



Application of Nanofluids in Machining Processes - A Review

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ABSTRACT

Machining is one of the largest and most widely used methods of producing segments in industries. In this way, cutting fluids play an important role in minimizing production time, cost and energy in different machining operations. In this research, at first, the role of machining in manufacturing and importance of lubrication fluids during cutting has been presented, then different machining processes have been explained and finally some issues about nanofluids have been illustrated. Moreover, influence of cutting parameters such as cutting force, surface roughness, machining temperature and environmental effects were investigated. Furthermore, some cases of utilizing nanofluids in machining operations have been reported briefly in a table. In this table some items like kinds of nanoparticle, tool and workpiece material and machining processes (grinding, turning, milling and drilling) are mentioned. Results reveal that because of suitable nanofluids characteristics, optimum utilizing of them for cooling and lubrication purpose, can be beneficial in different machining operations.

1. Introduction

Industrial development and application of new methods for improving production processes require extensive studies in various fields, especially in the machining. Manufacturers always look for higher yields and incomes. In fact, the main goal in manufacturing is to minimize production time, cost, energy and resources along with improving the function [1]. In this way cutting fluids play an important role. For this purpose, metalworking fluids, prevent from metal to metal contact and decrease internal friction [2]. In metalworking operations, the frictional resistance can be reduced by adding a lubricant between the surfaces. Lubricants separate the sliding surfaces by forming a film, and thereby reduce the frictional resistance and wearing [3]. Cooling ability of a fluid helps to control undesirable temperature of tool, workpiece and chip. Furthermore, during the process, cutting fluids can wash and remove generated chip [4]. Cutting fluids can also be used to prevent re-welding, corrosion protection, reducing the energy consumption of the machine, and increasing tool life [5].

In order to increase the performance of cutting processes, several technologies have been developed to control environmental pollution like: MQL [6], cryogenic [7], high pressure [8], solid lubrication [9]. Delivery method and nozzle position of the coolant is equally as important as the coolant and cooling technique itself [8].

Nowadays, using nanotechnology in science and industry improves yield of the different processes. Hence, in machining operations nanotechnology is used e.g. as nanofluid and coated cutting tools with nanoparticles.

Nanofluids are produced by distribution of solid nanoparticles in a base fluid like water, oil, ethylene glycol and so on. In this method, increasing the thermal conductivity factor is the main idea for improving heat transfer ability. Thermal conductivity factor of solid particles are greater than fluids, for example, copper thermal conductivity in ambient temperature is about 700 times more than water and 3000 times more than engine oil [10, 11].

Suspend nanoparticles directly affect motional and thermal characteristics of base fluid. Wide researches have been carried out on thermal characteristics of nanofluids in recent years and approximately all of them have shown remarkable improvement [12, 13]. Nanoparticles in

base fluid lead to rise in thermal conductivity, convective heat transfer coefficient and viscosity [14]. Additionally, they have unique attributes which differentiate them from usual materials. This special features result in many benefits and advantages of applying nanoparticles in industry. One of the most important applications of nanoparticles is nanofluids [12, 13].

Generally, nanofluids can be used in the most of the cryogenic systems, heat transfer and lubrication applications such as developing the performance of vehicles (in radiator and engine oil) [15, 16], coolant agent in shell and tube heat exchangers [14], cooling computer chips [17], etc.

Current study focuses on the utilizing of nanofluids as coolant and lubricant and their influence on cutting parameters in various machining processes (grinding, turning, milling and drilling). Finally, a brief review has been done on a number of published papers by different researchers.

2. Machining Processes

In this part, four machining operations which Nanofluid research mostly has been conducted have been explained, and in the next section, the effect of using nanofluid on machining parameters was evaluated.

2.1 Grinding

Grinding is widely used as the finishing machining process for components that require smooth surfaces and precise tolerances [18]. In grinding research, usually controlling the high workpiece- tool temperature is a considerable problem. The heat generated by the oxidation and metallurgical transformation can affect the quality of surface negatively [19]. Cooling and lubrication are two necessary agents to protect the workpiece and wheel from burning, phase transformations, undesirable residual tensile stresses, thermal distortion and inaccuracies [20]. Cutting fluids beside suitable cooling characteristics should have less operator and environmental hazards [18]. Approximately 85% of lubricants being used around the world are petroleum-based oils. Enormous use of these oils created many negative effects on environment e.g. water pollution, soil pollution and it is also reported that about 80% of all occupational diseases of operators were due to contact with cutting fluids [21]. Researches show that nanofluids in addition to less operator and environmental hazards have higher thermal conductivity and convection heat transfer factor [22]. Fig. 1 shows grinding process and its cooling system.

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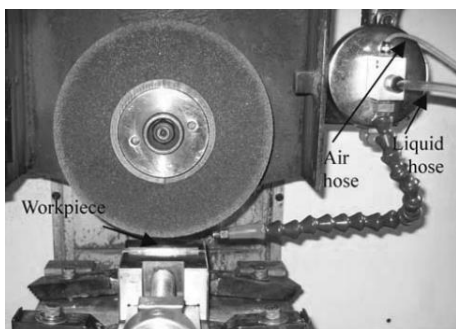


Fig. 1 Image of grinding process

2.2 Turning

Turning is one of the most fundamental processes in manufacturing industries [23]. This method widely is used for producing round shape workpieces such as shafts, pins, and threads. In this process, stationary tool is moved axially along a rotating workpiece and remove excess material in form of chip [5]. Owing to continuous contact between tool and workpiece, generated heat in this operation is very high and should carry away from cutting zone by using an appropriate coolant. Hence, cooling and lubricating continuously exert to the tool-workpiece interface [24]. Generally, due to high friction, lubricating action is necessary at low cutting speed, and cooling is more important at higher cutting speed because of large increase in generated heat during machining [25]. Fig. 2 shows turning operation.

Cutting parameters such as feed rate, cutting speed, depth of cut and workpiece and tool material effect produced part and energy consumption of machine tool [26]. Overall, optimum condition that has both excellent surface finished and lower power consumption for turning is combination of high cutting speed, low depth of cut and feed rate and finally proper cutting fluid [27]. Various metalworking fluids (petrol base, vegetable and synthetic oils) have been evaluated and in recent years utilizing nanofluids particularly in investigations and researches are very prevalent [28, 29].



Fig. 2 Image of turning operation



Fig. 3 Image of milling process

2.3 Milling

Milling includes chip removal operation with rotational and multi teeth tool on fixed workpiece. Milling is used for wide variety of parts specifically in molding. In this operation table has forward movement and tool has a rotational motion. Each tooth is in contact with the workpiece

for only a short span of time and after chipping is separated from workpiece. Milling machines are divided into three groups: horizontal, vertical and universal [25]. Cutting fluids are utilized in milling operation, too [30, 31]. Different studies demonstrate that Minimum Quantity Lubrication (MQL) works extremely well for milling and exhibits longer tool life and better surface finish [5, 24]. Fig. 3 indicates milling process.

2.4 Drilling

Drilling seems to be a simple machining operation that usually use a spiral fluted tool with two or more symmetrical cutting edges together with the simplest machine tool. In this operation, material is removed by a circular motion and transports the chips out of the hole by spiral flutes [32]. This deformation accompany with heat generation and high temperature in tool tip. High temperature can burn the drill and decrease surface quality [33]. Fig. 4 is an image of drilling operation.



Fig. 4 Image of drilling operation

3. Effect of Nanofluid on Machining Parameters

In order to improve cooling and lubrication ability of a fluid, various investigations for using different nanoparticles in water base or other solvents have been conducted. Some of these investigations in recent years are summarized in Table 1.

3.1 Cutting Force

Results illustrate that nanofluid in grinding processes [18, 22, and 39], turning [28, 29], milling [31, 34] and drilling [36] cause decrease in cutting forces. This depletion refers to lubrication and cooling features of nanofluids [22]. Of course, with increase in concentration of nanoparticles up to a particular level, cutting forces decrease and more than that the forces will rise to some extent.

In Fig. 5, cutting force during grinding by MQL method (with pure water and water includes nanoparticles) have been compared with each other. According to the graph, not only the existence of nanoparticle in base fluid, but also type, size and concentration of nanoparticle are effective on cutting forces. For instance, water- Al_2O_3 nanofluid with 2.5 vol% reduces machining forces and more than 4 vol% leads to increase in forces. This event is due to forming a dense and hard slurry layer in high concentrations of Al_2O_3 (4 vol%), therefore, grinding forces will increase [18].

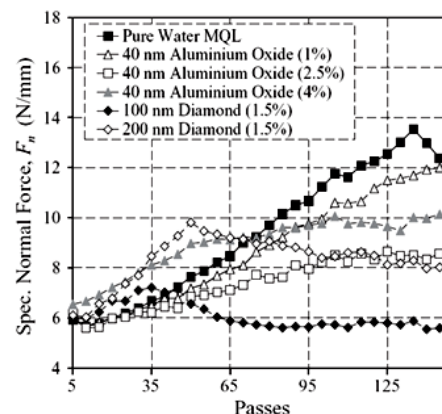


Fig. 5 Effect of nanofluids on the cutting force during grinding [18].

Table 1 Report of various articles about nanofluids as metalworking fluid

No.	Operation	Cooling Method*	Type of Nps	Base fluid	Tool	workpiece	Investigated parameters	Ref.
1	Facing operation	Wet	CuO	- **	Uncoated carbide tool	AISI 1040	- Tool wear, - Cutting temperature	[30]
2	Milling	MQL	MoS ₂	ECOCUT HSG 905S neat cutting oil	Tungsten carbide	Al 6061-T6 alloy	- Cutting temperature - Surface roughness, - Cutting forces	[31]
3	Micro milling	Wet	Graphite Nano platelet	Distilled water	Uncoated micro-grain carbide	H13 Steel	- Cutting forces, - Surface roughness	[34]
4	Milling	Wet	Copper Nano particle	Water soluble oil	Carbide tool	St37	- Cutting temperature - Surface roughness	[35]
5	Micro drilling	MQL	Diamond	- Paraffin oil - Vegetable oil	Uncoated carbide twist drill	Aluminum6061	- Number of drilled holes - Drilling torques, - Thrust forces	[36]
6	Grinding	MQL	Al ₂ O ₃ and Diamond	Water	Al ₂ O ₃ grinding wheel	Cast iron	- Grinding temperature -Surface roughness - Grinding force, -G-ratio	[18]
7	Grinding	Wet	Al ₂ O ₃	Emulsifier TRIM E709	Al ₂ O ₃ grinding wheel	EN-31 Steel	- Grinding temperature - Surface roughness	[20]
8	Grinding	MQL	Al ₂ O ₃	Water	SiC grinding wheel	Ti-6Al-4V alloy	- Surface roughness, - Grinding force	[22]
9	Grinding	- Nano coolant, -Conventional coolant	Zinc Oxide	Water	Al ₂ O ₃ grinding wheel	Ductile Cast Iron	- Optimizing cutting parameters such as table speed, depth of cut - Tool wear, - G-ratio	[37]
10	Micro Grinding	MQL	Al ₂ O ₃ and Diamond	Paraffin oil	Vitrified CBN	SK-41C tool steel	- Surface roughness, - Grinding force	[38]
11	Grinding	MQL	Al ₂ O ₃	Water	White aluminum oxide grinding wheel	AISI 52100	- Grinding temperature - Surface roughness, - Grinding forces, - Surface morphology	[39]
12	Grinding	MQL	Al ₂ O ₃	Deionized water	White aluminum oxide grinding wheel	hardened AISI 52100	- Grinding temperature - Surface roughness, - Grinding force	[40]
13	Grinding	Wet and ELID method	CNT	Water-soluble oil	CBN Diamond bonded	glass	- Surface roughness - Morphology and micro crack observation	[41]
14	Grinding	Wet	CNT	SAE20W40 oil	Vitrified alumina	AISI D2 tool steel	- Surface roughness	[42]
15	Grinding	MQL	Al ₂ O ₃	Water	-	-	-The effect of ultra-sonic vibration, Concentration of fluid and pH on stability of Nanofluid	[43]
16	Grinding	MQL	Al ₂ O ₃	Water	White aluminum oxide grinding wheel	Hardened AISI 52100	- Grinding temperature - Surface roughness, - Grinding force, - Grinding force ratio	[44]
17	Grinding	MQL	Al ₂ O ₃	Water	Ceramic bond aluminum oxide	AISI 52100	- Heat transfer coefficient analysis - Grinding temperature	[45]
18	Grinding	MQL	Nano-Diamond	Paraffin oil	Vitrified CBN	SK-41C tool steel	- Surface roughness, - Grinding force	[46]
19	Grinding	Wet	SiO ₂	Water	-	Ductile cast iron	- Material removal rate (MRR) - Surface roughness	[47]
20	Turning	Wet	Nano boric acid	Coconut oil	Carbide tool (SNMG)	AISI 304 Austenitic Stainless Steel	- Cutting temperature - Surface roughness, - Tool wear	[23]
21	Turning	MQL	Al ₂ O ₃	Vegetable oil	Coated carbide cutting tool	Inconel 600 alloy	- Cutting temperature - Surface roughness, - Tool wear	[28]
22	Turning	MQL	Graphite	Water soluble oil	- HSS - carbide tool	AISI 1040	- Average chip–tool interface Temperature, - Tool wear - Cutting forces	[29]
23	Turning	Wet	CuO	Water soluble oil	DNMG 150604-QM	AISI 4340	- Cutting forces, - Surface roughness	[48]
24	Turning	MQL	CuO	-	-Cemented carbide insert-	HSS AISI 1040	- Workpiece temperature	[49]
25	Turning	Wet	Nano Boric acid	- SAE40 oil - Coconut oil	Cemented carbide tool (SNMG)	AISI 1040	-Cutting temperature - Surface roughness, - Tool flank wear	[50]
26	Turning	Wet	AgNO ₃	Sodium borohydride	HSS	Mild steel	- Cutting force, - Surface roughness - Tool temperature	[51]
27	Turning	MQL	CNT	-	- HSS -Cemented carbide tools	AISI 1040	- Cutting temperature - Surface roughness, - Tool wear - Cutting force	[52]
28	Turning	MQL	Nano graphite	Water soluble oil	- HSS -Cemented carbide tools	AISI 1040	- Cutting temperature - Surface roughness, - Tool wear - Cutting force	[53]
29	Turning	MQL	MWCNT	Coconut oil	Carbide tool insert	Martensitic Stainless Steel	- Cutting temperature - Surface roughness	[54]
30	Turning	MQL	MWCNT	-	Multi-layered TiN top-coated insert	AISI 1040	- Cutting temperature - Finite, element analyses (FEAs)	[55]
31	Hobbing	Conventional lubrication	Al ₂ O ₃	25W-50 oil	P6M5K5 steel with TiN top-coated	DIN1.7131	- Surface roughness	[56]

3.2 Surface Roughness

Quality of machined surface when nanofluid is applied as coolant always is better than dry condition or other conventional fluids. The reason is more efficient lubricating, decrease in machining forces, depletion in friction and higher heat transfer coefficient [18] due to more heat extraction from cutting zone that cause decrease in micro crack pressure and workpiece temperature so improvement in surface finished [20]. In the bar chart of Fig. 6 surface roughness of workpiece during turning operation with Al_2O_3 nanofluid (with different volume concentrations), MQL and dry has compared with each other. It seems that, if nanofluids apply properly surface roughness will decline. Similar results are seen in other researches with different nanofluids and machining conditions [22, 28, 38, 51].

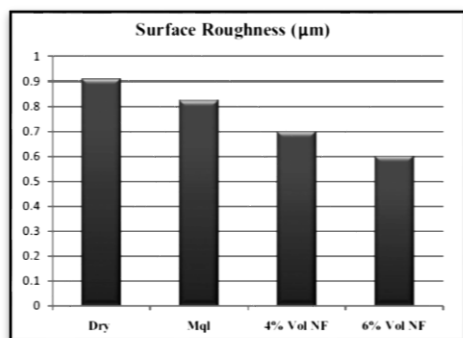


Fig. 6 Effect of nanofluids on the workpiece surface roughness [28].

3.3 Machining Temperature

Difference between using nanofluid (include MWCNT) as metalworking fluid and other conditions in turning are shown in Fig. 7. Nanofluids have better heat transfer features (especially higher thermal conductivity) and show wide influence on workpiece and tool temperature [39, 40]. Moreover, nanofluids with reduction in friction between tool and workpiece lead to lower heat generation [50, 51].

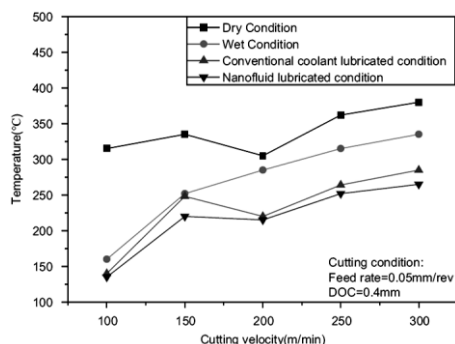


Fig. 7 Nanofluids effect on machining temperature [55].

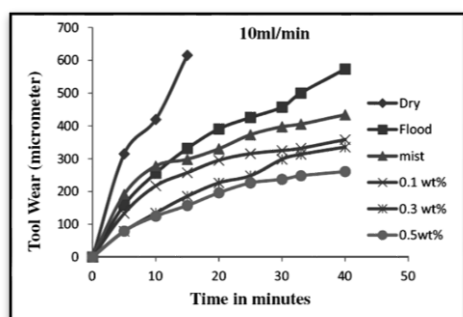


Fig. 8 Different fluids in machining process and its effect on tool wear workpiece [29].

3.4 Tool Wear

Tool wear is another important parameter which influences directly the final product quality, the machine tool performance, and tool life [37]. Tool wear is the agent of tool failure during cutting and, totally, friction and wear of cutting tools often detrimentally limit the performance of cutting processes [4]. Several reasons cause tool wear; the most significant ones

are: abrasion, adhesion and diffusion. Adhesion and diffusion occur at high tool-chip interface temperature [57]. It should be noted that tool wear effects economic of machining and early wear cause uneconomic machining operation. Studies illustrate that nanofluids owing to excellent cooling abilities and suitable lubricity, significantly reduce the rate of tool abrasion [23, 30, 37, 53]. Fig. 8 reveals the influence of oil-graphic nanofluid on tool wear in comparison with other situations.

3.5 Environmental Aspects

Machine operators are affected by destructive effects such as skin and breathing problems caused by the presence of some ingredients like chlorinated paraffin in extreme pressures (EPs) and other chemical additives in conventional cutting fluids [58, 59]. Used oil contain higher amount of halogens, especially chlorine are treated as special waste causing extremely high costs of disposal [3]. Furthermore, new cooling methods have their own problem. For instance, although MQL is presented as a friendly environment cooling technique, gas pressure evaporates and distributes some volume of cutting fluid in the air which could be harmful for machine operators so MQL does not guarantee operators from respiratory problems [2]. Nanofluid with MQL is an appropriate method for reducing environmental and operator hazards [38]. However, Limited investigations have been conducted on environmental aspects of application of nanoparticles in cutting fluids but it seems that according to anti-bacterial features of nanoparticles, they are effective in declining environmental problems [46].

4. Difficulties of Applying Nanofluids in Machining

Nanofluids differ with simple solid-liquid mixtures. Some special conditions in nanofluids are required, such as uniform and stable suspension, low clustering of particles, etc. To achieve these special conditions different ways are used. The main problem for preparing of a nanofluid is its clustering. For instance, to achieve the mentioned properties, changing in pH of solution suspension, using of surfactants, disperser, or vibrators can be used [11]. Moreover, cost of nanoparticles and preventing them from sedimentation are two other issues that should take into account.

5. Conclusion

In current study, first of all, various machining processes and nanofluids were introduced and then, effect of nanofluids on cutting parameters (cutting forces, surface roughness, tool-workpiece temperature, tool wear and environmental aspects) were reviewed. Present analysis illustrate that not only using nanofluids influence on machining parameters but also type of nanoparticle and base fluid, size of nanoparticle and concentration of particles in base fluid are important too. Results show if they applied properly, due to change in lubrication trait, physical characteristics (viscosity, thermal conductivity, density and thermal capacity) better heat transfer rate will be observed. In conclusion, utilizing nanofluids as coolant and lubricant lead to lower tool temperature, tool wear, higher surface quality and less environmental dangers. However, high cost of nanoparticles, need for particular devices, clustering and sediment are negative aspects of nanofluids applications in metalworking operations.

References

- [1] R. Neugebauer, W. Drossel, R. Wertheim, C. Hochmuth, M. Dix, Resource and energy efficiency in machining using high-performance and hybrid processes, *Procedia CIRP* 1 (2012) 3-16.
- [2] Y. Shokoohi, E. Khosrojerdi, B.H. Rassolian Shiadhi, Machining and ecological effects of a new developed cutting fluid in combination with different cooling techniques on turning operation, *J. of Cleaner Prod.* 94 (2015) 330-339.
- [3] W.J. Bartz, Ecological and environmental aspects of cutting fluids, *Lubrication Eng. Illinois* 57 (2001) 13-16.
- [4] K. Weinert, I. Inasaki, J. Sutherland, T. Wakabayashi, Dry machining and minimum quantity lubrication, *CIRP Annals-Manuf. Tech.* 53 (2004) 511-537.
- [5] J.P. Byers, *Metalworking fluids*, CRC Press, USA, 2012.
- [6] L. Yan, S. Yuan, Q. Liu, Influence of minimum quantity lubrication parameters on tool wear and surface roughness in milling of forged steel, *Chin. J. Mech. Eng.* 25 (2012) 419-429.
- [7] A.A. Khan, M.I. Ahmed, Improving tool life using cryogenic cooling, *J. Mat. Proc. Tech.* 196 (2008) 149-154.
- [8] M. Bermingham, S. Palanisamy, D. Kent, M. Dargusch, A comparison of cryogenic and high pressure emulsion cooling technologies on tool life and chip morphology in Ti-6Al-4V cutting, *J. Mat. Proc. Tech.* 212 (2012) 752-765.
- [9] P. Vamsi Krishna, D. Nageswara Rao, Performance evaluation of solid lubricants in terms of machining parameters in turning, *Int. J. Machine Tools Manuf.* 48 (2008) 1131-1137.

- [10] K.V. Wong, M.J. Castillo, Heat transfer mechanisms and clustering in nanofluids, *Adv. Mech. Eng.* 2 (2010) 1-9.
- [11] E. Shekarian, A.H. Tarighaleslami, F. Khodaverdi, Review of effective parameters on the nanofluid thermal conductivity, *J. Middle East App. Sci. Tech.* 15 (2014) 776-780.
- [12] X. Li, D. Zhu, X. Wang, N. Wang, J. Gao, H. Li, Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H₂O nanofluids, *Thermochimica Acta.* 469 (2008) 98-103.
- [13] S. Choi, Z. Zhang, W. Yu, F. Lockwood, E. Grulke, Anomalous thermal conductivity enhancement in nanotube suspensions, *App. Phys. Lett.* 79 (2001) 2252-2254.
- [14] M.R. Jafari Nasr, E. Shekarian, A.H. Tarighaleslami, F. Khodaverdi, M. Badini Pourazar, The impact of application of heat transfer enhancement technologies on design of shell and tube heat exchangers, *Iran. J. Chem. Eng.* 80 (2015) 64-74.
- [15] S. Zeinali Heris, Optimization of truck fuel consumption using new fluids in truck radiator, First National conf. on energy opt. Tehran, Iran, 2007.
- [16] S. Zeinali Heris, Study on nanofluid effect on performance improvement of vehicles, *Iran. Chem. Eng. J.* 7 (2008) 12-28.
- [17] S. Zeinali Heris, A. Sheikhi, A study on nanofluids to cooling of computer chips, *Mech. Eng. J.* 18 (2009) 54-61.
- [18] B. Shen, A.J. Shih, S.C. Tung, Application of nanofluids in minimum quantity lubrication grinding, *Trib. Trans.* 51 (2008) 730-737.
- [19] J. Sanchez, I. Pombo, R. Alberdi, B. Izquierdo, N. Ortega, S. Plaza, J. Martinez-Toledano, Machining evaluation of a hybrid MQL-CO₂ grinding technology, *J. Clean. Prod.* 18 (2010) 1840-1849.
- [20] V. Vasu, K.M. Kumar, Analysis of nanofluids as cutting fluid in grinding EN-31 steel, *Nano-Micro Lett.* 3 (2011) 209-214.
- [21] Y.M. Shashidhara, S.R. Jayaram, Vegetable oils as a potential cutting fluid—an evolution, *Trib. Int.* 43 (2010) 1073-1081.
- [22] D. Setti, S. Ghosh, P.V. Rao, Application of nano cutting fluid under minimum quantity lubrication (MQL) technique to improve grinding of Ti-6Al-4V alloy, *Proceedings of World Academy of Science, Engg. Tech.* 70 (2012) 512-516.
- [23] K. Sodavadia, A. Makwana, Experimental investigation on the performance of coconut oil based nano fluid as lubricants during turning of AISI 304 austenitic stainless steel, *Int. J. Adv. Mech. Eng.* 4 (2014) 55-60.
- [24] S. Lawal, I. Choudhury, Y. Nukman, Application of vegetable oil-based metalworking fluids in machining ferrous metals—a review, *Int. J. Mach. Tools Man.* 52 (2012) 1-12.
- [25] M.R. Razfar, Principles of machining, Amirkabir University of technology press, Tehran, Iran, 2010.
- [26] J. Ghani, I. Choudhury, H. Hassan, Application of Taguchi method in the optimization of end milling parameters, *J. Mat. Proc. Tech.* 145 (2004) 84-92.
- [27] D. Fratila, C. Caizar, Application of Taguchi method to selection of optimal lubrication and cutting conditions in face milling of AlMg³⁺, *J. Clean. Prod.* 19 (2011) 640-645.
- [28] V. Vasu, G.P.K. Reddy, Effect of minimum quantity lubrication with Al₂O₃ nanoparticles on surface roughness, tool wear and temperature dissipation in machining Inconel 600 alloy, *Proceedings of the Institution of Mechanical Engineers, Part N: Jour. Nanoeng. Nanosys.* 225 (2011) 3-16.
- [29] M. Amrita, R. Srikant, A. Sitaramaraju, M. Prasad, P.V. Krishna, Experimental investigations on influence of mist cooling using nanofluids on machining parameters in turning AISI 1040 steel, *Proc. Ins. Mech. Eng., Part J: J. Eng. Trib.* 227 (2013) 1334-1346.
- [30] R. Srikant, D. Rao, M. Subrahmanyam, V.P. Krishna, Applicability of cutting fluids with nanoparticle inclusion as coolants in machining, *Proc. Ins. Mech. Eng., Part J: J. Eng. Trib.* 223 (2009) 221-225.
- [31] B. Rahmati, A.A. Sarhan, M. Sayuti, Investigating the optimum molybdenum disulfide (MoS₂) nanolubrication parameters in CNC milling of AL6061-T6 alloy, *Int. J. Adv. Man. Tech.* 70 (2014) 1143-1155.
- [32] Gh. Alinejad, M. Ghafari, Principles of universal machining machine tool, Babol University Technology press, Babol, Iran, 2011.
- [33] A. Shokrani, V. Dhokia, P. Muñoz-Escalona, S. Newman, State-of-the-art cryogenic machining and processing, *Int. J. Com. Integrated Man.* 26 (2013) 616-648.
- [34] A. Marcon, S. Melkote, K. Kalaitzidou, D. Debra, An experimental evaluation of graphite nanoplatelet based lubricant in micro-milling, *CIRP Ann. Man. Tech.* 59 (2010) 141-144.
- [35] J.B. Dahmus, T.G. Gutowski, An environmental analysis of machining, in *ASME 2004 International Mechanical Engineering Congress and Exposition*, American Society of Mechanical Engineers, 2004. (BOOK or JOURNAL (give VOLUME and ISSUE)).
- [36] J.S. Nam, P.H. Lee, S.W. Lee, Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication, *Int. J. Mach. Tools Man.* 51 (2011) 649-652.
- [37] M. Rahman, K. Kadirgama, Performance of Water-Based Zinc Oxide Nanoparticle Coolant during Abrasive Grinding of Ductile Cast Iron, *J. Nanoparticles* 2014 (2014) 1-7.
- [38] P.H. Lee, J.S. Nam, C. Li, S.W. Lee, An experimental study on micro-grinding process with nanofluid minimum quantity lubrication (MQL), *Int. J. Precision Eng. Man.* 13 (2012) 331-338.
- [39] C. Mao, X. Tang, H. Zou, X. Huang, Z. Zhou, Investigation of grinding characteristic using nanofluid minimum quantity lubrication, *Int. J. Precision Eng. Man.* 13 (2012) 1745-1752.
- [40] 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. Man. Tech.* 64 (2013) 1791-1799.
- [41] S. Prabhu, B. Vinayagam, Analysis of surface characteristics by electrolytic in-process dressing (ELID) technique for grinding process using single wall carbon nano tube-based nanofluids, *Arab. J. Sci. Eng.* 38 (2013) 1169-1178.
- [42] S. Prabhu, B. Vinayagam, Nano surface generation of grinding process using carbon nano tubes, *Sadhana* 35 (2010) 747-760.
- [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. Man. Tech.* 71 (2014) 2073-2081.
- [44] C. Mao, J. Zhang, Y. Huang, H. Zou, X. Huang, Z. Zhou, Investigation on the effect of nanofluid parameters on MQL grinding, *Mat. Man. Proc.* 28 (2013) 436-442.
- [45] C. Mao, H. Zou, Y. Huang, Y. Li, Z. Zhou, Analysis of heat transfer coefficient on workpiece surface during minimum quantity lubricant grinding, *Int. J. Adv. Man. Tech.* 66 (2013) 363-370.
- [46] P.H. Lee, T.S. Nam, C. Li, S.W. Lee, Environmentally-friendly nano-fluid minimum quantity lubrication (MQL) meso-scale grinding process using nano-diamond particles, in *Manufacturing Automation (ICMA)*, International Conference on IEEE, The University of Hong Kong, China, 2010.
- [47] M.M. Rahman, K. Kadirgama, A. Aziz, Artificial neural network modeling of grinding of ductile cast iron using water based SiO₂ Nanocoolant, *Int. J. Automotive Mech. Eng.* 9 (2013) 1649-1661.
- [48] M.R. Shabgard, M. Jafarian Zenjanab, R. Azarafza, Experimental study on the influence of CuO nanofluid on surface roughness and machining force in turning of AISI 4340 steel, *Modares Mech. Eng.* 14 (2014) 27-33.
- [49] D.N. Rao, R. Srikant, P.V. Krishna, M. Subrahmanyam, Nano cutting fluids in minimum quantity lubrication, *International Multi-Conference on Engineering and Technological Innovation (IMETI 2008)*, Orlando, Florida, USA, 2008.
- [50] P. Vamsi Krishna, R. Srikant, D. Nageswara Rao, Experimental investigation on the performance of nanoboric acid suspensions in SAE-40 and coconut oil during turning of AISI 1040 steel, *Int. J. Mach. Tools Man.* 50 (2010) 911-916.
- [51] N. Saravanakumar, L. Prabu, M. Karthik, A. Rajamanickam, Experimental analysis on cutting fluid dispersed with silver nano particles, *J. Mech. Sci. Tech.* 28 (2014) 645-651.
- [52] S.N. Rao, B. Satyanarayana, K. Venkatasubbaiah, Experimental estimation of tool wear and cutting temperatures in MQL using cutting fluids with CNT inclusion, *Int. J. Eng. Sci. Tech.* 3 (2011) 2928-2931.
- [53] M. Prasad, R. Srikant, Performance evaluation of nano graphite inclusions in cutting fluids with MQL technique in turning of AISI 1040 Steel, *Int. J. Res. Eng. Tech.* 2 (2013) 381-393.
- [54] M.S. Kumar, K.S. Kumar, An investigation multi walled carbon nanotubes based nano cutting fluids in turning of martensitic stainless steel by using Taguchi and Anova analysis, *IOSR J. Mech. Civil Eng.* 7 (2010) 8-15.
- [55] S. Roy, A. Ghosh, High-speed turning of AISI 4140 steel by multi-layered TiN top-coated insert with minimum quantity lubrication technology and assessment of near tool-tip temperature using infrared thermography, *Proc. Ins. Mech. Eng., Part B: J. Eng. Man.* 228(9) (2014) 1058-1067.
- [56] S. Poorazari, Effect of alumina nanoparticles on the surface finish of the gear lubricant oil contains the simple production process Hobbing, *Mech. Eng.* 93 (2014) 38-47.
- [57] M. Nouari, G. List, F. Girot, D. Coupard, Experimental analysis and optimization of tool wear in dry machining of aluminum alloys, *Wear.* 255 (2003) 1359-1368.
- [58] E. Kuram, B. Ozelcik, M.H. Cetin, E. Demirbas, S. Askin, Effects of blended vegetable-based cutting fluids with extreme pressure on tool wear and force components in turning of Al 7075-T6, *Lubrication Sci.* 25 (2013) 39-52.
- [59] M.H. Cetin, B. Ozelcik, E. Kuram, E. Demirbas, Evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning of AISI 304L by Taguchi method, *J. Cleaner Prod.* 19 (2011) 2049-2056.