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Recent Advancement for Green and Sustainable Manufacturing Grinding Process: A Review

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ABSTRACT

Lubrication is prime requirement of metal cutting industries to assure high quality performance. A lot of heat developed because of high friction during an abrasive material removal process. The conventional method of cooling consumes high amount of coolant but still insufficient to control thermal related problems. The proper penetration of coolant is not possible and most of the fluid goes in waste form. This method is uneconomical and eco-friendly less. The alternative is minimum quantity lubrication technique, in which a minute amount of lubricant with high air velocity delivers directly to cutting zone for effective penetration. The nanofluids have excellent convection heat transfer and thermal conductivity properties. To reduce the excess usage of grinding fluid, nanofluid has recently applied to grinding process using minimum quantity lubrication technique. The MQL based nanofluid technique (nanofluid MQL) gives better cooling and lubricating effects which improves overall grinding performance compared to conventional flooded, MQL and pure nanofluid machining. This literature study provides a review on results obtained for grinding process in different grinding environments. It helps to find the research gap for the researchers to develop green and sustainable grinding process for better results.

1. Introduction

Grinding is generally used to achieve of high dimensional accuracy surfaces and good surface finish which categorized in final processing operation. The process of material removal in grinding is highly complex where the cutting edges are geometrically undefined and relatively large contact area. The contact time between wheel and work material is of microseconds. This generates comparatively large amount of heat over the cutting operation. A large quantity of coolant is required for better grinding performance in terms of grinding forces, metal removal rate; temperature at grinding zone, specific grinding energy and better work piece surface finish. The conventional role of coolant for machining is cooling, lubrication, corrosion inhibition and chip removal. These functions of coolant give improvement in tool life and surface finish [1-4]. A large use of coolants requires high amount of cost which is approximately 15% of total production cost. The recycling, disposing the coolant after use is the difficult task as it contains small particles of abrasive and toxic contaminants which pollute the land. Up to 32% of total energy of manufacturing unit is consumed for provision and cleaning of cutting fluid [5]. Different institute and agency have introduced several health and safety norms due to harmful emission from coolant to worker [6-9]. Thus, from cost, health and environmental point of view, the best alternative is to make eco-friendly coolant or to reduce the consumption [10-14].

Considering the consumption and effect of excess use of cutting fluid during machining processes on human health, environment, it is on demand to reduce the use of cutting fluids for machining process. In recent years, the much effort has been taken in this regard to reduce the friction using different techniques of cutting fluid. In this paper, the finding of nanofluid property at different concentration and base fluid is summarized for stable nanofluid. Similarly finding of micro-lubrication techniques namely MQL and MQL based nanofluid (nanofluid MQL) for grinding process are reviewed base on experimental work reported by different researchers. Total 160 papers were reviewed on different grinding environments for process performance. The selected papers on different grinding environments in percentage (%) are shown in Fig. 1.

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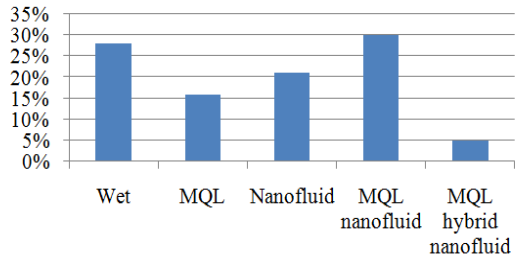

Fig. 1 Reviewed papers on lubricating and cooling techniques

2. Minimum Quantity Lubrication (MQL)

The papers reviewed on wet grinding stated that, the conventional fluid such as soluble oil generally use for machining as a coolant have good lubrication but poor thermal properties. The trend of papers on wet grinding indicates that, for quality product, the conventional machining process consumes large quantity of cutting fluid to reduced friction and heat generates during grinding at contact zone. Before several decades, the trend shows the massive amount of consumption of cutting fluids due to increase of production and mass production systems. The researchers considered the optimized process and machine parameters to minimize the friction, cutting forces and temperature for minimum coolant [15, 16]. The reason of high consumption of cutting fluid is due to ineffective penetration at contact zone [17, 18].

However, it has been reported that, a high consumption of cutting fluid is harmful to environment as it creates environmental pollution and economic loss. Again, more energy is consumed during grinding process to operate the equipment namely filtering, recirculating and coolant treatment required to treat the cutting fluid. Another source of expense is disposing the cutting fluid as it is not reused since it is contaminated with abrasive particles of grinding wheel and workpiece debris. In addition, post cleaning processes are required to clean the workpiece before used for next operation or process. The cutting fluids may cause health effects to operator as it contains pesticides and preservatives [19].

The problems associated with wet grinding are minimized by MQL technique. The working principle of MQL is to deliver the mixture of minute amount of cutting fluid as a mist by compressed air to grinding zone shown in Fig. 2. This technique is also known as micro lubrication and near-dry machining. The pressurized compressed air is used for effective penetration of fluid which minimized the heat generation and enhanced the abrasive removal from the contact interface. The pressurized air gives the cooling effects whereas the lubricating functions are achieved using the cutting fluids.

Fig. 2 Mist spray in MQL grinding process

In MQL, the characteristics such as safety properties, environment pollution and biodegradability are more important. Additionally, the workplace and machines can keep clean which improves the life of machine. The selected research papers [20-28] on MQL technique is summarized in Table 1.

3. Nanofluid MQL Grinding

In last few years, many researchers have reported a lot of work on preparation of stable nanofluid, heat transfer properties of nanoparticles, thermal and tribological properties of nanofluid. These nanoparticles have high potential characteristic like increasing thermal conductivity, heat transfer coefficient and tribological characteristics [29, 30]. The nanofluids improves heat transfer rate and reduced friction and wear properties [31]. Thus, grinding performance and surface roughness improved largely when such nanofluid applied to grinding zone as mist [32, 33]. The nanofluid thermal conductivity is a function of particle size. The stable nanofluid preparation is important part for application [34]. The importance of nanofluid parameters such as nanoparticle size, temperature, volume fraction, pretreatment process is stated for preparing the stable nanofluid and improves thermal conductivity [35, 36]. The results of convective heat transfer for different geometry and different techniques of nanofluid preparation are summarized [37]. The suspended nanoparticle in base fluid significantly change the transport and heat transfer characteristics of suspension due to increase of surface volume ratio and Brownian motion of nanoparticles [38]. The different techniques of nanofluid preparation and application of nanofluid in different areas are summarized [39, 40]. The effect of nanofluid parameters on thermal property and nanofluid suspension stability is listed in Table 2.

Table 1 Summary of researches on MQL grinding

S.No.	Material and base fluid	Speed (m/min)	Depth of cut (µm)	Air pressure (Bar)	Coolant flow rate (mL/hr)	Findings	Ref.
1.	D3 type. Soluble oil	3,3.75, 4.5	20,30,40	2,3,4	200,300,400	Coefficient of friction and surface roughness found better in MQL but specific grinding energy obtained comparatively higher than wet grinding.	[20]
2.	AISI 1060 steel. Vegetable oil.	6	10,20,30,40	8	120	Reduction of cutting temperature by 10 to 30%. Surface roughness and best lubrication found at 20 µm in- feed.	[21]
3.	Ti-6Al-4V. Synthetic, vegetable, cutting oil.	20,30,40	2, 5,7	3,4,5, 6	20,40,50,60,70,100,140	Reduction of grinding force and better grinding performance at 60 mL/hr and 4 bar respectively for synthetic oil.	[22]
4.	AISI 52100 steel. Soluble oil and pure mineral oil	3	10	6	60	Better reduction in tangential force, surface roughness for pure oil but soluble oil reduces grinding temperature.	[23]
5.	Hardened 100Cr6 and soft 42CrMo4 steel. Soluble oil	2.5, 5, 10	5,10,15,25	4	66	Surface finish of hardened steel found better. Significant reduction in grinding forces, friction coefficient and specific energy for both type of steel.	[24]
6.	Hardened 100 Cr6. Soluble oil	1	20	2,3,4,7	20,50,100	Explained the importance of nozzle position and mathematical model of tangential force, surface roughness for result improvement.	[25]
7.	Hardened 100 Cr6. Soluble oil	1, 2	20	2,3,4,7	20,50,100	Effective penetration and better grinding result is obtained when spray nozzle position angularly toward the wheel.	[26]
8.	AISI 5140 steel. Semi-synthetic.	0.5	100	6	240	Grind-hardening with MQL reduces grinding forces and temperature. It also improves surface integrity and lowers the surface roughness.	[27]
9.	Soft steel: CK45 and S305. Hard steel: 100Cr6 and HSS. Water	3	5,20,35, 50.	4	120	Grinding forces, friction coefficient decreases in both steel but better surface quality obtained in hard steel.	[28]

Table 2 Effect of nanofluid on thermal property and suspension stability

S.No.	Type of nanoparticle	Base fluid	Concentration (%), particle size (nm)	Measurement device	Findings	Ref.
1.	Al_2O_3, CuO, TiO2	Water	0.3, 0.6, 1, 1.5, 2 wt%. 20-30, 40, 10 nm.	KD2 Pro thermal properties analyzer.	Effective thermal conductivity increased with increase in concentration and temperature. It is increased by 10.2% for CuO/water nanofluid.	[41]
2.	Cu, Zn (for viscosity) Al_2O_3, CuO, TiO_2 nanofluid	Vegetable oil	Viscosity at 0.5 vol. fraction. Thermal conductivity at 0.3, 0.6, 1, 1.5, 2 wt%.	KD2 Pro thermal property analyzer for thermal conductivity and Redwood viscometer for viscosity.	Improvement of viscosity by 61% for hybrid nanofluid (Cu-Zn) when composition of 1:1 at 0.5% vol. fraction. Effective thermal conductivity increased with increase in concentration and temperature.	[42]
3.	Al_2O_3	De-ionized water	Nanofluid of 0.5 wt%. 10.	--	Good suspension stability obtained when ultrasonic vibration time of 1 hr, mass fraction of dispersant (SDBS) is 0.5% and base fluid pH is 7.	[43]
4.	Al_2O_3	Mixture (45 vol. % ethylene glycol and 55 vol. % water).	vol. fraction of 1, 2 and 3. 30.	Rheological property measured by viscometer and heat transfer coefficient by inbuilt setup.	The heat transfer coefficient of nanofluids of 1 and 2 vol. % is increased by 57% and 106% respectively. The viscosity increases with particle vol. fraction and decreases with increased temperature.	[44]
5.	TiO_2	Double distilled water, ethylene glycol, paraffin oil-based.	1-6 vol.% 5.	Thermal conductivity measured by KD2 Pro thermal property analyzer.	Highest enhancement of thermal conductivity (22%) for water based nanofluids at 6% vol. fraction till sonication time 60 min.	[45]

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Table 3 Summary of researches on nanofluid MQL grinding

S.No.	Nanoparticle (single type)	Base fluid	Concentration (%), particle size (nm)	Material	Findings	Ref.
1.	Al_2O_3	De-ionized water	Weight fraction 0.75, 60	AISI 52100 steel	Nozzle position angularly toward Grinding wheel (15° from GW), shorter spraying distance (40 mm) and air pressure (0.6 MPa) reduces roughness, forces and temperature.	[46]
2.	Al_2O_3	De-ionized water	1.2, 40	AISI 52100 steel	Reduces grinding force, temperature, roughness and improves surface integrity of workpiece.	[47]
3.	Al_2O_3	Water	Vol. fraction 1 and 4, 40.	Ti-6Al-4V alloy	Significant reduction of cutting forces and surface roughness at 4% concentration.	[48]
4.	Al_2O_3	De-ionized water	1, 2.5 and 4, 40.	Cast iron	Thermal conductivity of Al_2O_3 improved by 15% at 4% conc., reduction in grinding forces at 2.5%, G-ratio improved at 4% conc. Similarly for diamond nanofluid, the thermal conductivity improved at 100 nm, cutting forces (100 nm), G-ratio (200 nm). Better surface finish for Al_2O_3 at 4% conc. and 200 nm diamond particle size across grinding.	[49]
5.	Diamond	De-ionized water	Vol. fraction 1.5. 100 and 200			
6.	ZnO	Water	0.15, 30-40.	Ductile cast iron	Tool wear reduced by 50% compared to conventional coolant. Improvement in Grinding performance.	[50]
7.	Al_2O_3	TRIM E709 emulsifier	Vol. conc. 1.	EN-31	No use of MQL. Temperature reduced by 20% to 30% and surface roughness by 35 to 40%. FEM grinding model is explained for energy partition.	[51]
8.	MWCNT	SAE 20W40	2 g of MWCNT in 1000 mL. 10-20.	AISI D2 tool steel	Lowest surface roughness of 0.057 µm, reduced micro cracks, better surface morphology is obtained compared to other machining environments.	[52]
9.	Al_2O_3, CuO	Water	0.05, 0.1, 0.5 and 1. 40	Ti-6Al-4V	Coefficient of friction reduced (Al_2O_3 = 0.26 and CuO = 0.28) at 1% conc. The better results of surface roughness, grinding forces and grinding zone temperature obtained compared to dry and wet.	[53]
10.	MoS_2, CNT, ZrO_2	Colza oil	Vol.conc.1, 2 and 3. 50.	Hardened steel 45	Specific grinding energy and surface roughness of MoS_2 is reduced by 8.22% and 10.39% at 2% vol. concentration.	[54]
11.	MoS_2, CNT, ZrO_2	Soyabin oil	Vol. conc.1, 2, 3%. 50 nm	Hardened steel 45	Energy ratio coefficient shows best cooling performance of CNT obtained at 2% vol. conc.	[55]
12.	MWCNT	SAE20W40 oil	10 g in 500 mL oil, 10-20 nm.	AISI D3 tool steel	No use of MQL. Improvement in thermal property like flash and fire point. Decrease in roughness and depth of micro cracks reduces using CNT.	[56]
13.	Al_2O_3, CuO	Water	Vol.% 2. 50 and 100.	EN8	CuO at 2% vol. conc. and 100 nm gives better surface finish and G ratio.	[57]
14.	MWCNT	De-ionized water	0.6, 0.8, 1 and 1.4. 50.	AISI 52100 steel	Highest thermal conductivity (0.839 W.mK) at 1% conc. Better results in terms of cutting forces, G ratio and surface finish.	[58]
15.	Al_2O_3	Palm oil	0.5-4.0 vol.% 50.	Ni- based alloy	The smallest force ratio (0.281) and surface roughness (0.301 µm) obtained at 1.5 vol. % concentration. The stable nanofluid observed at below 2 vol. % conc.	[59]
16.	MWCNT and Al_2O_3	De-ionized water	1 wt%. 40.	Ti-6Al-4V	Reduction of specific grinding forces and specific energy is obtained for MWCNT nanofluid compared dry, wet and alumina nanofluid.	[60]
17.	Ag and ZnO	De-ionized water	Ag (10, 20, 30 mL in 100 mL DI water, 10) and ZnO (0.01, 0.1, 0.5 vol. %, 25).	Inconel 718 super alloy	Low grinding forces, friction coefficient and better ground surface is obtained for ZnO nanofluid.	[61]
18.	Al_2O_3	Pure synthetic lipids	2 vol.% 50.	Ti-6Al-4V	Improvement in surface roughness and grinding efficiency using NanoMQL grinding at optimized parameter setting.	[62]
19.	MoS_2, SiO_2, diamond, CNT, Al_2O_3, ZrO_2	Water-based, pure palm oil, palm oil-based nanofluid.	CNT: 10-30 µm (50). For other nanoparticle, the size is 50 nm. 6% mass fraction.	Nickel alloy GH4169	Al_2O_3 nanofluid gives the best lubrication performance in-terms of lowest values of friction coefficient, specific grinding energy, surface roughness and highest G-ratio.	[63]
20.	Graphite	Distilled water plus 20 vol.% canola oil	0.15, 0.25, and 0.35 vol. %. 32.	AISI 1045 steel	Lowest values of specific tangential force, force ratio and surface roughness. Better surface morphology is obtained using graphite based MQL nanofluid.	[64]

Table 4 Summary of researches on hybrid nanofluid using MQL grinding

S.No.	Hybrid nanofluid	Base fluid	Concentration(%), particle size (nm)	Material	Findings	Ref.
1.	MoS_2/CNT (mass ratio 2:1)	Synthetic lipids (oil based)	2, 4, 6, 8 and 10. MoS_2: 30. CNT: 10-30.	GH4169 Ni-based alloy (Inconel 718)	Lowest coefficient of friction (0.276), surface roughness (0.294 µm) and grinding forces obtained at 6 wt% conc. compared to different mixing ratio and single nanoparticle.	[65]
2.	Al_2O_3/SiC (2:1)	Synthetic lipids (oil based)	Mass fraction 6%. 50.	GH4169 Ni-based alloy	Smallest grinding force ratio (0.28), specific grinding energy (60.68 J/mm^3) and roughness (0.323 µm) compared to pure type nanoparticle and mixing ratios of hybrid nanofluid.	[66]
3.	MoS_2/CNT	Synthetic lipids (oil based).	2, 4, 6, 8, 10 and 12 wt.% MoS_2: 30. CNT: 10-30.	GH4169 Ni-based alloy (Inconel 718).	Lowest grinding force ratio (0.274) and surface roughness is obtained at 8 wt.% concentration.	[67]
4.	MWCNT/Al_2O_3	Oil	2.5 wt.%	100Cr6 hardened steel(bearing steel)	Hybrid nanofluid with ultrasonic assisted grinding gives better results in-terms of forces, power consumption, friction coefficient, temperature and ground surface.	[68]

Recently, studies are focused on nanofluid MQL technique due to excellent thermal, friction and wear properties of nanofluid. In nanofluid MQL, the compressed air is used to atomize the nanofluid in nozzle to achieve fine mist. The better thermal properties of nanofluid and its application using MQL achieves the significant results in-terms of reduction of grinding temperature, forces, specific energy and surface roughness due to effective penetration and high surface energy of nanoparticles. The proper nozzle position is important to penetrate the cutting fluid effectively at contact area [46]. The selected literature on nanofluid MQL grinding for process improvement is listed in Table 3.

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Many researchers have reported a lot of work on nanofluid MQL. The very few research works have been conducted on preparation and application of hybrid nanofluid for grinding. The hybrid nanofluid integrate the properties of two or more type of nanoparticles which gives better lubrication and heat transfer properties which is not possible by a single type nanoparticle. The hybrid nanofluid is generally used for hard cutting material. The performance of hybrid nanofluid using MQL in grinding process is summarized in Table 4.

Zhang et al. [66] investigated the lubrication and thermal conductivity effect of pure nanofluid Al_2O_3, SiC and Al_2O_3/SiC hybrid nanofluid at 6% mass fraction using different mixing ratio of hybrid nanoparticles. The nanofluids were formulated in synthetic lipids and experiments are conducted on Ni-based alloy using precision surface grinder for nanofluid MQL grinding. The results of experiment showed the reduction by 6.7% and 20.1% in grinding force ratio and specific grinding energy respectively, while the surface roughness was decreased by 16.32% compared to pure Al_2O_3 nanofluid. The results are shown in Fig. 3. Thus, the best lubrication performance was stated for 2:1 mixing ratio of Al_2O_3 and SiC nanoparticles.

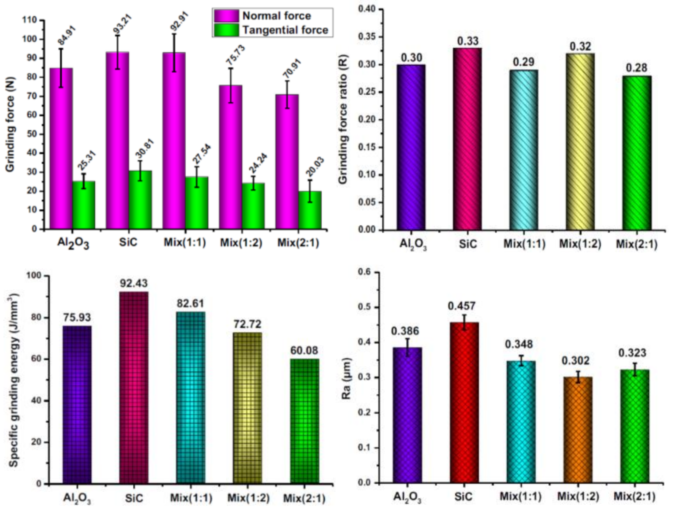

Fig. 3 Effects of different Al_2O_3/SiC mixing ratio on grinding force, grinding force ratio, specific grinding energy and Ra [66]

4. Conclusion

The paper presents an overview of experimental work contributed by different researchers in the field of cooling and lubrication for green and sustainable grinding process. MQL is efficient technique which reduces friction at contact zone by using small quantity of coolant. The Nanofluid MQL technique shows the significant reduction of cutting forces, temperature, specific energy, and improves the surface morphology and grinding wheel life.

Thus, overall grinding performance enhanced due to better thermo-physical properties of nanofluid and penetration effectively using MQL. The best lubrication and heat transfer performance was noted for hybrid nanofluid (mixing ratio 2:1) using MQL. The surface roughness (0.323 μm), specific grinding energy (60.68 J/mm^3) and grinding force ratio (0.28) obtained are lowest for hybrid nanofluid MQL compared to other grinding environments. Al_2O_3 nanofluid gives good lubrication performance as lower values of surface roughness (0.386 μm), specific grinding energy (75.93 J/mm^3) and grinding force ratio (0.3) is obtained compared to pure SiC nanofluid. Thus, suggested nanofluid MQL is green, sustainable manufacturing technique and economical.

Till date, most of the researchers have a lot of work on MQL, among them nanofluid MQL techniques have improved the process performance and avoided limitations of conventional approach of fluid flow. The synthesis of hybrid nanofluid and its application using MQL is still needed to focus for grinding process. The experimentation of nanofluid MQL at optimal values of process parameters yet not fully developed for different materials. Further investigation can also focus on synthesis of suitable nanofluid for specific materials and application.

References

[1] E. Brinksmeier, C. Heinzel, M. Wittmann, Friction, cooling and lubrication in grinding, CIRP Annals Manuf. Technol. 48(2) (1999) 581-598.

[2] J. Das, B. Linke, Effect of manual grinding operations on surface integrity, Procedia CIRP 45 (2016) 95-98.

[3] K. Li, F. Aghazadeh, S. Hatipkarasulu, T. Ray, Health risks from exposure to metal-working fluids in machining and grinding operations, Int. J. Occupat. Safety Ergon. 9(1) (2015) 75-95.

[4] R. Irani, R. Bauer, A. Warkentin, A review of cutting fluid application in the grinding process, Int. J. Machine Tools Manuf. 45 (2005) 1696-1705.

[5] J.C. Aurich, B. Linke, M. Hauschild, M. Carrella, B. Kirsch, Sustainability of abrasive processes, CIRP Annals Manuf. Technol. 62 (2013) 653-672.

[6] M. Najiha, M. Rahman, A. Yusoff, Environmental impacts and hazards associated with metal working fluids and recent advances in the sustainable systems: A review, Renew. Sustain. Energy Rev. 60 (2016) 1008-1031.

[7] M. Sokovic, K. Mijanovic, Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes, J. Mater. Process. Technol. 109 (2001) 181-189.

[8] S. Shaji, V. Radhakrishnan, Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method, J. Mater. Process. Technol. 141 (2003) 51-59.

[9] L.R. Da Silva, E.C. Bianchi, R.Y. Fusse, R.E. Catai, T.V. Franca, P.R. Aguiar, Analysis of surface integrity for minimum quantity lubricant-MQL in grinding, Int. J. Machine Tools Manuf. 47 (2007) 412-418.

[10] T. Lavanya, V. Annamalai, Design of an eco-friendly coolant for grinding applications, Int. J. Adv. Eng. Technol. 1(2) (2010) 46-54.

[11] S. Alves, G. Fernando, De Oliveira, Development of new cutting fluid for grinding process adjusting mechanical performance and environmental impact, J. Mater. Process. Technol. 179 (2006) 185-189.

[12] R. Monici, E. Bianchi, R. Catai, P. De Aguiar, Analysis of the different forms of application and types of cutting fluid used in plunge cylindrical grinding using conventional and super abrasive CBN grinding wheel, Int. J. Machine Tools Manuf. 46 (2006) 122-131.

[13] K. Ramesh, H. Huang, L. Yin, Analytical and experimental investigation of coolant velocity in high speed grinding, Int. J. Machine Tools Manuf. 44 (2004) 1069-1076.

[14] V. Gviniashvili, N. Woolley, W. Rowe, Useful coolant flow rate in grinding, Int. J. Machine Tools Manuf. 44 (2004) 629-636.

[15] S. Thakor, D. Patel, An experimental investigation on cylindrical grinding process parameters for En8 using regression analysis, Int. J. Eng. Develop. Res. 2 (2014) 2486-249.

[16] H. Demir, A. Gullu, I. Ciftci, U. Seker, An investigation into the influences of grain size and grinding parameters on surface roughness and grinding forces when grinding, J. Mech. Eng. 56 (7-8) (2010) 447-454.

[17] S. Ebbrell, N. Woolley, Y. Tridimas, D. Allanson, W. Rowe, The effects of cutting fluid application methods on the grinding process, Int. J. Machine Tools Manuf. 40 (2000) 209-223.

[18] B. Mandal, R. Singh, S. Das, S. Banerjee, Development of a grinding fluid delivery technique and its performance evaluation, Mater. Manuf. Process. 27 (2012) 436-442.

[19] H. Kim, K. Seo, K. Kang, D. Kim, Nano-lubrication: A review, Int. J. Precision Eng. Manuf. 17(6) (2016) 829-841.

[20] R.R. Chakule, S.S. Chaudhari, P.S. Talmale, Evaluation of the effects of machining parameters on MQL based surface grinding process using response surface methodology, J. Mech. Sci. Technol. 31(8) (2017) 3907-3916.

[21] M. Islam, N. Dhar, Effects of minimum quantity lubrication by vegetable oil-based cutting fluid on temperature, chip morphology and surface finish in grinding AISI 1060 steel, In: Proceedings of the 4th BSME-ASME International Conference on Thermal Engineering, Dhaka Bangladesh Society of Mechanical Engineers, Bangladesh, 2008, pp.861-866.

[22] M. Sadeghi, M. Haddad, T. Tawakoli, M. Emami, Minimal quantity lubrication-MQL in grinding of Ti_6Al_4V titanium alloy, Int. J. Adv. Manuf. Technol. 44 (2009) 487-500.

[23] C. Mao, X. Tang, H. Zou, Z. Zhou, W. Yin, Experimental investigation of surface quality for minimum quantity oil-water lubrication grinding, Int. J. Adv. Manuf. Technol. 59 (2012) 93-100.

[24] T. Tawakoli, M. Hadad, M. Sadeghi, A. Daneshi, S. Stockert, A. Rasifard, An experimental investigation of the effects of workpiece and grinding parameters on minimum quantity lubrication-MQL grinding, Int. J. Machine Tools Manuf. 49 (2009) 924-932.

[25] M. Hadad, An experimental investigation of the effects of machining parameters on environmentally friendly grinding process, J. Clean. Prod. 108 (2015) 217-231.

[26] T. Tawakoli, M. Hadad, M. Sadeghi, Influence of oil mist parameters on minimum quantity lubrication-MQL grinding process, Int. J. Machine Tools Manuf. 50 (2010) 521-531.

[27] X. Huang, Y. Ren, W. Jiang, Z. He, Z. Deng, Investigation on grind-hardening annealed AISI5140 steel with minimal quantity lubrication, Int. J. Adv. Manuf. Technol. 89(1-4) (2017) 1069-1077.

[28] F. Rabiei, A.R. Rahimi, M.J. Hadad, M. Ashrafijou, Performance improvement of minimum quantity lubrication (MQL) technique in surface grinding by modelling and optimization, J. Clean. Prod. 86 (2015) 447-460.

[29] Y. Ding, D. Wen, Particle migration in a flow of nanoparticle suspensions, J. Powder Technol. 149 (2005) 84-92.

[30] N. Sankar, N. Mathew, C. Sobhan, Molecular dynamics modeling of thermal conductivity enhancement in metal nanoparticle suspensions, Int. Commun. Heat Transfer 35 (2005) 867-872.

[31] J. Wu, B. Phillips, W. Jiang, J. Sanders, J. Zabinski, A. Malshe, Bio-inspired surface engineering and tribology of MoS_2 overcoated CBN-TiN composite coating, J. Wear 261(5-6) (2016) 592-599.

[32] B. Shen, A. Shih, S. Tung, Application of nanofluids in minimum quantity lubrication grinding, J. Tribol. 51 (2005) 730-737.

https://doi.org/10.30799/jnst.290.19050509

[33] B. Shen, A. Malshe, P. Kalita, A. Shih, Performance of novel MoS_2 nanoparticles-based grinding fluids in minimum quantity lubrication grinding, Trans. NAMRI/SME 36 (2008) 357-364.

[34] L. Joohyun, Y. Yoon, J. Eaton, K. Goodson, S. Bai, Analysis of oxide (Al_2O_3, CuO and ZnO) and CNT nanoparticles disaggregation effect on the thermal conductivity and the viscosity of nanofluids, Int. J. Precision Eng. Manuf. 15(4) (2014) 703-710.

[35] H. Xie, W. Yu, Y. Li, L. Chen, Discussion on the thermal conductivity enhancement of nanofluids, Nanoscale Res. Lett. 6 (124) (2011) 1-12.

[36] W. Yu, D. France, J. Routbort, S.J. Choi, Review and comparison of nanofluid thermal conductivity and heat transfer enhancements, Heat Transfer Eng. 29(5) (2008) 432-460.

[37] X. Wang, A. Mujumdar, A review on nanofluids-Part II: experiments and applications, Braz. J. Chem. Eng. 25(4) (2008) 631-648.

[38] L. Godson, B. Raja, D. Mohan Lal, S. Wongwises, Enhancement of heat transfer using nanofluids-An overview, J. Renew. Sustain. Energy Rev. 14(2) (2010) 629-641.

[39] D. Devendiran, V. Amirtham, A review on preparation, characterization, properties and applications of nanofluids, J. Renew. Sustain. Energy Rev. 60 (2016) 21-40.

[40] Y. Shokoohi, E. Shekarian, Application of nanofluids in machining processes-A Review, J. Nanosci. Technol. 2(1) (2016) 59-63.

[41] T. Srinivas, A. Venu Vinod, The effective thermal conductivity of water based nanofluids at different temperatures, J. Test. Evaluat. 44(1) (2016) 280-289.

[42] M. Sandeep Kumar, V. Vasu, A. Venu Gopal, Thermal conductivity and viscosity of vegetable oil-based Cu, Zn and Cu-Zn hybrid Nanofluids, J. Test. Evaluat. 44(3) (2016) 1077-1083.

[43] C. Mao, H. Zou, X. Zhou, Y. Huang, H. Gan, Z. Zhou, Analysis of suspension stability for nanofluid applied in minimum quantity lubricant grinding, Int. J. Adv. Manuf. Technol. 71 (2014) 2073-2081.

[44] W. Yu, H. Xie, Y. Li, L. Chen, Q. Wang, Experimental investigation on the heat transfer properties of Al_2O_3 nanofluids using the mixture of ethylene glycol and water as base fluid, Powder Technol. 230 (2012) 14-19.

[45] S.S. Sonawane, R.S. Khedkar, K.L. Wasewar, Effect of sonication time on enhancement of effective thermal conductivity of nano TiO_2-water, ethylene glycol, and paraffin oil nanofluids and models comparisons, J. Exp. Nanosci. 10(4) (2015) 310-322.

[46] C. Mao, H. Zou, X. Huang, J. Zhang, Z. Zhou, The influence of spraying parameters on grinding performance for nanofluid minimum quantity lubrication, Int. J. Adv. Manuf. Technol. 64(9-12) (2013) 1791-1799.

[47] C. Mao, X. Tang, H. Zou, X. Huang, Z. Zhou, Investigation of grinding characteristics using nanofluid minimum quantity lubrication, Int. J. Precision Eng. Manuf. 13(10) (2012) 1745-1752.

[48] D. Setti, S. Ghosh, P. Venkateswara Rao, Application of nano cutting fluid under minimum quantity lubrication (MQL) technique to improve grinding of Ti_6Al_4V alloy, World Acad. Sci. Eng. Tech. 70 (2012) 512-516.

[49] B. Shen, A. Shih, S. Tung, Application of nanofluids in minimum quantity lubrication grinding, Tribol. Trans. 51 (2008) 730-737.

[50] M. Rahman, K. Kadirgama, Performance of water-based zinc oxide nanoparticle coolant during abrasive grinding of ductile cast iron, J. Nanopart. 2014 (2014) 175896:1-7.

[51] V. Vasu, K. Manoj Kumar, Analysis of nanofluids as cutting fluid in grinding EN-31 steel, Nano-Micro Lett. 3(4) (2011) 209-214.

[52] S. Prabhu, B. Vinayagam, Nano surface generation of grinding process using carbon nanotubes, J. Sadhana 35(6) (2010) 747-760.

[53] D. Setti, M. Sinha, S. Ghosh, P. Venkateswara Rao, Performance evaluation of Ti-6Al-4V grinding using chip formation and coefficient of friction under the influence of nanofluids, Int. J. Machine Tools Manuf. 88 (2015) 237-248.

[54] D. Zhang, C. Li, D. Jia, Y. Zhang, X. Zhang, Specific grinding energy and surface roughness of nanoparticle jet minimum quantity lubrication in grinding, Chinese J. Aeronautics 28(2) (2015) 570-581.

[55] D. Zhang, C. Li, Y. Zhang, D. Jia, X. Zhang, Experimental research on the energy ratio coefficient and specific grinding energy in nanoparticle jet MQL grinding, Int. J. Adv. Manuf. Technol. 78 (2015) 1275-1288.

[56] S. Prabhu, B.K. Vinayagam, AFM investigation in grinding process with nanofluids using Taguchi analysis, Int. J. Adv. Manuf. Technol. 60 (2012) 149-160.

[57] P. Patil, C. Patil, Analysis of process parameters in surface grinding using single objective Taguchi and multi-objective grey relational grade, Perspect. Sci. 247 (2016) 1-3.

[58] K. ManojKumar, A. Ghosh, Synthesis of MWCNT nanofluid and evaluation of its potential besides soluble oil as micro cooling-lubrication medium in SQL grinding, Int. J. Adv. Manuf. Technol. 77 (2015) 1955-1964.

[59] Y. Wang, C. Li, Y. Zhang, M. Yang, X. Zhang, et al., Experimental evaluation on tribological performance of the wheel/workpiece interface in minimum quantity lubrication grinding with different concentrations of Al_2O_3 nanofluids, J. Clean. Prod. 142(4) (2017) 3571-3583.

[60] S. Paul, A.K. Singh, A. Ghosh, Grinding of Ti_6Al_4V under small quantity cooling lubrication environments using alumina and MWCNT nanofluids, Mater. Manuf. Process. 32(6) (2017) 608-615.

[61] M.K. Sinha, R. Madarkar, S. Ghosh, P.V. Rao, Application of eco-friendly nanofluids during grinding of Inconel 718 through small quantity lubrication, J. Clean. Prod. 141 (2017) 1359-1375.

[62] G. Liu, C. Li, Y. Zhang, M. Yang, D. Jia, et al., Process parameter optimization and experimental evaluation for nanofluid MQL in grinding Ti-6Al-4V based on grey relational analysis, Mater. Manuf. Process. 33(9) (2018) 950-963.

[63] Y. Wang, C. Li, Y. Zhang, B. Li, M. Yang, et al., Experimental evaluation of the lubrication properties of the wheel/workpiece interface in MQL grinding with different nanofluids, Tribol. Int. 99 (2016) 198-210.

[64] M. Seyedzavvar, M. Shabgard, M. Mohammad Pourfard, Investigation into the performance of eco-friendly graphite nanofluid as lubricant in MQL grinding, Machining Sci. Technol.: An Int. J. 23(4) (2019) 569-594.

[65] Y. Zhang, C. Li, D. Jia, D. Zhang, X. Zhang, Experimental evaluation of the lubrication performance of MoS_2/CNT nanofluid for minimal quantity lubrication in Ni-based alloy grinding, Int. J. Machine Tools Manuf. 99 (2015) 19-33.

[66] X. Zhang, C. Li, Y. Zhang, D. Jia, B. Li, et al., Performances of Al_2O_3/SiC hybrid nanofluids in minimum-quantity lubrication grinding, Int. J. Adv. Manuf. Technol. 86(9-12) (2016) 3427-3441.

[67] Y. Zhang, C. Li, D. Jia, B. Li, Y. Wang, et al., Experimental study on the effect of nanoparticle concentration on the lubricating property of nanofluids for MQL grinding of Ni-based alloy, Int. J. Mater. Process. Technol. 232 (2016) 100-115.

[68] F. Rabiei, A.R. Rahimi, M.J. Hadad, Performance improvement of eco-friendly MQL technique by using hybrid nanofluid and ultrasonic-assisted grinding, Int. J. Adv. Manuf. Technol. 93(1-4) (2017) 1001-1015.

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