Utilization of Nanofluid on Machining Process

Kunal Naukarkar, Gaurav ragit, Gajanan Lambat, Liladhar Kamdi, Niraj Thakre

Mechanical Engineering Department, RTM Nagpur University.

JD College of Engineering and Management, Nagpur, Maharashtra, India.

Abstract— **In many cutting operations. The cutting fluid plays an important role which enhanced the property of the tool during the operation. MQL is the resent technique instead of flood cooling in which the minimum quantity of fluid is used in the form of a spray. This paper gives information about the various machining process such as turning, drilling, milling, grinding, etc. and the effective use of nanoparticle with different types of base fluid in the MQL technique. Most of the experimental studies show that the application of Nanofluid with MQL reduces the cutting force, cutting zone temperature, tool wear, friction coefficient in comparison with flood/ dry machining.**

Keywords: Nanofluid, machining process, MQL, cutting fluid.

I. INTRODUCTION

Machining is the manufacturing term, it can be roughly defined as the process of removing material from the workpiece using power-driven machine tools to shape it into an intended design. Machining plays a significant role in the manufacturing industry nowadays.

The device which removes the excess material through direct mechanical contact is known as a cutting tool and the machine which provides the necessary relative motion between the workpiece and the cutting tool is commonly known as the machine tool.

The basic input parameters for the machining process are cutting speed, feed rate, and depth of cut.

The speed at which the work moves with respect to the tool is known as the cutting speed. The distance travel by the tool during one revolution of the part is known as feed rate. And the thickness of the layer of the metal removes in one in a direction perpendicular to the machined surface is known as depth of cut.

According to research (Bruin et at, 2006) states that when the machining is done almost 99% of the energy fed to the machine tool is converted into heat. When the high strength material is machined, the temperature rises with the speed and the tool strength decreased, leading to faster were and tool fails. Hence the heat produced needs to be cooled down constantly around the cutting zone so that the workpiece and cutting tool can be kept under controlled temperature. The overheating of the tool may reduce sharpness. To overcome the issues of temperature the cutting flood has been the conventional choice in the manufacturing industry. But the use of the flood coolants in the machining process is in much quantity and the cost of coolants contributed 16.9% among all the cost of the coolants in the manufacturing product.

(wiener et al 2005) observed that the use of cutting flood badly affects the environment and human health both during its use and during the disposal. Hence the excessive use of this fluid should be avoided apart from the conventional method of cooling, several other technologies have been developed in recent years to remove heat from the cutting zone.

MQL Minimum quantity lubrication is one of the technique which is reviewed by (Sharma et al. 2009) which gives the better result than the conventional machining cooling technique, vegetable oil is one of the lubrication oil. So it is seen that the lubricants are used as the heat transferred fluid but in the last few decades have witnessed that vast research on the new type of heat transfer fluid, namely “NANOFLUID”. Nanofluid was introduced by the ‘Choi’ and it has been proven to provide efficient heat transfer compared to conventional fluids

Much research has reported a number of research work on the effects of different cooling techniques using conventional cutting fluids on different machining operations. However, there is no compressive literature available on the effect of MQL with Nano and hybrid Nanofluid. The aim is to review the effect of MQL using different Nanofluids on different machining operations.

MINIMUM QUANTITY LUBRICATION WITH NANOFLUID

In the MQL technique, a very small amount of lubricant coolant is mixed with air to form a mixture, which is sprayed at high pressure in the cutting zone with the help of the nozzle.

In the whole system, the coolant is a switch with the Nanofluid, the Nanofluid is the mixture of nanoparticle and the base fluid this suspension of Nanosized particle in the base fluid is called as Nanofluid. The nanoparticle is in range of from 1 to 100nm. The Nanofluid has a high thermal conductivity which is much beneficial for the tool wear as well as the other parameters i.e. surface roughness, temperature and etc.

The MQL system consists of an air compressor, fluid tank, pump, mixing chamber, nozzle, etc.

In the system, the compressed air comes at a mixing chamber from the air compressor and Nanofluid from the tank with the help of pump the mixture of air and fluid in the mixing chamber sprayed on the interface of the workpiece where machining is done.

MQL minimizes the environmental impact and reduced the fluid consumption also faster machining speed and longer the tool life and helps to minimize the disposal cost and reduction in maintains cost.

II. MACHINING PROCESS

A. *Turning process.*

In this research paper, the turning operation is performed on AISI 304 steel under the MQL technique. The alumina/ graphene (GnP) hybrid nanoparticle is used. The hybrid Nanofluid is prepared by mixing graphene nameplates with alumina-based Nano cutting fluid in 0.25%, 0.75% and 1.25% volumetric concentration. By comparing hybrid Nano lubricant to alumina-based lubricant it shows that the Al/GnP shows tribological properties and as a result, it reduced the tool flank were and temperature [1].

In this research paper, the research used MWCNT (multiwalled carbon nanotube) as nanoparticle at 0.2% concentration mixed with base fluid ethylene glycol. The mixture of both used as cutting fluid on specimen workpiece alloy steel AISI 4340 under the MQL technique on CNC lathe machine. From the result, it is shown that feed rate and cutting fluid plays a major role in reducing lower surface roughness [2].

In this research paper, the Al_2O_3 Nano lubricant with surfactant dodecyl benzene sulfonate (SDBS) is used as a cutting fluid turning machining process AISI 1050 mild steel is work peace material. they compare two types of machining conditions dry and Nano lubricant and they found that the dry machining of steel caused the highest tool wear growth while Nano lubricant reduces tool wear and improves tool life [3].

In this study, SiO_2 severs as nanoparticle and is mixed with ordinary mineral oil at different concentrations to investigate tool wear reduction and surface quality improvement in CNC lathe turning machined steel AISI 4140. It results in a 0.5wt% concentration of nanoparticle are led to minimum tool wear and surface roughness [4].

The AISI 304 steel work peace material in which they used molybdenum disulfide (MoS_2) nanoparticle with alumina nanoparticle at a ratio of (10:90) in oil-water emulsified base fluid performing turning operation on CNC lathe machine with MQL system they have to conclude that hybrid lubricant shows better result compare to base fluid which reduced tool flank wear [5].

In this research paper research takes AISI 304 stainless steel as work peace material and MWCNTs (multiwalled carbon Nanotubes) with alumina-based nanoparticle into cutting fluid at 10:90 volumetric proportion the cutting fluid was prepared in three types of volumetric concentration 0.25, 0.75, 1.25 vol.%. they compare the MWCNTs aluminum-based nanoparticle with alumina-based lubricant. cutting speed, feed, depth of cut and nanoparticle concentration as input parameter on the basis of that it is concluded that the hybrid Nano lubricant significantly reduced tool flank wear and temperature by 11% and 27.36% respectively [6].

In these experimental studies, the AISI 4340 work peace material with Nanofluid on CNC turning lathe machine is used. In which the surface roughness and cutting force are the response variable and cutting speed, feed, depth of cut, nose radius, air pressure, fluid flow is such given input parameters. The multiwalled carbon Nanotube having 15nmdiameter, the 30-micrometer length is mixed in cutting fluid at 0.2% concentration. On base fluid ethylene glycol. By carrying 60 experimental trials and MQL mode with Nanofluids observed that the feed rate is the most significant factor. The optimum response variables obtain as surface roughness 1.26um and cutting force 7.69 kg f [7].

Sr.No.	Reference	Base fluid	Nanoparticle	Work peace
1	[1]	Alumina based cutting fluid	Alumina/ graphene (GnP)	AISI 304 steel
2	[2]	Ethylene glycol	MWCNTs	AISI 4340
3	[3]	Soluble cutting oil	Al_2O_3	AISI 10150
4	[4]	Mineral oil	Silicon dioxide (SiO_2)	Hardened steel AISI 4140
5	[5]	Oil-water emulsification	Alumina/ molybdenum disulphide (MoS_2)	AISI 304 steel
6	[6]	Vegetable oil	Alumina/ MWCNTs	AISI 304 stainless steel
7	[7]	Ethylene glycol	Multiwalled Carbon Nanotube (MWCNTs)	AISI 4340

B. *Grinding process.*

Grinding is an abrasive machining process. It is used for the finishing process. The grinding process gives the high accuracy and size of the workpiece. Grinding is the high energy intensifier manufacturing process. When grinding is starts and removes the material on a workpiece. In machining zone generated temperature and temperature affect the workpiece and grinding wheel so the coolant is used to decrease the temperature and achieve better surface finishing. Coolant having a thermal conductivity. In the grinding process no. Of Coolant used like oil, oil-water emulsion, paste, gels, aerosol, etc. We studied the research paper and concluded that as compared to coolant Nanofluid gives better results.

In this research paper, zinc oxide nanoparticles and ethylene glycol is base fluid. In the grinding process, they used an IN718+ superalloy material. And they concluded that the zinc oxide based NFS have shown better grinding response because of improved lubrication behavior. It is primarily due to better spreadability that includes stable lubricous film at the contacting surface even at higher temperatures. The findings of this work can be regarded as the first step towards the green and sustainable grinding of high strength superalloy [8].

In this research paper, they used MoS_2 nanoparticles and vegetable oil (soybean oil) as base fluid. They work on the 20crNiMo workpiece. The result shows that lubricant with MoS_2 nanoparticles significantly reduces the tangential grinding forces and friction between the wear flats and workpiece increases the G-ratio and improves the overall grinding performance in MQL applications [9].

In this research paper, they used MoS_2 - Ws_2 hybrid Nanofluid and base fluid as soybean oil. They work on Si_3N_4 and concluded that the reduction in normal grinding forces and specific grinding energy for MoS_2-Ws_2 hybrid Nanofluid has been 27%&39% respectively compared to the deionized water-based fluid. The surface roughness and chipping layer depth of silicon nitride workpieces using given Nanofluid have been reduced by 4%&6% in comparison to flood grinding. The thermally stable oxide on the ground surface attributes to grind ability improvement [10].

In this research paper, they used MoS_2 /CNT hybrid Nanofluid and base fluid is paraffin oil. In the grinding process, they used Ni-based alloy and the working grinding on the Ni-based alloy and results show that MoS_2 /CNT hybrid nanoparticle achieved better lubrication effects than mono nanoparticles [11].

In this research paper, they used mono nanoparticles CuO and based fluid is water. In grinding on Inconel /738 material and they obtained results revealed that applications of copper Nanofluid could improve wheel loading and surface roughness by the amount of 59.19% and 62.16% compared to dry grinding and by the amount of 35.15% and 36.36% compared to conventional grinding respectively [12].

In this research paper, they used MoS_2 nanoparticles and based fluid is paraffin oil. The result shows that the lubricant with novel MoS_2 nanoparticles significantly reduces the tangential grinding forces and friction between the wear and workpiece increases G-ratio and improves the overall grinding performance in MQL applications [13].

In this research paper, they used MWCNT/Al_2o_3 hybrid Nanofluid and base fluid is aerosol. In this research paper they work on superalloy and shows the result revealed that combination of MQL and UAG decrease of maximum grinding temperature up to 56.3% in comparison to the dry grinding (from 254°to 111°) moreover tangential and normal grinding forces and friction efficient have been reduced up to 61.5%,47%& 27% [14].

Sr.No.	Reference	Base fluid	Nanoparticle	Work peace
1	[8]	Ethylene glycol water	Al_2O_3, Sic, ZnO	IN718
2	[9]	Vegetable oil	MoS_2	20cr NiMo
3	[10]	Soybean oil	MoS_2	Si3N4
4	[11]	Paraffin oil	MoS_2/CNT	Ni-Based alloy
5	[12]	water	CuO	Incone l 738
6	[13]	Paraffin oil	MoS_2	-
7	[14]	Aerosols	MWCNT/Al_2O_3	-

C. Milling process.

In this research paper, the Nano MoS_2 nanoparticles are used with reinforced vegetable oil as the base fluid on the milling machining process. The system used is the MQL technique. The martensitic stainless steel is used as a workpiece and an uncoated Tungsten carbide cutting tool. The experimentation is carried out at constant cutting speed, feed rate, and depth of cut. The experimentation is done with two different flow rates of Nanofluid i.e. on 20 & 40 ml/h. The tool wear and surface roughness were investigated. In which the minimum tool wear obtained in Nano MQL at 40 ml/h MQL flow rate [15].

In this research paper, the MQL technique is used in which the SiO_2 is used as nanoparticles and ECOCUT SSN322 as lubricant oil. The milling is done on the AL6061-T6 aerospace workpiece. The experimentation is done on different concentration such as 0.0, 0.2,0.5 & 1 wt.%. The input parameter for the experiment is cutting speed, feed, and depth of cut. The lowest cutting force, cutting temperature and surface roughness were obtained at 0.2,0 & 1wt.% of SiO_2 concentration [16].

In this research paper, the milling operation is done on the Delta Seiki CNC-1050 vertical machine on the Inconel x-750 workpiece. The PVD TiA1 N coated S3oT quality cementite carbide is used. The experimentation is done with 3 different types of nanoparticles i.e. hexagonal boron nitride, graphene and MoS_2 and different concentration i.e. 0.25,0.50,0.75, & 1. the base fluid is vegetable oil the MQL technique is used in it. The input parameter is an axial depth of cut and the radial depth of cut is kept constant. The cutting speed and feed rate. The viscosity of HBN Nanofluid is lower than two Nanofluid for 0.50 vol.% of HBN Nanofluid the highest surface finish is observed [17].

In this research paper, the milling operation is done on the TiAIN - coated carbide flat surface. The steel ball is used as a milling tool. The EXF oil acted graphite Nano plate with base fluid as vegetable oil. The input parameter is feed rate, axial DOC, radial DOC XGnP with 1um diameter and 10 nm thickness showed the lowest friction coefficient [18].

In this research paper, the milling operation is done on duralumin AL-209 T4 workpiece with using MQL technique in which carbon onion Nano lubricant is used with mineral oil at different concentration i.e. 0.0,0.5,1.0 & 1.5% wt. where the depth of cut and feed and speed is input parameter. The researcher concluded that the cutting force and surface roughness values are reduced in the Nano lubricant case compared to the ordinary lubrication system [19].

In this research paper, the MoS_2 nanoparticles are used with ECOCUT HSG 9055 cutting fluid and base fluid on milling machines. In this, the MQL technique is used. The milling operation is carried out with Tungsten carbide (AE302100) cutting on workpiece AL6061-T6. The input parameter for this process is cutting speed, feed, and depth of cut. The base oil and nanoparticles concentration is 0.0,0.2,0.5 & 1.0 wt.%. The lowest surface roughness was found on the 0.5 wt.% of MoS_2 nanoparticles concentration [20].

In this resea14rch paper, the MQL technique is used which having SiO_2 nanoparticles and mineral oil as a base fluid having 0.2%. In this paper, the Nano lubrication is used to reduce the cost, extend tool life and improve the performance of machining process. The input parameters are spindle speed feed rate and depth of cut. The author uses the workpiece as aluminum AA6061- T6 and the cutting tool as high-speed steel (HSS) having dia. Of 10mm. The size of the nanoparticles is in the range of 5-15 nm with the application of Nano lubrication system the increment in cutting forces is reduced, improve machining performance as compared to ordinary lubrication system [21].

Sr.No.	Reference	Base fluid	Nanoparticle	Work peace
1	[15]	Reinforced Vegetable oil	MoS_2	Martensitic stainless steel
2	[16]	ECOCUT SSN322 Mineral oil	SiO_2	Aerospace AL 6061-T6
3	[17]	Vegetable oil	HBN Graphene MoS_2	Inconel X-750 super alloy
4	[18]	Vegetable oil	XGnP	TiA1N-coated carbide
5	[19]	mineral oil	Carbon onion	Duralumin AL-2017T4
6	[20]	ECOCUT HSG 9055	MoS_2	AL6061-T6
7	[21]	Mineral oil	SiO_2	Aluminum AA6061-T6

D. Drilling process.

In this research paper, titanium dioxide nanoparticle is used at a weight concentration of 0.3,0.6 and 1%having nanoparticle size 20nm is mixed with soluble oil as a base fluid. and these drilling operations perform on steel material for that 6 model MOBINES-HSS-COS drill bit like a cutting tool to remove material and create holes. the result shows that titanium dioxide mixed with soluble oil decreases the surface roughness and temperature of material as compared to pure soluble oil and dry condition [22].

In this research paper micro drill used was uncoated carbide twist drill (DIXI1138, DIXI) on the Titanium alloy (Ti-6AL-4v) workpiece for drilling operations performed and Nanodiamond particle at 35 nm size vegetable oil as the base fluid used for coolant. The drilling torque, thrust forces, and edge radii in terms of input parameters such as drill diameter, feed rate, spindle speed, and Nanofluid weight concentration. For objective optimization for Minimizing drilling torque Thrust forces and edge radii obtain [23].

In this research paper, aluminum dioxide nanoparticle is used of 20nm in size with a volumetric concentration of 1.5%

in soybean oil base fluid. in the drilling of aluminum 6063 alloys by using HSS drill tools. the objective us compare the performance of different lubrication i.e. dry, flooded, pure MQL and Nanofluid. the result shows that the increases number of drilled holes reduced drilling torques and thrust forces as compare to other coolant lubrication conditions. the nanoparticle with vegetable oil shows the performance reduction of friction and wear [24].

In this research paper for the Nanofluid MQL Nanodiamond particle having a size of 30nm is used with the base fluid of paraffin and vegetable oil and for micro-drilling operation and uncoated carbide twist drill (DIXI1138) use for the making holes in the aluminum 6061 workpiece. The MQL supply system delivered Nanofluid mist mixed with high pressurized air to the interface between a microfilming and work peace both pure and Nanofluid MQL could decrease the drilling torque and thrust force but the Nanofluid MQL was much more effective than pure MQL significantly increases the number of drilling holes and reduced the drilling torque and thrust force [25].

Sr.No.	Reference	Base fluid	Nanoparticle	Work peace
1	[22]	Soybean oil	Al_2O_3	Aluminum 6063 alloy
2	[23]	Paraffin oil	-	Aluminum 6061
3	[24]	Soluble oil	TiO_2	Steel
4	[25]	Vegetable oil	-	Titanium alloy
5	[26]	Vegetable oil	Carbon Nano tube particle	AISI1045 carbon steel
6	[27]	Ethylene glycol	Cupper nanoparticle	AA5052 alloy
7	[28]	Ethylene glycol	Cupper nanoparticle	AISI steel

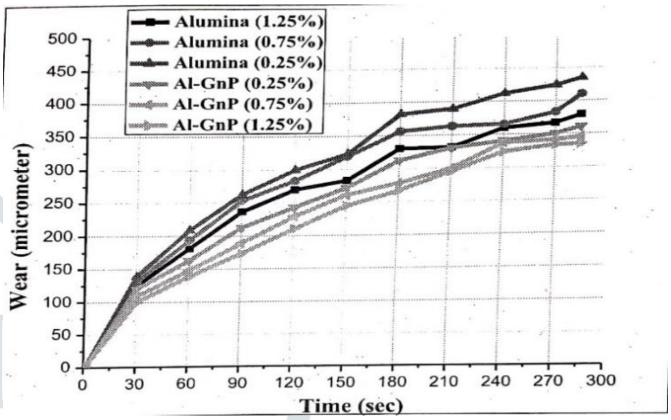
In this research paper, the drilling operation performs on the AISI 1045 carbon steel workpiece for used a drill bit is cobalt coated high-speed steel drill as a drilling tool to remove material to create holes. During experiment the Nanofluid in this type of mist was injected into the tool work contact interface. The MQL mist a mixture of carbon nanotube particles with vegetable oil of the base fluid. the aim of this paperwork is to study longitudinal ultra-sonic vibration and minimum quantity lubrication on drilling force, surface roughness burr height the result application of ultrasonic vibration and MQL condition to drilling condition significantly reduces the thrust force and torque that causes reduction of machining power [26].

In this research paper copper nanoparticles (white color) with size 50 nm with ethylene glycol as base fluid was selected in drilling on AA5052 material. The drilling operation performs the insert material the Tungsten carbide drill on NanodiamondAA5052 workpiece. The machining performed under MQL with Nanofluid provides effective lubrication and reduced the friction. The experiment performed an effect of variation in cutting speed on cutting temperature under dry oil and Nanofluid machining condition. The result shows that copper Nanofluid reduces the surface roughness cutting temp, flank wear and formation of large teeth [27].

In this research paper drilling operation perform on the AISI 4140 steel work pace for used an insert cutting tool is carbide to remove the material and create holes during the experiment the copper nanoparticle used with ethylene glycol as a base fluid for preparations of Nanofluid sodium lauryl sulfate used as surfactant to stabilize the Nanofluid. In this experiment, there are three operating parameters cutting speed, machining environment and feed rate using MQL technique in drilling on AISI 4140 steel. Results show that copper Nanofluid with MQL provides better cooling and eliminate microchipping and hence provide less wear on inserts [28].

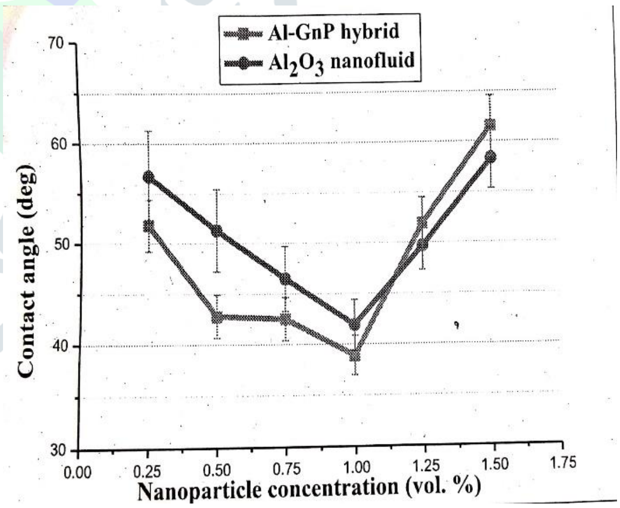
III. Conclusion

A. Turning



Contact the angel as a function of nanoparticle concentration of aluminum and its hybrid Nanofluid [1].

The graph shows for both the nanoparticle (alumina and AL-GnP hybrid) are in increases in volumetric concentration from 0% to 1.5% and the contact angel gets reduced at 1.00 vol% and then it increases.



Wear of AISI 304 with respect to time at a different volumetric concentration of Nanofluids [1].

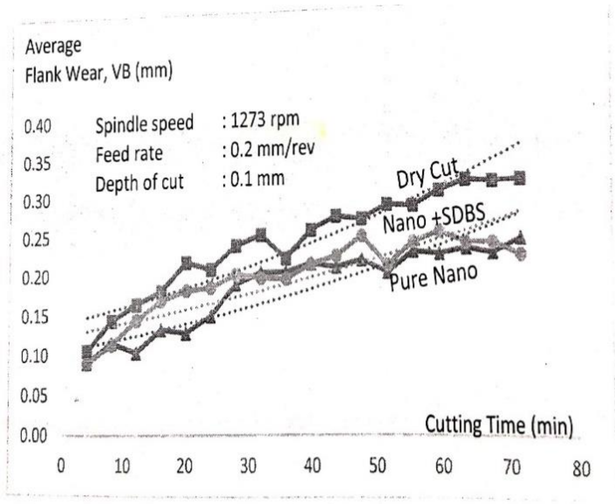
From the fig. it is observed that: -

a) Wear of ~332 um, ~342 um, ~350 um was recorded with 0.25%, 0.75% and 1.25 vol% for Al-GnP Nanofluid, respectively.
b) Wear of ~353 um, ~387 um, ~425 um was recorded with 0.25%, 0.75% and 1.25 vol% for alumina-based Nanofluid, respectively.

The response parameters are depending upon the input variables such as cutting speed, feed, depth of cut and nanoparticle concentration. The three trials of each response are taken and the average of it compares with the optimized values. it is observed that Al-GnP hybrid Nanofluid has reduction in temperature as compare to AL_2O_3 Nanofluid. at 1.24 vol% and

1.11 vol%, the lowest tool wear was achieved for alumina and Al-GnP hybrid Nanofluid.

In the sixty trial experiment, input parameters are spindle speed, feed rate, depth of cut and tool nose radius on the basis of these surface roughness and cutting force are taken as an output response variable. For surface roughness and cutting force the optimal parameters are lowest feed rate (FR = 0.04m/min, 0.04m/min), spindle speed (SS = 1000rpm, 1200rpm), depth of cut (DOC = 1mm, 0.5mm), tool nose radius (NR = 0.8mm, 0.4mm), respectively.



Growth of tool wear at different machining conditions [3].

The average growth graph shows the growth of tool wear at dry, Nano lubricant with SDBS and pure Nano lubricant machining. The steel caused high tool wear while SDBS and pure Nano lubricant having low tool wear increases the tool life and reduces the temperature of machining.

The reduction of tool wear and surface roughness gives clean and improvable machining. In which MQL with SiO_2 nanoparticle and ordinary mineral oil shows an effective surface finishing on AISI 4140 specimen. It is clear from the experiment that 3 to 0.5% of concentration of nanoparticle gives lowest tool wear and best surface finish [4]. the hybrid Nanofluid improves tribological and thermal properties if it is in ratio of (90;10) in which alumina-based Nanofluid with MWCNT have in volumetric concentration, respectively. The Al-MWCNT hybrid Nanofluid shows high thermal conductivity, lower tool flank wear, and coefficient of friction as compared to alumina Nanofluid [6]. It is observed that in all the input parameters such as cutting speed, feed, depth of cut, tool nose radius. The feed rate is most significant factor for obtaining the optimal response variable as surface roughness and cutting force [7].

B. Grinding

Grinding is a machining process and in this process, Nanofluids use as a coolant. According to research to most researchers focus on the surface finishing, tool wear, and feed. Nanofluid gives better lubrication as compared to oil. When lubrication is better then it gives good surface finishing and decreases the temperature. According to research hybrid nanofluids having good thermal conductivity and shows better results as compared to mono nanofluid.

Hence hybrid nanofluid gives better surface finishing and increases the tool life as compared to single nanofluid and oil.

C. Milling

This paper gives a brief idea about the Experimental investigation on the Nano-enhanced cutting fluids and its application in the machining process. It is also discussing the brief about the Experimental setup and procedure adopted by researcher for the investigation in a systematic manner. According to the research most of the researchers take feed, depth of cut and speed as the input parameters and surface roughness tool were and topological properties as the output parameter but most of the researchers focused on the surface roughness. It is seen by the most of the researcher that the increase in the concentration of nanoparticle increase the tool were as well as the other properties and also mixture of nanoparticle in cutting fluids showed a remarkable revolution in power consumption specific energy cutting force surface roughness during machining

It is also seen that the hybrid Nanofluid gives better results than the mono Nanofluid during machining but it is seen by the researcher that the large size particles do not produce a stable suspension and caused segregation.

D. Drilling

It is seen by the researchers the nanoparticles mixed with the based fluid (soluble oil, vegetable oil, paraffin oil, soyabean oil, etc.) To result showed an increase in the number of holes reduces the drilling torque and thrust force, decreases the surface roughness of workpiece and drilling temperature.

REFERENCES

(1) Sharma, A. K., Tiwari, A. K., Dixit, A. R., Singh, R. K., & Singh, M. (2018). Novel uses of alumina/graphene hybrid nanoparticle additives for improved tribological properties of lubricant in turning operation. Tribology International, 119, 99-111.

(2) Patole, P. B., & Kulkarni, V. V. (2018). Optimization of process parameters based on surface roughness and cutting force in MQL turning of AISI 4340 using nanofluid. Materials Today: Proceedings, 5(1), 104-112.

(3) Khalil, A. N. M., Ali, M. A. M., & Azmi, A. I. (2015). Effect of Al2O3 nano lubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant. Procedia Manufacturing, 2, 130-134.

(4) Sayuti, M., Sarhan, A. A., & 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.

(5) Sharma, A. K., Singh, R. K., Dixit, A. R., & Tiwari, A. K. (2017). Novel uses of alumina-MoS2 hybrid nanoparticle enriched cutting fluid in hard turning of AISI 304 steel. Journal of Manufacturing Processes, 30, 467-482.

(6) Sharma, A. K., Katiyar, J. K., Bhaumik, S., & Roy, S. (2019). Influence of alumina/MWCNT hybrid nanoparticle additives on tribological properties of lubricants in turning operations. Friction, 7(2), 153-168.

(7) Patole, P. B., & Kulkarni, V. V. (2017). Experimental investigation and optimization of cutting parameters with multi-response characteristics in MQL turning of AISI 4340 using nanofluid. Cogent Engineering, 4(1), 1303956.

(8) Sinha, M. K., Madarkar, R., Ghosh, S., & Rao, P. V. (2017). Application of eco-friendly nanofluids during grinding of Inconel 718 through small quantity lubrication. Journal of cleaner production, 141, 1359-1375.

(9) Zhang, Y., Li, C., Jia, D., Zhang, D., & Zhang, X. (2015). Experimental evaluation of MoS2 nanoparticles in jet MQL grinding with different types of vegetable oil as base oil. Journal of Cleaner Production, 87, 930-940.

(10) Kumar, A., Ghosh, S., & Aravindan, S. (2019). Experimental investigations on surface grinding of silicon nitride subjected to mono and hybrid nanofluids. Ceramics International.

(11) Zhang, Y., Li, C., Jia, D., Zhang, D., & Zhang, X. (2015). Experimental evaluation of the lubrication performance of MoS2/CNT nanofluid for minimal quantity lubrication in Ni-based alloy grinding. International Journal of Machine Tools and Manufacture, 99, 19-33.

(12) Pashmforoush, F., & Bagherinia, R. D. (2018). Influence of water-based copper nanofluid on wheel loading and surface roughness during grinding of Inconel 738 superalloy. Journal of Cleaner Production, 178, 363-372.

(13) Shen, B., Malshe, A. P., Kalita, P., & Shih, A. J. (2008). Performance of novel MoS2 nanoparticles based grinding fluids in minimum quantity lubrication grinding. Trans. NAMRI/SME, 36(357), e364.

(14) Rabiei, F. A. R. S. H. A. D., Rahimi, A. R., & Hadad, M. (2017). Performance improvement of eco-friendly MQL technique by using hybrid nanofluid and ultrasonic-assisted grinding. The International Journal of Advanced Manufacturing Technology, 93(1-4), 1001-1015.

(15) Uysal, A., Demiren, F., & Altan, E. (2015). Applying minimum quantity lubrication (MQL) method on milling of martensitic stainless steel by using nano MoS2 reinforced vegetable cutting fluid. Procedia-Social and Behavioral Sciences, 195, 2742-2747.

(16) Sayuti, M., Erh, O. M., Sarhan, A. A., & Hamdi, M. (2014). Investigation on the morphology of the machined surface in end milling of aerospace AL6061-T6 for novel uses of SiO2 nanolubrication system. Journal of Cleaner Production, 66, 655-663.

(17) Şirin, Ş., & Kıvak, T. (2019). Performances of different eco-friendly nanofluid lubricants in the milling of Inconel X-750 superalloy. Tribology International, 137, 180-192.

(18) Park, K. H., Ewald, B., & Kwon, P. Y. (2011). Effect of nano-enhanced lubricant in minimum quantity lubrication balling milling. Journal of tribology, 133(3), 031803.

(19) Sayuti, M., Sarhan, A. A., Tanaka, T., Hamdi, M., & Saito, Y. (2013). Cutting force reduction and surface quality improvement in machining of aerospace duralumin AL-2017-T4 using carbon onion nanolubrication system. The International Journal of Advanced Manufacturing Technology, 65(9-12), 1493-1500.

(20) Rahmati, B., Sarhan, A. A., & Sayuti, M. (2014). Morphology of surface generated by end milling AL6061-T6 using molybdenum disulfide (MoS2) nanolubrication in end milling machining. Journal of Cleaner Production, 66, 685-691.

(21) Sarhan, A. A., Sayuti, M., & Hamdi, M. (2012). Reduction of power and lubricant oil consumption in milling process using a new SiO 2 nanolubrication system. The International Journal of Advanced Manufacturing Technology, 63(5-8), 505-512.

(22) Salimi-Yasar, H., Heris, S. Z., Shanbedi, M., Amiri, A., & Kameli, A. (2017). Experimental investigation of thermal properties of cutting fluid using soluble oil-based TiO2 nanofluid. Powder Technology, 310, 213-220.

(23) Nam, J., Kim, J. W., Kim, J. S., Lee, J., & Lee, S. W. (2018). Parametric analysis and optimization of nanofluid minimum quantity lubrication micro-drilling process for titanium alloy (Ti-6Al-4V) using response surface methodology and desirability function. Procedia Manufacturing, 26, 403-414.

(24) Chatha, S. S., Pal, A., & Singh, T. (2016). Performance evaluation of aluminium 6063 drilling under the influence of nanofluid minimum quantity lubrication. Journal of cleaner production, 137, 537-545.

(25) Nam, J. S., Lee, P. H., & Lee, S. W. (2011). Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication. International Journal of Machine Tools and Manufacture, 51(7-8), 649-652.

(26) Teimouri, R., Amini, S., Lotfi, M., & Alinaghian, M. (2019). Sustainable drilling process of 1045 steel plates regarding minimum energy consumption and desired work quality. International Journal of Lightweight Materials and Manufacture.

(27) Naresh Babu, M., & Muthukrishnan, N. (2018). Experimental analysis in drilling of AA 5052 using copper nanofluids under minimum quantity lubrication. Australian Journal of Mechanical Engineering, 1-10.

(28) Muthuvel, S., Naresh Babu, M., & Muthukrishnan, N. (2018). Copper nanofluids under minimum quantity lubrication during drilling of AISI 4140 steel. Australian Journal of Mechanical Engineering, 1-14.