turning with minimal cutting fluid application (HTMF) and its comparison with dry and wet turning. . Int. J. Mach. Tools Manuf., 42(2): 193-200.
5. Sharma, A.K., Tiwari, A.K. and Dixit, A.R. (2016): Effects of Minimum Quantity Lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: A comprehensive review. Journal of cleaner production, 127: 1-18.
6. Tiwari, A.K., Ghosh, P., Sarkar, J. (2012): Investigation of thermal conductivity and viscosity of nanofluids. Journal of environmental research and development, 7(2): 768-777.
7. Peng, D.X., Kang, Y., Hwang, R.M., Shyr, S.S. and Chang, Y.P. (2009): Tribological properties of diamond and SiO2 nanoparticles added in paraffin, Tribology international, 42: 911-917.
8. Lee, K., Hwang, Y., Cheong, S., Choi, Y., Kwon, L., Lee, J., Kim, (2009): S.H. Understanding the role of nanoparticles in nano-oil lubrication. Tribology letters, 35: 127-131.
9. Krishna, P.V., Srikant, R.R., Rao, D.N. (2010): Experimental investigation on the performance of nano boric acid suspensions in SAE-40 and coconut oil during turning of AISI 1040 steel. International journal of machine tools and manufacture, 50: 911-916.
10. Amrita, M., Shariq, S.A., Manoj, gopal, C. (2014): Experimental investigation on application of emulsifier oil based nano cutting fluids in metal cutting process. Procedia Engineering, 97: 115-124.
11. Prasad, M.M.S., Srikant, R.R. (2013): Performance evaluation of nano graphite inclusion in cutting fluids with MQL technique in turning of AISI 1040 steel. International Journal of Research in Engineering and Technology, 2(11): 381-393.
12. Sayuti, M., Sarhan, A.A.D., salem, F. (2014): Novel uses of SiO2 nano-lubrication system in hard turning process of hardened steel AISI4140 for less tool wear, surface roughness and oil consumption. Journal of cleaner production, 67: 265-276.
13. Park, K.H., Ewald, B., Kwon, P.Y. (2011): Effect of Nano-Enhanced Lubricant in Minimum Quantity Lubrication Balling Milling. Journal of Tribology, 133: 031803(1-8).

14. Setti, D., Ghosh, S. and Rao, P.V. (2012): Application of Nano Cutting Fluid under Minimum Quantity Lubrication (MQL) Technique to Improve Grinding of Ti – 6Al – 4V Alloy. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 6(10): 2107-2111.
15. Sharma, P., Sidhu, B.S., Sharma, J. (2015): Investigation of effects of nanofluids on turning of AISI D2 steel using minimum quantity lubrication. Journal of cleaner production, 108: 72-79.
16. Samuel, J., Rafiee, J., Dhiman, P., Yu, Z.-Z., and Koratkar, N. (2011): Graphene Colloidal Suspensions as High Performance Semi-Synthetic Metal-Working Fluids. The journal of Physical Chemistry C. 115: 3410-3415.
17. Amrita, M., Srikant, R.R., Sitaramaraju, A.V. (2013): Evaluation of Cutting Fluid with Nanoinclusions. Journal of Nanotechnology in Engineering and Medicine, 4: 031007(1-11).
18. Dai, W., Kheireddin, B., Gao, Liang, H.H. (2016): Roles of nanoparticles in oil lubrication. Tribology International, 102: 88-98.