MODELLING AND VERIFICATION OF TiO_2/ZnO/EGW NANO COOLANT ON THE TiN MILLING TOOL PERFORMANCE

LINGENTHIRAN A/L SAMYLINGAM

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR’S DECLARATION

We hereby declare that we have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of Doctor of Philosophy.

____

(Supervisor’s Signature)

Full Name : DR. KUMARAN A/L KADIRGAMA

Position : ASSOCIATE PROFESSOR

Date :

____

(Co-Supervisor’s Signature)

Full Name : Dr. MD MUSTAFIZUR RAHMAN

Position : PROFESSOR

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : LINGENTHIRAN A/L SAMYLINGAM

ID Number : PMM16001

Date :

MODELLING AND VERIFICATION OF TiO_2/ZnO/EGW NANO COOLANT ON THE TiN MILLING TOOL PERFORMANCE

LINGENTHIRAN A/L SAMYLINGAM

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

APRIL 2019

ACKNOWLEDGEMENTS

First and foremost, the deepest sense of gratitude to my mother and the God, who guide and gave me the strength and ability to complete this research successfully. Infinite thanks I brace upon my mother and Him. I would like to express my sincere gratitude to my supervisor Associate Prof. Dr. Kumaran Kadirgama and Associate Prof. Dr. Devarajan for their continuous guidance, support and encouragement, which gave me huge inspiration in accomplishing this research. Their supports encourage me to become confident and competent person to work individually as well as in group.

Not forgot to thank the panels who critics the outcome of this research besides providing some suggestions to improve the discussion and conclusion as well. I would also like to express my deepest appreciation to my family whom always support and motivate me to complete this research and thesis. I also owe a depth of gratitude to my university friends Yoges, Arvind and Mohanesen who shared their knowledge and ideas that lead to the completion of this thesis.

Finally, to individuals who has involved neither directly nor indirectly in succession of this research with thesis writing. Indeed I could never adequately express my indebtedness to all of them. Hope all of them stay continue support me and give confidence in my efforts in future. Thank you

ABSTRAK

Kekasaran permukaan, hayat alat dan mekanisme haus memainkan peranan utama untuk mengoptimumkan prestasi alat dalam proses pemesinan. Memperkenalkan nanopartikel menjadi penyejuk telah terbukti dapat meningkatkan pengoptimuman prestasi alat. Kajian ini telah dijalankan untuk mengkaji kesan penyejuk berasaskan zarah nano (TiO_2/EGW) dan penyejuk berasaskan zarah nano hibrid (TiO_2/ZnO/EGW) pada penambahbaikan alat Titanium Nitrat (TiN). Persamaan model linear kekasaran permukaan dan hayat alat dibangunkan menggunakan kaedah permukaan respon (RSM). Daripada RSM, parameter yang paling penting adalah kadar suapan, maka kedalaman paksi dipotong dan akhirnya memotong kelajuan. Operasi pengilangan akhir dengan menggunakan penyejuk berasaskan zarah hibrid nano (TiO_2/ZnO/EGW) memperoleh kekasaran permukaan yang lebih rendah dan hayat alat yang tinggi. Operasi pengilangan akhir dengan menggunakan penyejuk berasaskan zarah nano (TiO_2/EGW) dan penyejuk larut air (EGW). Penggantian berasaskan zarah hibrid nano (TiO_2/ZnO/EGW) menurunkan kekasaran permukaan 38% daripada EGW dan 17% daripada (TiO_2/EGW). Menurut ISO 8688-2-1989 (E) kriteria pemakaian untuk penggilingan dengan penyejuk larut air mencapai purata jarak pemotongan 885 mm. Jarak pemotongan untuk penggilingan dengan penyejuk berasaskan zarah nano (TiO_2/EGW) dilakukan dengan lebih baik pada jarak 55.55% untuk mencapai kriteria pemakaian pada purata jarak pemotongan 1450 mm. Sementara itu, jarak pemotongan untuk penggilingan dengan penyejuk berasaskan zarah hibrid nano (TiO_2/ZnO/EGW) bertindak lebih baik pada 80% untuk mencapai kriteria pemakaian pada jarak pemotongan purata 1585 mm. Nanofluid hibrid dan kekonduksian terma nanofluid tunggal lebih tinggi daripada EGW 13% dan 11%. Nanofluid dan kapasiti tunggal khusus nanofluid tunggal lebih tinggi daripada EGW kira-kira 30% dan 22%. Model antara pemotongan parameter dan tindak balas untuk kekasaran permukaan dan alat alat telah ditubuhkan. Untuk kekasaran permukaan kesilapan untuk nilai yang diramalkan berbanding nilai sebenar ialah 7%. Sementara itu, untuk kegunaan alat kesilapan untuk nilai ramalan berbanding nilai sebenar adalah 11%. Kelajuan pemotongan yang tinggi, kadar suapan rendah dan kedalaman paksi rendah akan memberikan kekasaran permukaan halus. Kelajuan pemotongan rendah dan kadar suapan rendah akan meningkatkan hayat alat. Pengoptimuman pelbagai objektif bagi parameter telah ditubuhkan. Di mana kelajuan pemotongan optimum = 2166 rpm, Feedrate = 0.02 mm/tooth dan kedalaman paksi dipotong = 0.1 mm yang menghasilkan hayat alat = 37.07 min dan kekasaran permukaan = 0.1452 µm. Keutamaan adalah hampir 1 (0.713), dan ia memenuhi matlamat pengoptimuman.

ABSTRACT

Surface roughness, tool life and wear mechanism plays major role for optimizing tool performance in machining process. Introducing nanoparticles into coolant has been proved to improve the optimization of the tool performance. This research has conducted to study the effect of nano particle based coolant (TiO_2/EGW) and hybrid nano particle based coolant (TiO_2/ZnO/EGW) on the Titanium Nitrate (TiN) tool enhancement. The linear model equation of surface roughness and tool life are developed using response surface methodology (RSM). From the RSM the most significant parameter is feed rate then axial depth of cut and lastly cutting speed. The end-milling operation by using hybrid nano particle based coolant (TiO_2/ZnO/EGW) obtains lower surface roughness and high tool life. End-milling operation by using nano particle based coolant (TiO_2/EGW) and water soluble coolant (EGW). Hybrid nano particle based coolant (TiO_2/ZnO/EGW) lower the surface roughness 38% than EGW and 17% than TiO_2/EGW. According to ISO 8688-2-1989 (E) the wear criteria for milling with water soluble coolant reached at average of cutting distance of 885 mm. Cutting distance for milling with nano particle based coolant (TiO_2/EGW) performed better at distance of 55.55% to reach the wear criteria at average cutting distance of 1450 mm. Meanwhile for the cutting distance for milling with hybrid nano particle based coolant (TiO_2/ZnO/EGW) perform better at 80% to reach the wear criteria at average cutting distance of 1585 mm. Hybrid nanofluid and single nanofluid's thermal conductivity higher than EGW 13% and 11%.Hybrid nanofluid and single nanofluid specific heat capacity higher than EGW about 30% and 22%. The models between cutting parameters and response for surface roughness and tool life have been established. For surface roughness the error for the predicted value vs the actual value is 7%. Meanwhile for tool life the error for the predicted value vs the actual value is 11%. High cutting speed, low feed rate and low axial depth will provide fine surface roughness. Low cutting speed and Low feed rate will increase the tool life. The multi objective optimization for the parameters has been established. Where the optimum cutting speed= 2166 rpm, Feedrate = 0.02 mm/tooth and axial depth of cut = 0.1 mm which produces tool life = 37.07 min and surface roughness = 0.1452 µm. The desirability is nearly 1 (0.713), and it satisfy the goal of the optimization.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

R_a	Roughness Average
R_z	Roughness Depth
k	Thermal Conductivity of Nanofluid
k_0	Thermal Conductivity of based liquid
L	Sampling Length
Y	Ordinate of the Profile Curve
K	Kelvin
γ	tool rake angle
l_c	tool-chip contact distance
l_s	shear plane length
a_c	undeformed chip thickness
a_o	deformed chip thickness
ϕ	shear angle
α	clearance angle
V	Volts
ω	weight percentage
φ	volume percentage
F_m	Feed Rate in mm/min
TL	Total Length to reach Flank Wear Criterion 0.3mm

LIST OF ABBREVIATION

TiO_2	Titanium Oxide
SiO_2	Silicon Oxide
ZnO	Zinc Oxide
TiN	Titanium Nitrite
BUE	Build- Up- Edge
CVD	Chemical Vapor Deposition
RSM	Response Surface Method
SEM	Scanning Electron Microscope
EG	Ethylene Glycol
TEM	Transmission Electron Microscope
Al_2O_3	Aluminum Oxide
CrN	Chromium Nitride
Cr_2O_3	Chromium(iii) oxide
DOE	Design of Experiment
CCD	Central Composite Design
BBD	Box-Behnken Design
CBED	Convergent Beam Electron Diffraction
EDX	Energy Dispersive X-ray

REFERENCES

Aberoumand, S., & Jafarimoghaddam, A. (2016). Mixed convection heat transfer of nanofluids inside curved tubes: An experimental study. *Applied Thermal Engineering, 108,* 967-979.

Abou-El-Hossein, K., & Yahya, Z. (2005). High-speed end-milling of AISI 304 stainless steels using new geometrically developed carbide inserts. *Journal of materials processing technology, 162,* 596-602.

Abu-Nada, E., & Oztop, H. F. (2009). Effects of inclination angle on natural convection in enclosures filled with Cu–water nanofluid. *International Journal of Heat and Fluid Flow, 30*(4), 669-678.

Afrand, M. (2017). Experimental study on thermal conductivity of ethylene glycol containing hybrid nano-additives and development of a new correlation. *Applied Thermal Engineering, 110,* 1111-1119.

Afrand, M., Toghraie, D., & Ruhani, B. (2016). Effects of temperature and nanoparticles concentration on rheological behavior of Fe3O4–Ag/EG hybrid nanofluid: an experimental study. *Experimental Thermal and Fluid Science, 77,* 38-44.

Alauddin, M., El Baradie, M., & Hashmi, M. (1995). Computer-aided analysis of a surface-roughness model for end milling. *Journal of materials processing technology, 55*(2), 123-127.

Alauddin, M., El Baradie, M., & Hashmi, M. (1996). Optimization of surface finish in end milling Inconel 718. *Journal of materials processing technology, 56*(1-4), 54-65.

Alauddin, M., El Baradie, M., & Hashmi, M. (1997). Prediction of tool life in end milling by response surface methodology. *Journal of materials processing technology, 71*(3), 456-465.

Altintas, Y. (2012). *Manufacturing automation: metal cutting mechanics, machine tool vibrations, and CNC design*: Cambridge university press.

Angayarkanni, S., & Philip, J. (2015). Review on thermal properties of nanofluids: Recent developments. *Advances in colloid and interface science, 225,* 146-176.

Anijdan, S. M., Madaah-Hosseini, H., & Bahrami, A. (2007). Flow stress optimization for 304 stainless steel under cold and warm compression by artificial neural network and genetic algorithm. *Materials & design, 28*(2), 609-615.

Astakhov, V. P. (1998). *Metal cutting mechanics*: CRC press.

Astakhov, V. P. (2006). *Tribology of metal cutting* (Vol. 52): Elsevier.

Atkins, A. (2003). Modelling metal cutting using modern ductile fracture mechanics: quantitative explanations for some longstanding problems. *International Journal of Mechanical Sciences, 45*(2), 373-396.

Avila, R., & Abrao, A. (2001). The effect of cutting fluids on the machining of hardened AISI 4340 steel. *Journal of Materials Processing Technology, 119*(1), 21-26.

Azmi, W., Hamid, K. A., Mamat, R., Sharma, K., & Mohamad, M. (2016). Effects of working temperature on thermo-physical properties and forced convection heat transfer of TiO 2 nanofluids in water–Ethylene glycol mixture. *Applied Thermal Engineering, 106,* 1190-1199.

Baghbanzadeh, M., Carbone, L., Cozzoli, P. D., & Kappe, C. O. (2011). Microwave-assisted synthesis of colloidal inorganic nanocrystals. *Angewandte Chemie International Edition, 50*(48), 11312-11359.

Bailey, J., Jeelani, S., & Becker, S. (1976). Surface integrity in machining AISI 4340 steel. *Journal of engineering for industry, 98*(3), 999-1006.

Balint, D., & Hutchinson, J. (2005). An analytical model of rumpling in thermal barrier coatings. *Journal of the Mechanics and Physics of Solids, 53*(4), 949-973.

Baradie, M. E. (1993). Surface roughness model for turning grey cast iron (154 BHN). *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 207*(1), 43-54.

Bawa, H. (1995). *Workshop Technology*: Tata McGraw-Hill India.

Behrens, B.-A., Doege, E., Reinsch, S., Telkamp, K., Daehndel, H., & Specker, A. (2007). Precision forging processes for high-duty automotive components. *Journal of materials processing technology, 185*(1-3), 139-146.

Benardos, P., & Vosniakos, G.-C. (2003). Predicting surface roughness in machining: a review. *International journal of machine tools and manufacture, 43*(8), 833-844.

Bjurka, E. (2012). Analyze of insert geometries, wear types and insert life in milling.

Boothroyd, G. (1988). *Fundamentals of metal machining and machine tools* (Vol. 28): Crc Press.

Boubekri, N., & Shaikh, V. (2015). Minimum quantity lubrication (MQL) in machining: Benefits and drawbacks. *Journal of Industrial and Intelligent Information, 3*(3).

Bouzid, W., Zghal, A., & Sai, L. (2004). Taguchi Method For Design Optimisation of Milled Surface Roughness. *Materials Technology, 19*(3), 159-162.

Box, G. E., & Draper, N. R. (1987). *Empirical model-building and response surfaces*: John Wiley & Sons.

Bruni, C., d'Apolito, L., Forcellese, A., Gabrielli, F., & Simoncini, M. (2008). Surface roughness modelling in finish face milling under MQL and dry cutting conditions. *International Journal of Material Forming, 1*(1), 503-506.

Budak, E. (1992). Flexible milling force model for improved surface error predictions. *Proc. 1992 Engineering system Design and Analysis, Istanbul, Turkey, 47*, 89.

Byrne, G., Dornfeld, D., & Denkena, B. (2003). Advancing cutting technology. *CIRP Annals, 52*(2), 483-507.

Chandrasekar, M., Suresh, S., & Bose, A. C. (2010). Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid. *Experimental Thermal and Fluid Science, 34*(2), 210-216.

Chen, W. (2000). Cutting forces and surface finish when machining medium hardness steel using CBN tools. *International journal of machine tools and manufacture, 40*(3), 455-466.

Chen, X., Engle, K. M., Wang, D. H., & Yu, J. Q. (2009). Palladium (II)-catalyzed C-H activation/C-C cross-coupling reactions: versatility and practicality. *Angewandte Chemie International Edition, 48*(28), 5094-5115.

Choi, S., Singer, D., & Wang, H. (1995). Developments and applications of non-Newtonian flows. *ASME FED, 66*, 99-105.

Choudhury, I., & El-Baradie, M. (1999). Machinability assessment of inconel 718 by factorial design of experiment coupled with response surface methodology. *Journal of materials processing technology, 95*(1-3), 30-39.

Cormier, M. J., Young, W. A., Johnson, J. A., & Daddona, P. E. (2011). Microprojection array having a beneficial agent containing coating. In: Google Patents.

Coromant, S. (1994). *Modern metal cutting*: Sandvik Coromant.

Das, B., Chattopadhyay, P., Upadhyay, A., Gupta, K., Mandal, M., & Karak, N. (2014). Biophysico-chemical interfacial attributes of Fe 3 O 4 decorated MWCNT nanohybrid/bio-based hyperbranched polyurethane nanocomposite: an antibacterial wound healing material with controlled drug release potential. *New Journal of Chemistry, 38*(9), 4300-4311.

Das, S. K., Choi, S. U., & Patel, H. E. (2006). Heat transfer in nanofluids—a review. *Heat transfer engineering, 27*(10), 3-19.

Davis, J. R. (1995). *ASM specialty handbook: tool materials*: ASM international.

De Oliveira, A. J., & Diniz, A. E. (2009). Tool life and tool wear in the semi-finish milling of inclined surfaces. *Journal of materials processing technology, 209*(14), 5448-5455.

Dearnley, P., & Grearson, A. (1986). Evaluation of principal wear mechanisms of cemented carbides and ceramics used for machining titanium alloy IMI 318. *Materials Science and Technology, 2*(1), 47-58.

Deshmukh, S., & Sangawar, V. (2016). One-step synthesis of polyethylene microspheres using a modified chemical route for pulmonary drug delivery. *Journal of Taibah University for Science, 10*(4), 485-489.

Dewes, R., Ng, E., Chua, K., Newton, P., & Aspinwall, D. (1999). Temperature measurement when high speed machining hardened mould/die steel. *Journal of materials processing technology, 92,* 293-301.

Dhar, N., Kamruzzaman, M., & Ahmed, M. (2006). Effect of minimum quantity lubrication (MQL) on tool wear and surface roughness in turning AISI-4340 steel. *Journal of materials processing technology, 172*(2), 299-304.

Diniz, A., & Ferreira, J. (2003). Influence of refrigeration/lubrication condition on SAE 52100 hardened steel turning at several cutting speeds. *International journal of machine tools and manufacture, 43*(3), 317-326.

Duangthongsuk, W., & Wongwises, S. (2008). Effect of thermophysical properties models on the predicting of the convective heat transfer coefficient for low concentration nanofluid. *International Communications in Heat and Mass Transfer, 35*(10), 1320-1326.

Dureja, J., Gupta, V., Sharma, V. S., & Dogra, M. (2009). Design optimisation of flank wear and surface roughness for CBN-TiN tools during dry hard turning of hot work die steel. *International Journal of Machining and Machinability of Materials, 7*(1-2), 129-147.

Eastman, J. A., Choi, S., Li, S., Yu, W., & Thompson, L. (2001). Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. *Applied physics letters, 78*(6), 718-720.

El-Khabeery, M., & Fattouh, M. (1989). Residual stress distribution caused by milling. *International journal of machine tools and manufacture, 29*(3), 391-401.

Eldem, S., & Barrow, G. (1976). Tool life in interrupted turning operations. *Isr. J. Technol., 14*(4), 172-178.

Endres, J. (2002). *The effects of corner radius on tool flank wear.* Paper presented at the Proceedings of the 2002 NSF Design, Service and Manufacturing Grantees and Research Conference, San Juan, Puerto Rico.

Epifani, M., Giannini, C., Tapfer, L., & Vasanelli, L. (2000). Sol–gel synthesis and characterization of Ag and Au nanoparticles in SiO2, TiO2, and ZrO2 thin films. *Journal of the American Ceramic Society, 83*(10), 2385-2393.

Esfe, M. H., Saedodin, S., Bahiraei, M., Toghraie, D., Mahian, O., & Wongwises, S. (2014). Thermal conductivity modeling of MgO/EG nanofluids using experimental data and artificial neural network. *Journal of Thermal Analysis and Calorimetry, 118*(1), 287-294.

Ezugwu, E., Wang, Z., & Machado, A. (1999). The machinability of nickel-based alloys: a review. *Journal of materials processing technology, 86*(1-3), 1-16.

Farkas, P. (1972). A method of coating diamond particles with metal. In: Google Patents.

Fuh, K.-H., & Wu, C.-F. (1995a). A proposed statistical model for surface quality prediction in end-milling of Al alloy. *International journal of machine tools and manufacture, 8*(35), 1187-1200.

Fuh, K.-H., & Wu, C.-F. (1995b). A residual-stress model for the milling of aluminum alloy (2014-T6). *Journal of materials processing technology, 51*(1-4), 87-105.

Furner, J. M., Yahya, N., & Duffy, M. L. (2005). Teach mathematics: Strategies to reach all students. *Intervention in school and clinic, 41*(1), 16-23.

Gautier, G., Priarone, P. C., Rizzuti, S., Settineri, L., & Tebaldo, V. (2015). A contribution on the modelling of wire electrical discharge machining of a γ-TiAl alloy. *Procedia CIRP, 31*, 203-208.

Ghadimi, A., Saidur, R., & Metselaar, H. (2011). A review of nanofluid stability properties and characterization in stationary conditions. *International Journal of Heat and Mass Transfer, 54*(17-18), 4051-4068.

Giovanola, J. H. (1988). Adiabatic shear banding under pure shear loading part i: direct observation of strain localization and energy dissipation measurements. *Mechanics of Materials, 7*(1), 59-71.

Gökkaya, H. (2010). The Effects of Machining Parameters on Cutting Forces, Surface Roughness, Built-Up Edge (BUE) and Built-Up Layer (BUL) During Machining

AA2014 (T4) Alloy. *Strojniski Vestnik/Journal of Mechanical Engineering, 56*(9).

Gorlenko, O. (1981). Assessment of surface roughness parameters and their interdependence. *Precision Engineering, 3*(2), 105-108.

Grzesik, W. (2008). *Advanced machining processes of metallic materials: theory, modelling and applications*: Elsevier.

Grzesik, W. (2009). Wear development on wiper Al2O3–TiC mixed ceramic tools in hard machining of high strength steel. *Wear, 266*(9-10), 1021-1028.

Gupta, M. K., Sood, P., & Sharma, V. S. (2016). Optimization of machining parameters and cutting fluids during nano-fluid based minimum quantity lubrication turning of titanium alloy by using evolutionary techniques. *Journal of Cleaner Production, 135*, 1276-1288.

Hadadian, M., Samiee, S., Ahmadzadeh, H., & Goharshadi, E. K. (2013). Nanofluids for heat transfer enhancement–a review. *Physical chemistry research, 1*(1), 1-33.

Harandi, S. S., Karimipour, A., Afrand, M., Akbari, M., & D'Orazio, A. (2016). An experimental study on thermal conductivity of F-MWCNTs–Fe3O4/EG hybrid nanofluid: effects of temperature and concentration. *International Communications in Heat and Mass Transfer, 76*, 171-177.

Hasegawa, M., Seireg, A., & Lindberg, R. (1976). Surface roughness model for turning. *Tribology international, 9*(6), 285-289.

Henglein, A. (1993). Physicochemical properties of small metal particles in solution:" microelectrode" reactions, chemisorption, composite metal particles, and the atom-to-metal transition. *The Journal of Physical Chemistry, 97*(21), 5457-5471.

Hill, W. J., & Hunter, W. G. (1966). A review of response surface methodology: a literature survey. *Technometrics, 8*(4), 571-590.

Hong, I., & Koo, C. H. (2005). Antibacterial properties, corrosion resistance and mechanical properties of Cu-modified SUS 304 stainless steel. *Materials Science and Engineering: A, 393*(1-2), 213-222.

Hoyle, G. (1964). Recent developments in high-speed steels. *Metallurgical Reviews, 9*(1), 49-91.

Hsien, W. L. Y. (2015). Utilisation of Vegetable Oil, Solid Lubricant, Mist Lubrication, Minimum Quantity Lubrication (MQL) in Machining. In *Towards Green Lubrication in Machining* (pp. 19-31): Springer.

Hussein, A. M., Bakar, R. A., Kadirgama, K., & Sharma, K. (2013). Experimental measurement of nanofluids thermal properties. *International Journal of Automotive and Mechanical Engineering, 7*, 850.

Inspektor, A., Oles, E., & Bauer, C. (1997). Theory and practice in diamond coated metal-cutting tools. *International Journal of Refractory Metals and Hard Materials, 15*(1-3), 49-56.

Iranidokht, V., Hamian, S., Mohammadi, N., & Shafii, M. B. (2013). Thermal conductivity of mixed nanofluids under controlled pH conditions. *International Journal of Thermal Sciences, 74*, 63-71.

Jawaid, A., Sharif, S., & Koksal, S. (2000). Evaluation of wear mechanisms of coated carbide tools when face milling titanium alloy. *Journal of materials processing technology, 99*(1-3), 266-274.

Jayal, A. D., & Balaji, A. (2009). Effects of cutting fluid application on tool wear in machining: Interactions with tool-coatings and tool surface features. *Wear, 267*(9), 1723-1730.

Kadirgama, K., Abou-El-Hossein, K., Mohammad, B., Noor, M., & Sapuan, S. (2008). Prediction of tool life by statistic method in end-milling operation. *Scientific Research and Essays, 3*(5), 180-186.

Kadirgama, K., Noor, M., & Rahman, M. (2008). Optimization of surface roughness in end milling on mould aluminium alloys (AA6061-T6) using response surface method and radian basis function network. *Jourdan Journal of Mechanical and Industrial Engineering, 2*(4).

Kakaç, S., & Pramuanjaroenkij, A. (2016). Single-phase and two-phase treatments of convective heat transfer enhancement with nanofluids–A state-of-the-art review. *International Journal of Thermal Sciences, 100*, 75-97.

Khamsehzadeh, H. (1991). *Behaviour of ceramic cutting tools when machining superalloys.* University of Warwick,

Khandekar, S., Sankar, M. R., Agnihotri, V., & Ramkumar, J. (2012). Nano-cutting fluid for enhancement of metal cutting performance. *Materials and Manufacturing Processes, 27*(9), 963-967.

Khuri, A. I., & Cornell, J. A. (1996). *Response surfaces: designs and analyses* (Vol. 152): CRC press.

Kishawy, H., & Elbestawi, M. (1998). Effects of edge preparation and cutting speed on surface integrity of die materials in hard machining. *Proc Int Mech Eng Congr Exp MED, 8*, 269-276.

Kiyak, M., & Çakır, O. (2007). Examination of machining parameters on surface roughness in EDM of tool steel. *Journal of materials processing technology, 191*(1-3), 141-144.

Kline, W., DeVor, R., & Shareef, I. (1982). The prediction of surface accuracy in end milling. *Journal of engineering for industry, 104*(3), 272-278.

Konermann, L., & Douglas, D. (1997). Acid-induced unfolding of cytochrome c at different methanol concentrations: electrospray ionization mass spectrometry specifically monitors changes in the tertiary structure. *Biochemistry, 36*(40), 12296-12302.

Koo, J., & Kleinstreuer, C. (2004). A new thermal conductivity model for nanofluids. *Journal of Nanoparticle Research, 6*(6), 577-588.

Korkut, I., Kasap, M., Ciftci, I., & Seker, U. (2004). Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel. *Materials & design, 25*(4), 303-305.

Kumar, S. A., Meenakshi, K. S., Narashimhan, B., Srikanth, S., & Arthanareeswaran, G. (2009). Synthesis and characterization of copper nanofluid by a novel one-step method. *Materials Chemistry and Physics, 113*(1), 57-62.

Lawal, S., Choudhury, I., & Nukman, Y. (2012). Application of vegetable oil-based metalworking fluids in machining ferrous metals—a review. *International Journal of Machine Tools and Manufacture, 52*(1), 1-12.

Lee, P.-H., Nam, J. S., Li, C., & Lee, S. W. (2012). An experimental study on micro-grinding process with nanofluid minimum quantity lubrication (MQL). *International Journal of Precision Engineering and Manufacturing, 13*(3), 331-338.

Lee, S., Choi, S.-S., Li, S., and, & Eastman, J. (1999). Measuring thermal conductivity of fluids containing oxide nanoparticles. *Journal of Heat transfer, 121*(2), 280-289.

Liao, Y., & Shiue, R. (1996). Carbide tool wear mechanism in turning of Inconel 718 superalloy. *Wear, 193*(1), 16-24.

Lima, J., Avila, R., Abrao, A., Faustino, M., & Davim, J. P. (2005). Hard turning: AISI 4340 high strength low alloy steel and AISI D2 cold work tool steel. *Journal of materials processing technology, 169*(3), 388-395.

Liu, C., & Barash, M. (1982). Variables governing patterns of mechanical residual stress in a machined surface. *Journal of engineering for industry, 104*(3), 257-264.

Lu, W., Wei, Z., Gu, Z.-Y., Liu, T.-F., & Park, J. (2014). Tuning the structure and function of metal–organic frameworks via linker design. *Chemical Society Reviews, 43*(16), 5561-5593.

M'Saoubi, R., Outeiro, J., Chandrasekaran, H., Dillon Jr, O., & Jawahir, I. (2008). A review of surface integrity in machining and its impact on functional performance and life of machined products. *International Journal of Sustainable Manufacturing, 1*(1-2), 203-236.

Madhesh, D., & Kalaiselvam, S. (2014). *Energy efficient hybrid nanofluids for tubular cooling applications.* Paper presented at the Applied Mechanics and Materials.

Maheshwary, P., & Nemade, K. (2015). Enhancement in heat transfer performance of ZrO2/H2O nanofluid via ultrasonication time. *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC), 3*(2), 35-37.

Manjunathaiah, J., & Endres, W. J. (2000). A new model and analysis of orthogonal machining with an edge-radiused tool. *Journal of Manufacturing Science and Engineering, 122*(3), 384-390.

Masmali, M., & Mathew, P. (2016). *Geometric Chip Analysis of Helical End Milling Based on a Variable Flow Stress Machining Theory.* Paper presented at the Proc. 6th International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia: IEOM Society International.

Matsumoto, Y., Barash, M., & Liu, C. (1986). Effect of hardness on the surface integrity of AISI 4340 steel. *Journal of engineering for industry, 108*(3), 169-175.

Matsumoto, Y., Hashimoto, F., & Lahoti, G. (1999). Surface integrity generated by precision hard turning. *CIRP Annals-Manufacturing Technology, 48*(1), 59-62.

McEachron, R., Connors, E. J., & Slutz, D. E. (1993). Multi-layer metal coated diamond abrasives with an electrolessly deposited metal layer. In: Google Patents.

Mead, R., & Pike, D. (1975). A biometrics invited paper. A review of response surface methodology from a biometric viewpoint. *Biometrics, 31*(4), 803-851.

Megatif, L., Ghozatloo, A., Arimi, A., & Shariati-Niasar, M. (2016). Investigation of laminar convective heat transfer of a novel TiO2–carbon nanotube hybrid water-based nanofluid. *Experimental Heat Transfer, 29*(1), 124-138.

Mehrali, M., Sadeghinezhad, E., Latibari, S. T., Kazi, S. N., Mehrali, M., Zubir, M. N. B. M., & Metselaar, H. S. C. (2014). Investigation of thermal conductivity and rheological properties of nanofluids containing graphene nanoplatelets. *Nanoscale research letters, 9*(1), 15.

Melkote, S., & Thangaraj, A. (1994). An enhanced end milling surface texture model including the effects of radial rake and primary relief angles. *Journal of engineering for industry, 116*(2), 166-174.

Minea, A. A. (2017). Hybrid nanofluids based on Al2O3, TiO2 and SiO2: numerical evaluation of different approaches. *International Journal of Heat and Mass Transfer, 104*, 852-860.

Mintsa, H. A., Roy, G., Nguyen, C. T., & Doucet, D. (2009). New temperature dependent thermal conductivity data for water-based nanofluids. *International Journal of Thermal Sciences, 48*(2), 363-371.

Mishra, A., & Prasad, T. (1985). Residual stresses due to a moving heat source. *International Journal of Mechanical Sciences, 27*(9), 571-581.

Mital, A., & Mehta, M. (1988). Surface finish prediction models for fine turning. *The International Journal Of Production Research, 26*(12), 1861-1876.

Montgomery, D. C. (2017). *Design and analysis of experiments*: John wiley & sons.

Munkhbayar, B., Tanshen, M. R., Jeoun, J., Chung, H., & Jeong, H. (2013). Surfactant-free dispersion of silver nanoparticles into MWCNT-aqueous nanofluids prepared by one-step technique and their thermal characteristics. *Ceramics International, 39*(6), 6415-6425.

Muraka, P., Barrow, G., & Hinduja, S. (1979). Influence of the process variables on the temperature distribution in orthogonal machining using the finite element method. *International Journal of Mechanical Sciences, 21*(8), 445-456.

Murshed, S., Leong, K., & Yang, C. (2005). Enhanced thermal conductivity of TiO2—water based nanofluids. *International Journal of Thermal Sciences, 44*(4), 367-373.

Murshed, S., Leong, K., & Yang, C. (2008). Investigations of thermal conductivity and viscosity of nanofluids. *International Journal of Thermal Sciences, 47*(5), 560-568.

Muthukrishnan, N., & Davim, P. (2011). Influence of coolant in machinability of titanium alloy (Ti-6Al-4V). *Journal of Surface Engineered Materials and Advanced Technology, 1*(1), 9-14.

Muthusamy, Y., Kadirgama, K., Rahman, M., Ramasamy, D., & Sharma, K. (2016). Wear analysis when machining AISI 304 with ethylene glycol/TiO 2 nanoparticle-based coolant. *The International Journal of Advanced Manufacturing Technology*, *82*(1-4), 327-340.

Najiha, M., Rahman, M., & Kadirgama, K. (2015). Machining performance of aluminum alloy 6061-T6 on surface finish using minimum quantity lubrication. *International Journal of Automotive and Mechanical Engineering, 11*, 2699.

Najiha, M., Rahman, M., & Kadirgama, K. (2016). Performance of water-based TiO2 nanofluid during the minimum quantity lubrication machining of aluminium alloy, AA6061-T6. *Journal of Cleaner Production, 135*, 1623-1636.

Ng, E.-G., Aspinwall, D., Brazil, D., & Monaghan, J. (1999). Modelling of temperature and forces when orthogonally machining hardened steel. *International journal of machine tools and manufacture, 39*(6), 885-903.

Ning, Y., Rahman, M., & Wong, Y. (2001). Investigation of chip formation in high speed end milling. *Journal of materials processing technology*, *113*(1-3), 360-367.

Öktem, H., Erzurumlu, T., & Kurtaran, H. (2005). Application of response surface methodology in the optimization of cutting conditions for surface roughness. *Journal of materials processing technology, 170*(1-2), 11-16.

Okushima, K., Kakino, Y., Hagihara, S., & Hashimoto, N. (1971). A stress analysis in the orthogonal cutting by photo elasto-plasticity method. *Bulletin of Japan Society of Precision Engineering*(1), 1.

Ostwald, P. F., & Munoz, J. (2008). *Manufacturing processes and systems*: John Wiley & Sons.

Ouchi, C. (2001). Development of steel plates by intensive use of TMCP and direct quenching processes. *ISIJ international, 41*(6), 542-553.

Oxley, P. L. B. (1989). *The Mechanics of Machining: An Analytical Approach to Assesing Machinability*: Ellis Horwood.

Ozcelik, B., & Bayramoglu, M. (2006). The statistical modeling of surface roughness in high-speed flat end milling. *International journal of machine tools and manufacture, 46*(12-13), 1395-1402.

Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer an International Journal, 11*(2), 151-170.

Parashar, B. N., & Mittal, R. (2002). *Elements of manufacturing processes*: PHI Learning Pvt. Ltd.

Philip, J., & Shima, P. (2012). Thermal properties of nanofluids. *Advances in colloid and interface science, 183*, 30-45.

Philip, J., Shima, P., & Raj, B. (2008). Evidence for enhanced thermal conduction through percolating structures in nanofluids. *Nanotechnology, 19*(30), 305706.

Pozhar, L. A. (2000). Structure and dynamics of nanofluids: Theory and simulations to calculate viscosity. *Physical Review E, 61*(2), 1432.

Pozhar, L. A., & Gubbins, K. E. (1997). Quasihydrodynamics of nanofluid mixtures. *Physical Review E, 56*(5), 5367.

Rahman, M., Kadirgama, K., & Ab Aziz, A. S. (2014). Artificial Neural Network Modeling of Grinding of Ductile Cast Iron Using Water Based SiO2 Nanocoolant. *International Journal of Automotive & Mechanical Engineering, 9*.

Rahman, M., Kumar, A. S., & Salam, M. (2002). Experimental evaluation on the effect of minimal quantities of lubricant in milling. *International journal of machine tools and manufacture, 42*(5), 539-547.

Reen, O. W. (1966). Cutting tool material. In: Google Patents.

Ren, H., & Altintas, Y. (2000). Mechanics of machining with chamfered tools. *Journal of Manufacturing Science and Engineering, 122*(4), 650-659.

Research, G. V. (June 2018). Metal Working Fluids Market Worth $14.54 Billion by 2025. *Metal Working Fluids Market*.

Richardson, J., & Zaki, W. (1954). The sedimentation of a suspension of uniform spheres under conditions of viscous flow. *Chemical Engineering Science, 3*(2), 65-73.

Sajid, M. U., & Ali, H. M. (2018). Thermal conductivity of hybrid nanofluids: A critical review. *International Journal of Heat and Mass Transfer, 126*, 211-234.

Sarafraz, M., Hormozi, F., & Kamalgharibi, M. (2014). Sedimentation and convective boiling heat transfer of CuO-water/ethylene glycol nanofluids. *Heat and Mass Transfer, 50*(9), 1237-1249.

Sarkar, J., Ghosh, P., & Adil, A. (2015). A review on hybrid nanofluids: recent research, development and applications. *Renewable and Sustainable Energy Reviews, 43*, 164-177.

Schuldt, S., Arnold, G., Kowalewski, J., Schneider, Y., & Rohm, H. (2016). Analysis of the sharpness of blades for food cutting. *Journal of Food Engineering, 188*, 13-20.

Senevirathne, S., & Ranaweera, R. (2018). Investigation of effects of Cutting Speed on Tool Wear with Optimum Temperature MQL Aerosol.

Shao, G., Kibira, D., & Lyons, K. (2010). *A virtual machining model for sustainability analysis.* Paper presented at the ASME 2010 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Sharif, F., Arjmand, M., Moud, A. A., Sundararaj, U., & Roberts, E. P. (2017). Segregated hybrid poly (methyl methacrylate)/graphene/magnetite nanocomposites for electromagnetic interference shielding. *ACS applied materials & interfaces, 9*(16), 14171-14179.

Sharif, S. (1999). *Face milling of titanium coated alloys using coated and uncoated carbide tools.* Coventry University,

Sharma, K., Sarma, P., Azmi, W., Mamat, R., & Kadirgama, K. (2012). Correlations to predict friction and forced convection heat transfer coefficients of water based nanofluids for turbulent flow in a tube. *Int. J. Microscale Nanoscale Therm. Fluid Transport Phenom, 3*(4), 1-25.

Sharman, A., Dewes, R. C., & Aspinwall, D. K. (2001). Tool life when high speed ball nose end milling Inconel 718™. *Journal of materials processing technology, 118*(1-3), 29-35.

Shaw, M. C., & Cookson, J. (2005). *Metal cutting principles* (Vol. 2): Oxford university press New York.

Shintani, K., Ueki, M., & Fujimura, Y. (1989). Optimum tool geometry of CBN tool for continuous turning of carburized steel. *International journal of machine tools and manufacture, 29*(3), 403-413.

Smith, S. (1991). An Over View of Modeling and Simulaiton of Milling Process. *Trans of ASME, J. Eng. for Ind., 113*, 169-175.

Sodavadia, K., & Makwana, A. (2014). 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*(1), 55-60.

Stefanescu, D. M., Upadhya, G., & Bandyopadhyay, D. (1990). Heat transfer-solidification kinetics modeling of solidification of castings. *Metallurgical Transactions A, 21*(3), 997-1005.

Stirnimann, J., & Kirchheim, A. (1997). *New Cutting Force Dynamometers for High Precision-Machining.* Paper presented at the Industrial Tooling Conference, Southampton.

Sturesson, P.-O., Håkansson, L., & Claesson, I. (1997). Identification of the Statistical Properties of the Cutting Tool Vibration in a Continuous Turning Operation: Correlation to Structural Properties. *Mechanical Systems & Signal Processing, 11*(3), 459-499.

Sun, S., Brandt, M., & Dargusch, M. (2009). Characteristics of cutting forces and chip formation in machining of titanium alloys. *International journal of machine tools and manufacture, 49*(7-8), 561-568.

Sundar, L. S., Ramana, E. V., Singh, M., & De Sousa, A. (2012). Viscosity of low volume concentrations of magnetic Fe3O4 nanoparticles dispersed in ethylene glycol and water mixture. *Chemical physics letters, 554*, 236-242.

Sundar, L. S., Ramana, E. V., Singh, M. K., & Sousa, A. C. (2014). Thermal conductivity and viscosity of stabilized ethylene glycol and water mixture Al2O3 nanofluids for heat transfer applications: An experimental study. *International Communications in Heat and Mass Transfer, 56*, 86-95.

Sundar, L. S., Singh, M. K., & Sousa, A. C. (2013). Thermal conductivity of ethylene glycol and water mixture based Fe3O4 nanofluid. *International Communications in Heat and Mass Transfer, 49*, 17-24.

Sundaram, R., & K Lambert, B. (1981). Mathematical models to predict surface finish in fine turning of steel. Part II. *The International Journal Of Production Research, 19*(5), 557-564.

Suresh, S., Venkitaraj, K., Selvakumar, P., & Chandrasekar, M. (2011). Synthesis of Al2O3–Cu/water hybrid nanofluids using two step method and its thermo physical properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 388*(1-3), 41-48.

Sutherland, J., & Devor, R. E. (1986). An improved method for cutting force and surface error prediction in flexible end milling systems. *Journal of engineering for industry, 108*(4), 269-279.

Tahat, M. S., & Benim, A. C. (2017). *Experimental Analysis on Thermophysical Properties of Al2O3/CuO Hybrid Nano Fluid with its Effects on Flat Plate Solar Collector.* Paper presented at the Defect and diffusion forum.

Taraman, K. (1974). Multi machining output—multi independent variable turning research by response surface methodology. *International Journal of Production Research, 12*(2), 233-245.

Teng, T.-P., Cheng, C.-M., & Pai, F.-Y. (2011). Preparation and characterization of carbon nanofluid by a plasma arc nanoparticles synthesis system. *Nanoscale research letters, 6*(1), 293.

Thiele, J. D., & Melkote, S. N. (1999). Effect of cutting edge geometry and workpiece hardness on surface generation in the finish hard turning of AISI 52100 steel. *Journal of materials processing technology, 94*(2-3), 216-226.

Thiele, J. D., Melkote, S. N., Peascoe, R. A., & Watkins, T. R. (2000). Effect of cutting-edge geometry and workpiece hardness on surface residual stresses in finish hard turning of AISI 52100 steel. *Journal of Manufacturing Science and Engineering, 122*(4), 642-649.

Tieu, A., Fang, X., & Zhang, D. (1998). FE analysis of cutting tool temperature field with adhering layer formation. *Wear, 214*(2), 252-258.

Timofeeva, E. V., Gavrilov, A. N., McCloskey, J. M., Tolmachev, Y. V., Sprunt, S., Lopatina, L. M., & Selinger, J. V. (2007). Thermal conductivity and particle agglomeration in alumina nanofluids: experiment and theory. *Physical Review E, 76*(6), 061203.

Trent, E., & Wright, P. (1991). Heat in Metal Cutting. *Metal Cutting, 3rd Ed. Butterworth Heinemann, Oxford, UK*, 57-85.

Ulutan, D., & Ozel, T. (2011). Machining induced surface integrity in titanium and nickel alloys: A review. *International journal of machine tools and manufacture, 51*(3), 250-280.

Usui, E., & Shirakashi, T. (1982). Mechanics of machining—from descriptive to predictive theory. *On the Art of Cutting Metals—75 Years Later, 7*, 13-35.

Vajjha, R. S., & Das, D. K. (2009). Experimental determination of thermal conductivity of three nanofluids and development of new correlations. *International Journal of Heat and Mass Transfer, 52*(21-22), 4675-4682.

Vivancos, J., Luis, C., Ortiz, J., & González, H. (2005). Analysis of factors affecting the high-speed side milling of hardened die steels. *Journal of materials processing technology, 162*, 696-701.

Wei, X., Zhu, H., Kong, T., & Wang, L. (2009). Synthesis and thermal conductivity of Cu2O nanofluids. *International Journal of Heat and Mass Transfer, 52*(19-20), 4371-4374.

Wilborn, E. (2014). Nanofluid enhancement of mineral oil and thermal properties instrument design.

Wu, D., & Matsumoto, Y. (1990). The effect of hardness on residual stresses in orthogonal machining of AISI 4340 steel. *Journal of engineering for industry, 112*(3), 245-252.

Xia, Y., Yang, P., Sun, Y., Wu, Y., Mayers, B., Gates, B., . . . Yan, H. (2003). One-dimensional nanostructures: synthesis, characterization, and applications. *Advanced materials, 15*(5), 353-389.

Yang, J., Ding, Y., Chen, G., & Li, C. (2007). Synthesis of conducting polyaniline using novel anionic Gemini surfactant as micellar stabilizer. *European polymer journal, 43*(8), 3337-3343.

Yazid, M., CheHaron, C., Ghani, J., Ibrahim, G., & Said, A. (2011). Surface integrity of Inconel 718 when finish turning with PVD coated carbide tool under MQL. *Procedia Engineering, 19*, 396-401.

Yiamsawas, T., Mahian, O., Dalkilic, A. S., Kaewnai, S., & Wongwises, S. (2013). Experimental studies on the viscosity of TiO2 and Al2O3 nanoparticles suspended in a mixture of ethylene glycol and water for high temperature applications. *Applied energy, 111*, 40-45.

Yu, W., & Xie, H. (2012). A review on nanofluids: preparation, stability mechanisms, and applications. *Journal of nanomaterials, 2012*, 1.

Yu, W., Xie, H., Chen, L., & Li, Y. (2010). Investigation on the thermal transport properties of ethylene glycol-based nanofluids containing copper nanoparticles. *Powder technology, 197*(3), 218-221.

Zhou, X., Wang, D., Liu, X., Zhang, D., Qu, S., Ma, J., . . . Liu, W. (2015). 3D-imaging of selective laser melting defects in a Co–Cr–Mo alloy by synchrotron radiation micro-CT. *Acta Materialia, 98*, 1-16.

Zhu, H.-t., Lin, Y.-s., & Yin, Y.-s. (2004). A novel one-step chemical method for preparation of copper nanofluids. *Journal of colloid and interface science, 277*(1), 100-103.