[Abbas* *et al.*, 5(7): July, 2016]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

OPTIMIZATION THE CUTTING PARAMETERS TO IMPROVE SURFACE ROUGHNESS ON AISI4340 STEEL IN TURNING OPERATION USING TAGUCHI METHOD

Mohd Abbas*, Jitendra Kumar, Atishey Mittal
* Assistant Professor, Department of Mechanical Engineering, AFSET, Faridabad
P.G Student, Department of Mechanical Engineering, AFSET, Faridabad
Assistant Professor, Department of Mechanical Engineering, SRM University, Modinagar

DOI: 10.5281/zenodo.58565

ABSTRACT

Recently the concept of hard turning has gained much attention in the metal cutting industry. In hard turning, multiple operations can be performed in single step, thereby it replaces the traditional process cycle. But it involves very large quantities of cutting fluid. Procurement, storage and disposal of cutting fluid involve expenses and environmental problem. Pure dry turning is a solution to this problem as it does not require any cutting fluid at all. But pure dry turning requires ultra hard cutting tools and extremely rigid machine tools, and also it is midcult to implement in the existing shop floor as the machine tool may not be rigid enough to support hard turning. In this context, turning with minimal fluid application is a viable alternative wherein, extremely small quantities of cutting fluid are introduced at critical contact zones as high velocity pulsing slugs, so that for all practical purposes it resembles pure dry turning and at the same time free from all the problems related to large scale use of cutting fluid as in conventional wet turning. In this study, fluid application parameters that characterize the minimal fluid application scheme were optimized and its effect on cutting performance and tool vibration was studied. From the results, it was observed that minimal fluid application in the optimized mode brought forth low vibration levels and better cutting performance.

KEYWORDS: Tool vibration, Hard turning, Minimal fluid application, Injector, Surface finish, Pulsing jet.

INTRODUCTION

This experimental study presents an effective approach for the optimization of lathe machine using MINITAB 16 and Taguchi Technique in varying condition. The information about machining of difficult cutting materials is inadequate and complicated. Therefore an experimental study has to be conducted to come out with an optimum outcome. In hard turning, multiple operations can be performed in single step, thereby it replaces the traditional process cycle. But it involves very large quantities of cutting fluid. Procurement, storage and disposal of cutting fluid involve expenses and environmental problem. Pure dry turning is a solution to this problem as it does not require any cutting fluid at all. But pure dry turning requires ultra hard cutting tools and extremely rigid machine tools, and also it is midcult to implement in the existing shop floor as the machine tool may not be rigid enough to support hard turning. In this context, turning with minimal fluid application is a viable alternative wherein, extremely small quantities of cutting fluid are introduced at critical contact zones as high velocity pulsing slugs, so that for all practical purposes it resembles pure dry turning and at the same time free from all the problems related to large scale use of cutting fluid as in conventional wet turning. In this study, fluid application parameters that characterize the minimal fluid application scheme were optimized and its effect on cutting performance and tool vibration was studied. Moreover we have to demonstrate a systematic procedure of using Taguchi Parameter Design in process control of individual lathe machine and to identify the optimum Material Removal Rate and Surface Roughness performance with particular combination of cutting parameters in a turning process. At first the design of experiment has to be implemented to select manufacturing process parameters that could result in a better quality product. The response table and response graph for each level of machining parameters are obtained from the Taguchi method and the optimum levels of machining parameters are being selected. For the statistical representation MINITAB 16 was used.

LITERATURE REVIEW

Amol Thakare et.al., say in this paper that Plastic deformation of the tool is one of the most important wear modes in metal cutting, especially in continuous cutting operations. Since the strength of the tool material depends strongly on the temperature, a correct temperature distribution in the cutting edge is of key importance for the prediction of plastic deformation of the cutting edge. The temperature distribution in coated cemented carbide cutting tools is investigated using experimental techniques (IR-CCD) and finite element analysis. CVD coated cemented carbide inserts are tested in continuous turning of quenched and tempered steel (AISI 4340). Cutting forces and edge temperature distributions are measured in 2D orthogonal turning. Finite element simulations of orthogonal turning of AISI 4340 steel with CVD coated cemented carbide inserts are performed. The simulation results are used to predict steady state temperature distribution in tool by performing further coupled thermo mechanical finite element simulations. Different methods of heat source on tool rake face are used. It is observed that steady state temperature distribution from simulation matches well with experimental result.

Seyed Majid SAFI et.al in his paper of Saving energy by modification of Tomita heat treatment method for AISI 4340 steel says that a modified up-quenching heat treatment method (Tomita method) for AISI 4340 steel (ultra high strength steel) is proposed. A low alloy steel (0.33%C), was used to study the effect of isothermal austempering and modified up-quenching austempering heat treatment on the mechanical properties. The specimens, were cut from a bar with 25 mm diameter and after achieving the best temperature and time of austenitizing, austenitized at 800oC for 60min and followed by quenching at 430^{o}C for the high austempering temperature to achieve the upper bainite morphology and at 360^{o}C for the lower austempering temperature to achieve the lower bainite morphology. The specimens selected for up-quenching, after austenitization were quenched to below Ms (martensite start temperature) (320^{o}C) for 120sec, followed by heating at 500oC to achieve the mixed structure of tempered martensite and upper bainite for 1000sec. The specimens selected for modified up-quenching, after austenitization were quenched to below Ms for 120sec, followed by heating at 400oC to achieve the mixed structure of tempered martensite and lower bainite for 1000sec. It is also shown that the best combination of strength and ductility can be achieved by the modified heat treatment that has been suggested in this investigation by the decrement of heat energy for the austenitization temperature, up-quenching temperature and time.

METHODOLOGY

In the present study, we are using the AISI4340. This material is a composite of the aluminium of the alloys. The purpose of using this AISI 4340 is that to reduce the manufacturing cost of the material and the performance of the machining. In this we also were checking the surface roughness for the outcome of the manufacturing product.

Work material

AISI 4340 steel which was widely used in die making, automobile and allied industries was selected as a work material. Its other applications include aircraft engine mounts, propeller shafts, connecting rods, gear shafts, crane shafts, heavy forgings such as rotor shafts, discs, welded tubing applications etc. In all these applications, vibration has deleterious effect on product performance. Considering its wide range of application in the industry, this grade of steel was used as the work material in the present investigation. AISI4340 steel known for its toughness, tensile strength and fatigue strength is a through harden able medium alloy steel that was hardened to 46HRc. The chemical composition for this material is shown table 1. Bars of 75 mm diameter and 380 mm length hardened to 46HRC were used for this investigation.

Table 1 Chemical composition of work material

Element	% composition in weight
Carbon	0.38 – 0.43
Chromium	0.7 – 0.9
Manganese	0.6 – 0.8
Molybdenum	0.2 – 0.3
Nickel	1.65 – 2.0
Phosphorus	0.035 max
Silicon	0.15 – 0.3
Sulphur	0.04 max
Iron	Rest

Formulation of cutting fluid

Since the quantity of cutting fluid used is extremely small, a specially formulated cutting fluid which can full fill the task of cooling and lubrication was employed in this investigation. Accordingly commercially available mineral oil (considered as base) along with other ingredients such as friction modifiers, emulsifying agents, coupling agents and anti-corrosion agents are identified. 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 [19]. Also the performance of sodium sulfonate was found to be superior com-pared to potassium, calcium lithium and magnesium sulfonate [20]. 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 [21]. Oleic acid is an unsaturated fatty acid which is used as an emulsifying or solubilizing agent in aerosol products. Besides serving as an agent for improving the lubricity of the cutting fluid (agent for lowering the friction coefficient – friction modifier), this compound forms an effective agent for enhancing permeability and it was considered for 3% [22]. In water soluble cutting fluids, Triethanol amine is used to provide the alkalinity needed to protect against rusting and it acts as an anti-oxidant. It also controls the evaporation rate of water in cutting fluid and its composition constituted for 3% [23]. Alcohol ethoxylate is a non ionic surfactant created by adding ethylene oxide groups to a long chain (high molecular weight) alcohol [24]. Alcohol ethoxylates which comprises of 4% by weight possess greater resistance to water hardness than any other surfactants [25]. It also acts as a secondary emulsifier which enhances the emulsification capability of the sulfonate [26]. 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 [19, 27]. In minimal fluid application, heat transfer is predominantly in the evaporative mode, which is more ancient than the convective heat transfer prevalent in conventional wet turning. Special proprietary water based cutting fluids was developed in this investigation which can, even when used in a very small quantity, fulfill the task of cooling and lubrication. Since the evaporation enthalpy of water is as high as 2260 kJ/kg, large scale cooling effect can be achieved by encouraging evaporative heat transfer in water based cutting fluids. Because of this fact and also based on the information avail-able in the literature, cutting fluid with composition of 10% oil and the rest water was used in this investigation [3]. This composition of cutting fluid eliminates problem related to pollution and resembles dry turning.

Principal Component Analysis

Principal Component Analysis is a dimension reduction tool that can be used in multi variable analysis problem. Principal Component Analysis aims at reducing a large set of variables to a small set that still contains most of the information contained in the large set. It is a method to identify patterns in a data in such a way as to highlight their similarities and differences. So the data can be compressed without losing any information. It is the most meaningful basis to re-express a noisy and grabled data set. We often do not know what measurements best reflect the dynamics of our system in question. Sometimes we record more dimensions than we really need PCA alleviates this problem by mapping the original predictors into a set of principal components that is lesser in dimension than the number of the original variables. Such a transformation will usually be accompanied by a loss of information. The goal of PCA is, therefore, to preserve as much information contained in the data as possible. The optimal number of principal components (PCs) needed to achieve this task is not known a priori. The task is to find a set of principal components with eigen values that have a significantly larger value than the remaining components.

ISSN: 2277-9655
Impact Factor: 4.116

Interpretation of results

The influence of fluid application parameters on cutting performance was investigated in this section and it was observed that fluid application parameters do influence tool vibration and cutting performance.

Pulsing jet of cutting fluid

From literature it was seen that a pulsing slug of cutting fluid gave better cutting performance than a continuous jet during minimal fluid application. In tune with this, a pulsing slug of cutting fluid was used in the present investigation also. It is also reported that the frictional forces between two sliding surfaces can be reduced considerably by rapidly fluctuating the width of the lubricant filled gap separating them. In the normal case when a lubricant fills the gap separating two sliding surfaces, the lubricant tends to form an ordered layer. The formation of a stable ordered layer of fluid film with comparatively higher shear strength is not the best condition for reduction of friction between the sliding surfaces. According to them, a disordered molecular film will be more effective in reducing the friction.

Creating small discrepancies in the gap separating the two sliding surfaces upsets the ability of the lubricant molecules to fit comfortably between the surfaces. This technique keeps the lubricant in a state of dynamic disorder. Also this results in constant rearrangement of the lubricant molecules and prevents formation of an ordered layer. Frequency at which the gap width alterations are to be made is decided by the viscosity of the lubricant. Thicker liquids require more time to move from the gap when the distance is reduced and more time to return when the gap is increased. The process of frustrating the formation of an ordered layer leads to a higher level of fluidity and provides better lubrication. A pulsing jet can create this type of frustration to the lubricant film. Instead of fluctuating the width of the lubricating film, a pulsing jet of lubricant can be used to create a sort of disorder to the molecular layer. When a pulsing jet is used, the width of the lubricant filled gap between the tool rake face and the chip fluctuates with a frequency equal to the frequency of pulsing of the fluid slug. The width of the cutting fluid will be maximum when the fluid slug falls at the gap and will be minimum when no particles fall on the gap during the pulsing cycle. This process continues as the fluid particles fall in the gap between the chip and the tool intermittently.

From the results it was observed that frequency of pulsing (N) at 500 pulses/min favored better cutting performance and minimum tool vibration. When the frequency of pulsing was more than 500 pulses/min, the quantity of fluid delivered per pulse (q) will be less when compared to that when the frequency of pulsing was 500 pulses/min. This is due to the fact that for any fixed rate of fluid application (Q in ml/min), the cutting fluid delivered per pulse (q) is given by $q = Q/N$, where N is the frequency of pulsing. Hence the fluctuation in the width of the liquid film between the tool and the chip is less appreciable when the frequency of pulsing was more than 500 pulses/min when compared to that at a frequency of 500 pulses/min. A minimum quantity of cutting fluid should be de-livered per pulse to get appreciable fluctuation in the width. This leads to the presence of fresh fluid droplets in the tool–chip inter-face unlike a stagnant layer of cutting fluid as will be the case if a continuous jet were employed. The presence of fresh fluid drop-lets facilitates better filling up of the gap on the tool–chip interface thereby providing better lubrication and to some extent enhanced cooling as the droplets evaporate. Enhanced cooling and lubrication is responsible for reduction in tool vibration and improvement in cutting performance. Moreover, when the frequency of pulsing is very high (750 pulses/min), the individual particles will be very small in size and may lack kinetic energy to penetrate into the tool chip interface. This leads to less fluid particles reaching the rake face and hence less efficient rake face lubrication.

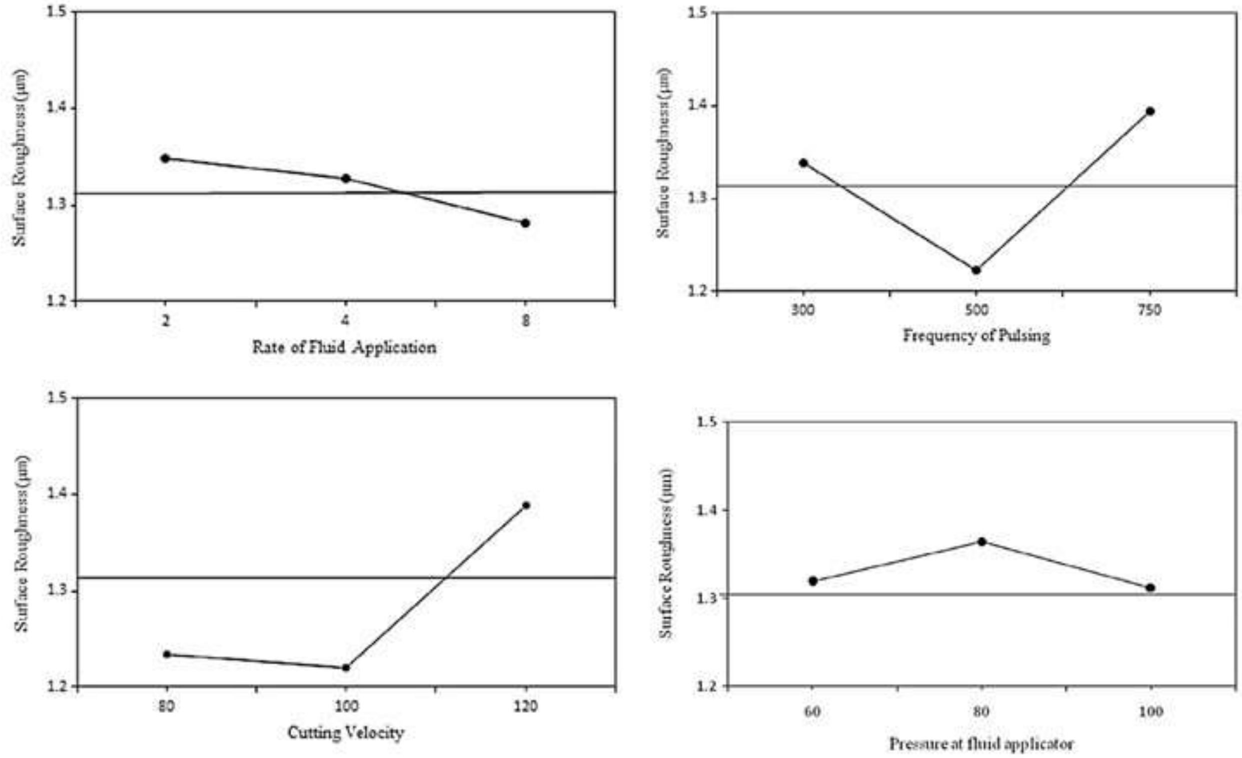

Fig 1:- Effect of fluid application parameters on surface roughness

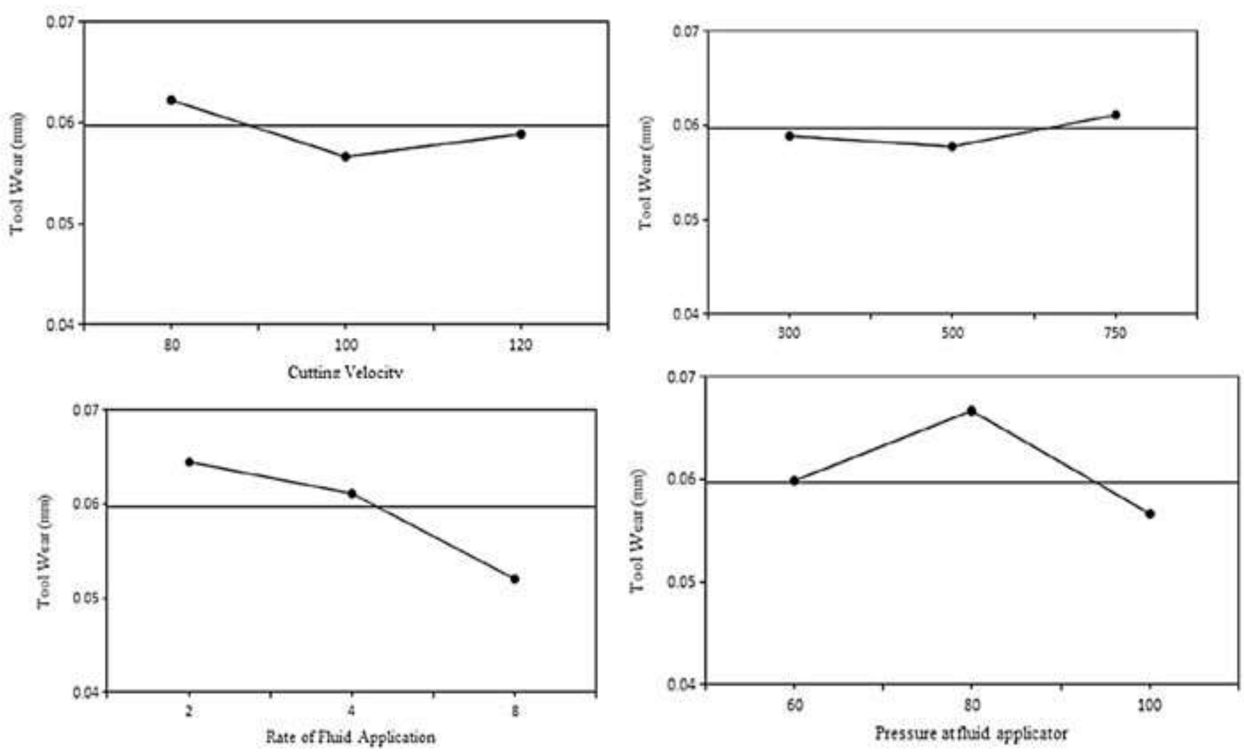

Fig 2:- Effect of fluid application parameters on tool wear

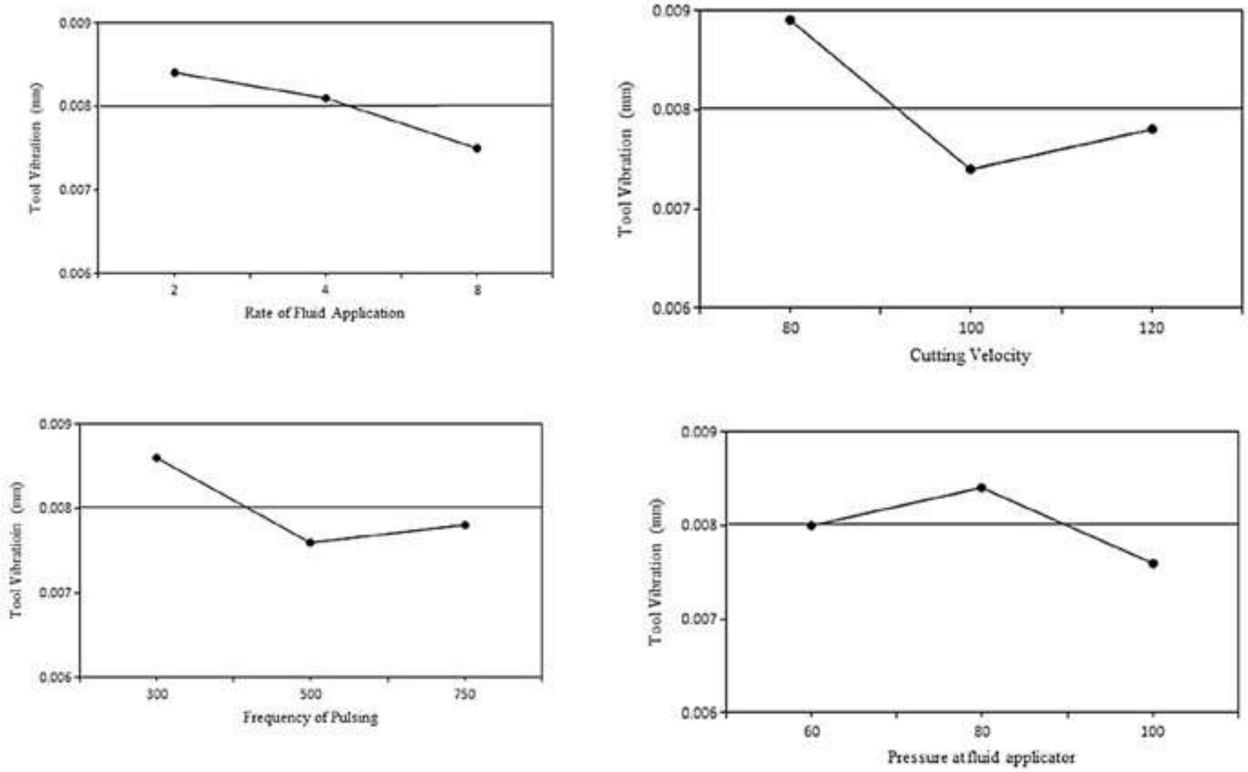

Fig 3:- Effect of fluid application parameters on tool vibration

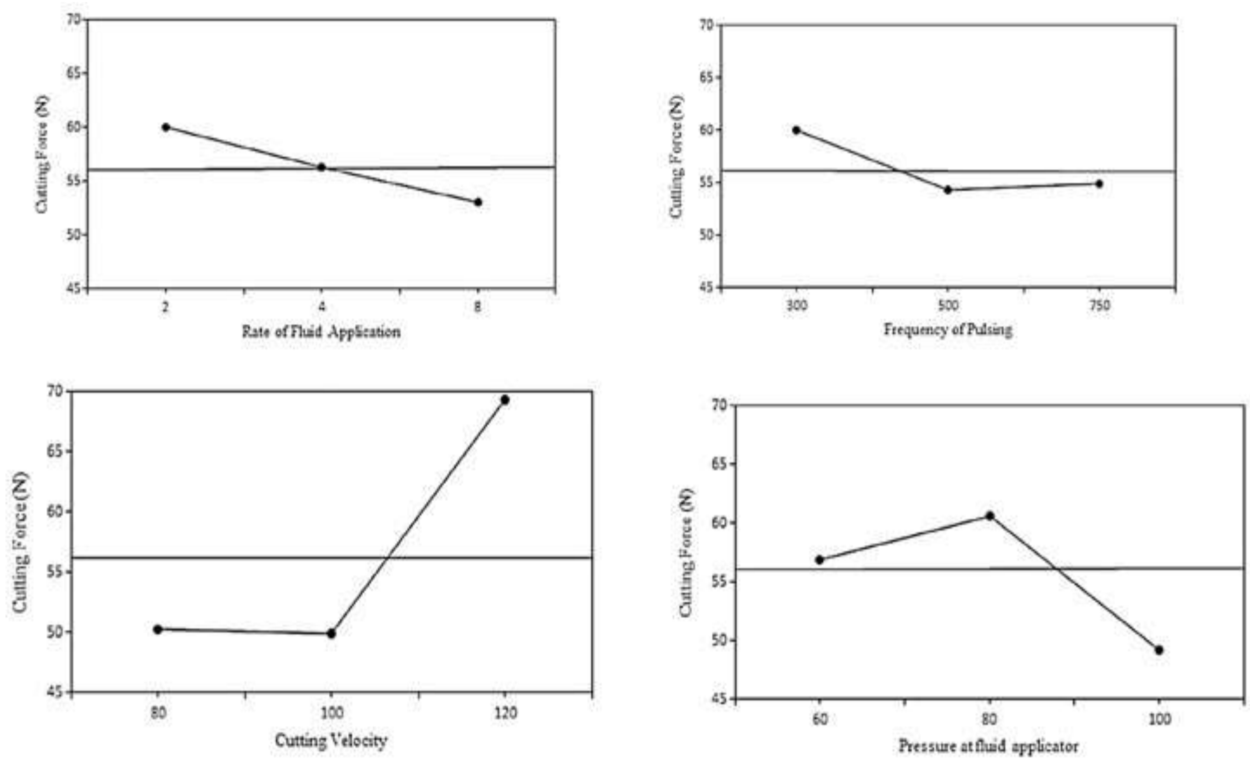

Fig 4:- Effect of fluid application parameters on cutting force

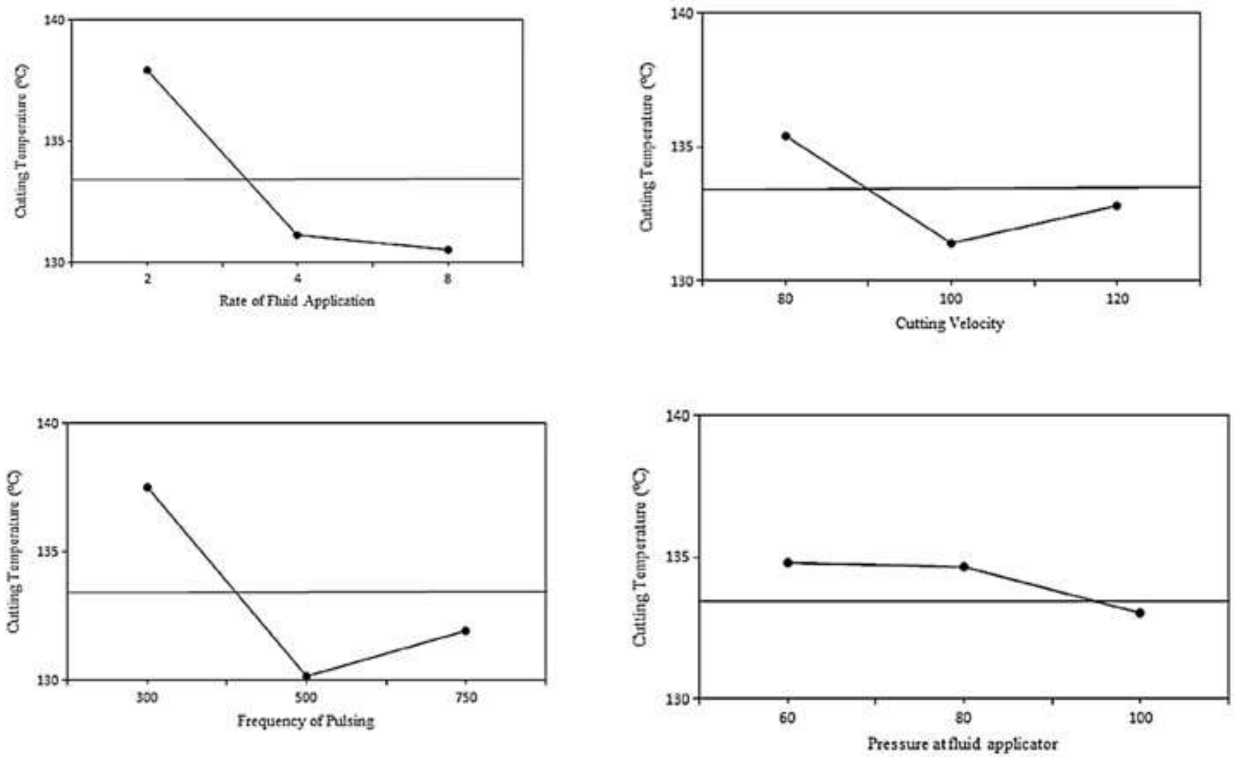

Fig 5:- Effect of fluid application parameters on cutting temperature

Rate of fluid application

From the results it was observed that the rate of fluid application at a rate of 8 ml/min was advantageous in terms of minimum tool vibration, better surface finish, lower flank wear and lower cutting force. The mean diameter of a droplet coming out of the injector is inversely proportional to the quantity of fluid delivered per pulse.

According to the empirical relationship developed by Hiroyasu and Kadota [31], the mean diameter D_p for a droplet of fluid delivered is given by

$$D_P = K(P)^{-0.135}\rho^{0.121}V_q^{0.131} \qquad (2)$$

When the rate of fluid application was maintained at a high level (8 ml/min), fluid droplets have sufficient size with requisite kinetic energy to penetrate into the tool–chip interface and provide better rake face lubrication. If the delivery rates are very low (2 ml/min and 4 ml/min), the individual droplets will be very small in size and may lack in their ability to penetrate into the tool–chip interface on account of their lower kinetic energy. This results in inferior cutting performance. Also if the size of individual particles is very high, their penetration power will be less owing to their greater size. Hence a rate of fluid application must be selected in such a manner so as to strike a balance between their kinetic energy and penetration power in order to reduce tool vibration and to improve cutting performance. It appears that a delivery rate of 8 ml/min results in optimum droplet size that ensures better penetration which leads to better rake face lubrication and hence lower tool vibration.

During conventional wet turning, heat is removed by convective heat transfer and the quantity of heat removed is given by

$$Q_c = M_C C_p T \qquad (3)$$

However during minimal fluid application cooling occurs due to both convective and evaporative heat transfer. The evaporative heat transfer is facilitated by the increase in surface area caused by atomization and the quantity of heat removed is given by

$$Q_e = M_C C_p\ T + \mathrm{mL} \quad (4)$$

In the case of water, the evaporation enthalpy is 2260 kJ/kg and in the case of mineral oil it is about 210 kJ/kg. The specific heat capacity C_p for water is 4.2 kJ/kgK and that for mineral oil is 1.9 kJ/kgK. Since the evaporation enthalpy of water is very high, evaporation of even a very small quantity of water is sufficient to create better cooling. Moreover the cutting fluid droplets by virtue of their high velocity can puncture the blanket of vapour and reach the interface facilitating more efficient evaporative heat transfer that is not possible in conventional wet turning where the adherent film of lubrication retards the heat transfer.

Pressure at fluid applicator

The exit velocity of the droplets of cutting fluid piercing out of the fluid injector is influenced by the pressure at the applicator. Therefore, the higher the pressure at the fluid injector, the higher will be the velocity of droplets [32]. The penetration power of the fluid droplet is directly proportional to the exit velocity (approximately 70 m/s) and the velocity varies as a function of the square root of the injection pressure whereas the size of the individual drop-lets is inversely proportional to the exit velocity [32]. As cutting performance is directly related to chip friction, higher friction at the tool–chip interface can lead to higher cutting temperature which results in excessive tool wear leading to shorter tool life and poor surface finish [33]. In metal cutting, friction at tool–chip interface has to be decreased in order to improve surface finish, reduce tool vibration, reduce tool wear and cutting force. During machining, the pressure that exists in the tool chip interface prevents the easy penetration of cutting fluids. But the penetration of fluid particles will be easier if the drops are smaller in size and possess sufficient kinetic energy. When the fluid is applied at high pressure (100 bar) it can easily penetrate into the tool chip interface and provide better lubrication at the contact surfaces. This reduces the friction at tool– work interface, leading to lower tool vibration level and better cutting performance. But the fluid applied at a pressure of 60 and 80 bar have poor penetrating abilities which further leads to lesser cutting performance compared to pressure at 100 bar.

Comparison of performance with that during conventional wet turning and dry turning

Cutting experiments were conducted to compare the performance during dry turning, conventional wet turning and turning with minimal fluid application. The cutting and fluid application parameters were maintained constant and the results are presented in Table 4.1. The results show a definite advantage for turning with minimal fluid application when compared to dry turning and conventional wet turning. Tool vibration, tool wear, cutting temperature, surface roughness and cutting force were found to be less during minimal application followed by wet turning and dry turning. In conventional wet turning, rake face lubrication is not as effective as in fluid injection as the fluid particles cannot reach the tool chip interface. Consequently the chip curls due to rebinder effect and the associated reduction in tool–chip contact length is less pronounced in conventional wet turning. But the cutting fluid droplets by virtue of their high pressure can puncture the blanket of vapour formed and reach the hot interfaces facilitating more efficient heat transfer than is possible in conventional wet turning, where the adherent film of lubricant retards the heat transfer [3]. During minimal fluid application cooling occurs due to both convective, evaporative heat transfer and the evaporative heat transfer is facilitated by the increase in surface area caused by atomization. This provides effective heat transfer leading to lower cutting temperatures com-pared to conventional dry and wet turning. Cutting temperature of 141.23 °C during dry turning was significantly reduced to 133.65 °C for hard turning with minimal fluid application. Reduction in cutting temperature facilitates decrease in abrasion wear by retaining tool hardness and adhesion; diffusion types of wear are also highly sensitive to temperature.

Also myriads of high velocity droplets are formed by the minimal fluid application of cutting fluid. When these cutting fluid particles reach the root of the chip, severe pressure and temperature condition at that location cause decomposition of cutting fluid. These decomposed products lead to embrittlement effect on the chip surface near to the root. This embrittlement can form numbers of microcracks on the chip which become the stress concentrators and reduces the energy required for the chip formation. This phenomenon is called Rebinder effect [7]. This rebinder effect consequently reduced the cutting force acting on the tool. The product of cutting fluid decomposition which penetrates into the cracks at the chip surface forms a lubrication layer and helps to reduce friction and to improve the rake face lubrication [34]. It is observed that tool damage was found to be less during hard turning with minimal fluid application when compared to dry turning and wet turning. The better rake face lubrication and reduction in cutting force resulted in less tool wear during hard turning with minimal fluid application. Average flank wear for optimum parameter during hard turning with minimal fluid application was found to be 0.07 mm whereas in dry and conventional wet turning it was found to be 0.08 mm and 0.075 mm respectively.

Tool wear inversely affects machining dynamics by causing in-stability to cutting processes [35]. The process instability caused by tool wear involves variation in cutting forces and self-excited vibrations. In actual metal cutting conditions, the vibration of the cutting tool depends on the tool wear and increases as the tool wear progresses. The tool will be sharp in the beginning and will slowly lose its sharpness as the cutting process progresses. Hence the amplitude of tool vibration will be less during the initial stage which increases slowly as the tool wear progresses and becomes very high when the tool is nearing the end of its life. In metal cutting, there exists a relation between vibration and surface roughness [36,37]. When the bouncing of the tool in and out of the work piece (tool vibration) increases, there will be high irregularities on the surface which will result in poor surface finish. The more the rigidity, the more will be the surface finish and a highly finished surface limits the risk of crack initiation and subsequent failure of the machined surface [38]. Also it appears that when the flank wear increases, the contact zone between the cutting tool and work piece surface becomes larger causing extra rubbing on the surface which results in poor surface finish. As a result of the wearing away of certain regions of the face and flank of the cutting tool, there will be gradual deviation of the surface finish from the tolerance limit as the tool wear progresses and finally necessitates the replacement of the cutting tool. Also the surface morphology SEM images obtained for the optimum parameters of conventional dry, wet and minimal fluid application. This clearly signifies that the reduction in friction at the tool chip interface due to better lubrication and less tool wear during MFA resulted in lower tool vibration which further led to the improvement in surface finish.

Sl.No	Output parameter	Objective	Velocity (m/min)	Pressure at fluid applicator (bar)	Rate of flow (ml/mim)	Frequency of pulsing (pulses/min)
1	Surface roughness	To minimize surface roughness	V2 (100)	P3 (100)	Q3 (8)	N2 (500)
2	Flank wear (mm)	To minimize tool wear	V2 (100)	P3 (100)	Q3 (8)	N2 (500)
3	Cutting force (N)	To minimize cutting force	V2 (100)	P3 (100)	Q3 (8)	N2 (500)
4	Tool vibration(mm)	To minimize tool vibration	V2 (100)	P3 (100)	Q3 (8)	N2 (500)
5	Cutting temperature	To minimize cutting temperature	V2 (100)	P3 (100)	Q3 (8)	N2 (500)

Table 4.1:- Summary of operating parameters for optimum performance

Sl. NO	Cutting condition	Surface roughness (µm)	Flank wear (mm)	Cutting force (N)	Tool Vibration (mm)	Cutting Temperature (°C)
1	Dry Turning	1.282	0.080	65.34	0.0061	141.23
2	Conventional wet turning	1.267	0.075	64.25	0.0058	135.27
3	Turning with minimal fluid application	1.250	0.070	63.06	0.0053	133.65

Table 4.2:- Comparison of performance during dry turning, conventional wet turning and turning with minimal fluid application

RESULT AND DISCUSSION

The experimental results were analyzed using Qualitek-4 and the levels of input parameters for achieving better cutting performance are presented in Table 5. ANOVA analysis was also carried out using Qualitek-4 software to find out the percentage influence of individual parameters on tool vibration, cutting force, cutting temperature; surface finish and tool wear surface roughness, flank wear and cutting force. From the ANOVA results, it was evident that pres-sure at the fluid injector forms the most significant parameter influencing the output parameters followed by rate of flow and frequency of pulsing. The results of the analysis which led to a set of levels of fluid application parameters to minimize surface roughness, tool vibration, flank wear, cutting temperature and cutting force.

From the summary of results, it is observed that fluid application parameters namely frequency of pulsing, pressure at fluid applicator and rate of fluid application have their own influence on tool vibration and cutting performance. In the range investigated, tool vibration, cutting force, surface roughness, tool wear and cutting temperature were minimum for a combination consisting of rate of fluid application at higher level (8 ml/min) and frequency of pulsing at medium level (500 pulses/min) with a pressure at 100 bar maintained at the fluid injector.

CONCLUSION

The present study indicates that the minimal fluid application scheme is characterized by the parameters of fluid application namely frequency of pulsing, rate of fluid application and the pres-sure at the fluid injector. The effect that was developed in amplitude of tool vibration and cutting performances due to set of operating and fluid application parameters were studied and optimum parameters were identified. From the present study the following observations were made

1. Hard turning with minimal fluid application reduces tool vibration and provides better cutting performance as compared with conventional wet turning where a commercial cutting fluid was applied at a rate of 5 l/min and with dry turning. For achieving better cutting performance, rate of fluid application should be applied at 8 ml/min, frequency of pulsing at 500 pulses/min with a pressure of 100 bar maintained at the fluid injector.
2. When the set of levels of parameters for optimum performance were used, there was 8.6% reduction in tool vibration, 1.3% reduction in surface roughness and 6.7% reduction in tool wear when compared to conventional wet turning.
3. The present study illustrates that if minimal fluid application is properly applied it would be an effective alternative for dry and wet turning. Also the concept of minimal fluid application resembles dry turning, free from pollution related problem and acts similar to damper in reducing tool vibration.

REFERENCE

[1] C. Richt, A hard turn towards efficiency, Gear solutions 7 (2009) 22–31.
[2] U. Landman, 'Frustrated' lubricant molecules offer new strategy for reducing friction in mechanical devices, Georgia Tech – Research news, 1998. <http:// gtresearchnews.gatech.edu/newsrelease/FRICTION.html>, (accessed 23.05. 2015).
[3] A.S. Varadarajan, P.K. Philip, B. Ramamoorthy, Investigations on hard turning with minimal fluid application (HTMF) and its comparison with dry and wet turning, Int. J. Mach. Tools. Manuf. 42 (2002) 193–200.
[4] C.H.R. Vikram Kumar, B. Ramamoorthy, Performance of coated tools during hard turning under minimum fluid application, J. Mater. Process. Technol. 185 (2007) 210–216.
[5] C.H.R. Vikram Kumar, P. Kesavan Nair, B. Ramamoorthy, Performance of TiCN and TiAlN tools in machining hardened steel under dry, wet and minimum fluid application, Int. J. Mach. Mach. Mater. 3 (2008) 133–142.
[6] T. Thepsonthi, M. Hamdi, K. Mitsui, Investigation into minimal-cutting-fluid application in high-speed milling of hardened steel using carbide mills, Int. J. Mach. Tools. Manuf. 49 (2009) 156–162.
[7] V.P. Astakhov, Metal cutting theory foundations of near-dry (MQL) machining, Int. J. Mach. Mach. Mater. 7 (2010) 1–16.
[8] P. Sam Paul, A.S. Varadarajan, S. Mohanasundaram, Study on the effect of magnetorheological fluid on tool wear during hard turning with minimal fluid application, Arch. Civ. Mech. Eng. 15 (2015) 124–132.
[9] P. Sam Paul, A.S. Varadarajan, Effect of impact mass on tool vibration and cutting performance during turning of hardened AISI4340 steel, Rom. J. Acoust. Vib. 11 (2014) 154–163.

[10] S.A. Tobias, Machine Tool Vibration, Blackie and Sons Ltd, London, 1965.
[11] M.M. Sadek, B. Mills, The application of the impact damper to the control of machine tool chatter, in: Proceedings of the Seventh International Machine Tool and Die Research Conference, 1966, pp. 243–257.
[12] K.P. Duffy, R.L. Bagley, O. Mehmed, A self-tuning impact damper for rotating blades, NASA Tech Briefs TSPLEW 168333, 2001, pp. 1–15.
[13] B.L. Fowler, E.M. Flint, S.E. Olson, Design methodology for particle damping, in: Proceedings of SPIE Conference on Smart Structures and Materials, 2001, pp. 1–12.
[14] A. Rivero, G. Aramendi, S. Herranz, L.N. Lopez de Lacalle, An experimental investigation of the effect of coatings and cutting parameters on the dry drilling performance of aluminium alloys, Int. J. Adv. Manuf. Technol. 28 (2006) 1–11.
[15] A. Rivero, L.N. López de Lacalle, M. Luz Penalva, Tool wear detection in dry high-speed milling based upon the analysis of machine internal signals, Mechatronics 18 (2008) 627–633.
[16] S.S. Abuthakeer, P.V. Mohanram, G. Mohankumar, The effect of spindle vibration on surface roughness of workpiece in dry turning using ANN, Int. J. Lean Thinking 2 (2011) 1–16.
[17] K. Leo Dev Wins, A.S. Varadarajan, B. Ramamoorthy, Optimization of surface milling of hardened AISI4340 steel with minimal fluid application using a high velocity narrow pulsing jet of cutting fluid, Engineering 2 (2010) 793– 801.
[18] P.K. Philip, A.S. Varadarajan, B. Ramamoorthy, Influence of cutting fluid composition and delivery variables on performance in hard turning using minimal fluid in pulsed jet form, J. Inst. Eng. (India) 82 (2001) 12–19.
[19] M. Mikulan Kristine, C. Norman Ross, The relationship of various sodium sulfonates to their properties and their performance in soluble base products, Tribol. Lubr. Technol. 55 (1999) 21–26.
[20] H. Hong, A.T. Riga, J.M. Cahoon, J.N. Vinci, Evaluation of overbased sulfonates as extreme-pressure additives in metal working fluids, J. Soc. Tribol. Lubr. Eng. 49 (1992) 19–24.
[21] P.A. Rock, Chemical Thermodynamics, University Science Books, Sausalito, CA, 1983.
[22] B. Cornoils, P. Lappe, Dicarboxylic Acids, Aliphatic, Ullmann's Encyclopeida of Industrial Chemistry, Wiley-VCH, Weinheim, 2006.
[23] Ethanolamines, Technical Data sheet, Dow Ethanolamines, 2003. <http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_017d/0901b8038017d302.pdf?filepath=amines/pdfs/noreg/111-01375.pdf& fromPage=GetDoc>, (accessed 23.05.15).