MAGNETIC POLARITY INFLUENCE ON MACHINING PERFORMANCE OF MAGNETIC FIELD-ASSISTED EDM

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MASTER OF SCIENCE

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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.

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ABSTRAK

Pemesinan pelepasan caj elektrik (EDM) adalah salah satu teknik pemesinan bukan tradisional yang biasa digunakan dalam industry pembuatan acuan dan setem logam lembaran. Walaubagaimanapun, masa pemesinan yang panjang ketika proses EDM membawa kepada kadar penyingkiran bahan yang rendah (MRR). Meningkatkan MRR dengan cara meningkatkan nilai arus puncak, ia akan menjejaskan kualiti kekasaran permukaan bahan. Proses EDM menawarkan pelbagai parameter pemesinan dan teknik EDM hybrid yang boleh dimanipulasikan bagi menyelesaikan masalah ini. Kajian ini adalah bertujuan untuk mengkaji kesan polariti magnet terhadap EDM yang dibantu oleh medan magnet (MFAEDM). Selain MRR, kadar haus elektrod dan kekasaran permukaan (R_a) sampel menggambarkan keberkesanan EDM process. Pemasangan bahan magnet di sekitar kawasan pemesinan telah dilaksanakan untuk mengkaji penambahbaikan pada process EDM. Tambahan pula, perihal kesan polariti magnet dalam proses EDM yang dibantu oleh medan magnet (MFAEDM) masih belum diterokai. Dalam eksperimen ini, EDM Charmiles Roboform22 yang menggunakan minyak tanah dan elektrod grafit berbentuk silinder pada ukuran Ø25 mm digunakan untuk mencetuskan letusan EDM kedalaman 2 mm pada bahan besi AISI 420.mod.Arus puncak antara 8 A hingga 24 A dan masa nadi 50 μs hingga 100 μs telah ditetapkan bersama dengan 0.54 Tesla bagi mencetuskan proses pemesinan untuk polariti Utara-Selatan (N-S) dan Utara-Utara (N-N). Keputusan ujikaji menunjukkan teknik MFAEDM meningkatkan MRR sebanyak 13% berbanding EDM konvensional pada 24 A dan 100 μs. Kekasaran permukaan yang dihasilkan oleh MFAEDM dikurangkan masing-masing sebanyak 16% dan 20% untuk arus puncak 8 A dan 24 A. Kombinasi polariti N-S menghasilkan penurunan nilai R_a sebanyak 10% untuk arus puncak 8A dan 8% untuk arus puncak 24 A berbanding kombinasi N-N. Ia adalah kerana medan magnet memerah percikan api dan memurnikan proses dengan menarik dan memerangkap habuk besi dengan pantas kepada bahan magnet. Teknik MFAEDM berpotensi untuk menyingkirkan serpihan habuk pemesinan secara lebih cekap dan menambah baik MRR. Dengan demikian ianya turut meningkatkan kualiti kekasaran permukaan untuk memenuhi permintaan aplikasi perindustrian moden.

ABSTRACT

Electrical discharge machining (EDM) is one of the non-traditional machining techniques where it is commonly used in the mould and die making industry. However, the lengthy machining time in EDM process leads to low material removal rate (MRR). While increasing MRR by increasing peak current value, it affects the quality of surface finish. The EDM process offers a wide-range of machining parameters and hybrid EDM techniques can be manipulated in solving the EDM drawbacks. The present research aims to study the magnetic polarity influence on magnetic field-assisted EDM. In addition to MRR, electrode wear rate and surface roughness (R_a) of the sample illustrate the effectiveness of the EDM process. The installation of magnetic tools in the EDM machining area was implemented to study its improvements in EDM process. Moreover, the description of magnetic polarity impact in magnetic field-assisted EDM (MFAEDM) remains unacquainted. In the experiment, the EDM Charmiles Roboform22 utilized kerosene and cylindrical Ø25 mm graphite electrode to spark 2 mm depth of cut on AISI 420.mod tool steel. Peak current in the range of 8 A to 24 A and 50 µs to 100 µs of pulse time were designated along with 0.54 Tesla for both North-South (N-S) and North–North (N-N) polarity. The results show that MFAEDM technique enhanced MRR by 13% as compared to conventional EDM at 24 A and 100 µs. Surface roughness produced by MFAEDM was reduced by 16% and 20% respectively for peak current of 8 A and 24 A. N-S polarity combination improved R_a value as much as 10% for peak current of 8 A and 8% for 24 A as compared to N-N combination. The reason is the magnetic field squeezes and purifies spark-eroded process by trapping evaporated debris promptly onto the magnetic bar. MFAEDM causes removal of machining debris more efficiently and is able to attain high-efficiency of MRR. Thus, it improves surface finish quality to meet the demands of modern industrial application.

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LIST OF SYMBOLS

A	Ampere
Ø	Diameter
g/min	Gram per minute
I_p	Peak current
kg	Kilogram
g	Gram
mm	Millimetres
τ_p	Pulse time
t_{on}	Pulse time on
t_{off}	Pulse time off
T	Tesla
µs	Micro-second
µm	Micro-meter
R_a	Arithmetic average of absolute height profile value
V	Voltage

LIST OF ABBREVIATIONS

3D	Three dimensional
ANOVA	Analysis of variance
BeCu	Berylium copper
C	Carbon
Cr	Chromium
DOE	Design of experiment
EDM	Electric discharge machining
EDX	Energy-dispersive X-ray spectroscopy
EWR	Electrode wear rate
Fe	Ferum
HAZ	Heat affected zone
MFAEDM	Magnetic field assisted EDM
Mn	Manganese
MRR	Material removal rate
N-N	North to north
N-S	North to south
SEM	Scanning electron microscope
SR	Surface roughness
TEM	Transmission electron microscope
V	Vanadium

REFERENCES

Abbas, N. M., Solomon, D. G., & Bahari, M. F. (2007). A review on current research trends in electrical discharge machining (EDM). *International Journal of Machine Tools and Manufacture, 47*(7), 1214-1228.

Abdulkareem, S., Khan, A. A., & Konneh, M. (2009). Reducing electrode wear ratio using cryogenic cooling during electrical discharge machining. *The International Journal of Advanced Manufacturing Technology, 45*(11), 1146-1151.

Aghdeab, S. H., & Mohammed, L. A. (2013). Experimental Investigations of Hole-EDM to Optimize Electrode Wear through Full Factorial of Design of Experiment. *Engineering and Technology Journal, 31*(13 Part (A) Engineering), 2572-2579.

Ali, M., Amran, M., HUSSEIN, N. I. S., Mohd Rizal, S., Izamshah, R., Abdullah, R., . . . Sivarao, S. (2013). The effect of EDM die-sinking parameters on material removal rate of beryllium copper using full factorial method. *Middle-East Journal of Scientific Research*, 44-50.

Ali, M. Y., Banu, A., Rahman, M. A., Al Hazza, M. H., & Chowdhury, A. G. K. (2020). *Micro Dry Wire EDM: Kerf Investigation using Response Surface Methodology*. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Anderson, M. J., & Whitcomb, P. J. (2016). *DOE simplified: practical tools for effective experimentation*: Productivity press.

Arikatla, S. P., Mannan, K. T., & Krishnaiah, A. (2013). Influence of Pulse Current and Pulse on Time on Material Removal Rate and Surface Roughness in Electric Discharge Machining of AISI T1 High Speed Steel.

Banu, A., Ali, M. Y., Rahman, M. A., & Konneh, M. (2020). Stability of micro dry wire EDM: OFAT and DOE method. *The International Journal of Advanced Manufacturing Technology, 106*(9), 4247-4261.

Beeteson, J. S. (2001). *Visualising magnetic fields: numerical equation solvers in action* (Vol. 1): Academic Press.

Bojorquez, B., Marloth, R., & Es-Said, O. (2002). Formation of a crater in the workpiece on an electrical discharge machine. *Engineering Failure Analysis, 9*(1), 93-97.

Bormann, R. (1991). Getting those better EDM'd surfaces. *Modern Machine Shop, 63*(9), 56-66.

Chakraborty, S., Mitra, S., & Bose, D. (2020). Experimental investigation on enhancing die corner accuracy during powder mixed wire EDM of Ti6Al4V. *Materials Today: Proceedings*.

Chen, S., Yan, B., & Huang, F. (1999). Influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti–6A1–4V. *Journal of materials processing technology, 87*(1), 107-111.

Choubey, M., Maity, K., & Sharma, A. (2020). Finite element modeling of material removal rate in micro-EDM process with and without ultrasonic vibration. *Grey Systems: Theory and Application*.

Choudhary, R., Kumar, A., Yadav, G., Yadav, R., Kumar, V., & Akhtar, J. (2020). Analysis of cryogenic tool wear during electrical discharge machining of titanium alloy grade 5. *Materials Today: Proceedings*.

Choudhary, S. K., & Jadoun, R. (2014). Current advanced research development of electric discharge machining (EDM): a review. *International Journal of Research in Advent Technology, 2*(3), 273-297.

Das, M., Kumar, K., Barman, T., & Sahoo, P. (2013). Optimization of surface roughness and MRR in EDM using WPCA. *Procedia Engineering, 64,* 446-455.

De Wolf, D., Cardon, L., & Balic, J. (2010). Parameter affecting quality of the electrical discharge machining process. *Adv Prod Eng Manag*, *5*(4), 245-252.

Efendee, A., Saifuldin, M., Gebremariam, M., & Azhari, A. (2018). *Effect of magnetic polarity on surface roughness during magnetic field assisted EDM of tool steel.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Eubank, P. T., Patel, M. R., Barrufet, M. A., & Bozkurt, B. (1993). Theoretical models of the electrical discharge machining process. III. The variable mass, cylindrical plasma model. *Journal of applied physics*, *73*(11), 7900-7909.

Fan, Y., Bai, J., Li, Q., Li, C., Cao, Y., & Li, Z. (2016). Research on maintaining voltage of spark discharge in EDM. *Procedia CIRP, 42*, 28-33.

George, J., Chandan, R., Manu, R., & Mathew, J. (2020). Experimental Investigation of Silicon Powder Mixed EDM Using Graphene and CNT Nano Particle Coated Electrodes. *Silicon*, 1-17.

Gholipoor, A., Baseri, H., Shakeri, M., & Shabgard, M. (2016). Investigation of the effects of magnetic field on near-dry electrical discharge machining performance. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230*(4), 744-751.

Gholipoor, A., Shabgard, M. R., Mohammadpourfard, M., & Abbasi, H. (2020). Comparative study of ultrasonic vibrations assisted EDM and magnetic field assisted EDM processes. *Iranian Journal of Mechanical Engineering Transactions of the ISME, 21*(1), 45-64.

Giancoli, D. (2013). *Physics for Scientists & Engineers with Modern Physics: Pearson New International Edition*: Pearson Higher Ed.

Goyal, R., Rohilla, V., Kumar, A., Goyal, A., & Mittal, S. (2020). Selection of range of pulse duration during cryogenically assisted electric discharge machining. *Materials Today: Proceedings*.

Haron, C. C., Ghani, J., Burhanuddin, Y., Seong, Y., & Swee, C. (2008). Copper and graphite electrodes performance in electrical-discharge machining of XW42 tool steel. *Journal of materials processing technology, 201*(1-3), 570-573.

Ho, K., & Newman, S. (2003). State of the art electrical discharge machining (EDM). *International Journal of Machine Tools and Manufacture, 43*(13), 1287-1300.

Hocheng, H., Guu, Y., & Tai, N. (1998). The feasibility analysis of electrical-discharge machining of carbon-carbon composites. *MATERIAL AND MANUFACTURING PROCESS, 13*(1), 117-132.

Jeavudeen, S., Jailani, H. S., & Murugan, M. (2020). Powder additives influence on dielectric strength of EDM fluid and material removal. *International Journal of Machining and Machinability of Materials, 22*(1), 47-61.

Joshi, S., Govindan, P., Malshe, A., & Rajurkar, K. (2011). Experimental characterization of dry EDM performed in a pulsating magnetic field. *CIRP Annals-Manufacturing Technology, 60*(1), 239-242.

Khan, A. A., Ndaliman, M. B., Mohammad, Y. A., Al-Falahi, M. D., Ibrahim, H. A., & Mustapa, M. S. (2013). The Effect of EDM with external magnetic field on surface roughness of stainless steel.

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

Klocke, F., Hensgen, L., Klink, A., Ehle, L., & Schwedt, A. (2016). Structure and composition of the white layer in the wire-EDM process. *Procedia CIRP, 42*, 673-678.

Klocke, F., Schwade, M., Klink, A., & Veselovac, D. (2013). Analysis of material removal rate and electrode wear in sinking EDM roughing strategies using different graphite grades. *Procedia CIRP, 6*, 163-167.

Konig, W., & Klocke, F. (1997). Fertigungsverfahren-3, Abtragen and Generieren: Springer, Berlin.

Kumar, A., Mandal, A., Dixit, A. R., & Mandal, D. K. (2020). Quantitative analysis of bubble size and electrodes gap at different dielectric conditions in powder mixed EDM process. *The International Journal of Advanced Manufacturing Technology*, 1-11.

Kumar, S., & Choudhury, S. (2007). Prediction of wear and surface roughness in electro-discharge diamond grinding. *Journal of materials processing technology, 191*(1), 206-209.

Kumar, S., Goud, M., & Suri, N. M. (2020). An Investigation of Magnetic-field-assisted EDM by Silicon and Boron Based Dielectric of Inconel 706. *Silicon*, 1-9.

Kumar, S., Srivastava, B., & Kumar, C. (2015). Study of MRR on AISI D3 Die Steel with Different EDM Parameters using Two Level Full Factorial Design. *IJIRST–International Journal for Innovative Research in Science & Technology, 1*(12), 380-387.

Lee, H.-T., & Tai, T. Y. (2003). Relationship between EDM parameters and surface crack formation. *Journal of materials processing technology, 142*(3), 676-683.

Li, L., Zhao, L., Li, Z., Feng, L., & Bai, X. (2017). Surface characteristics of Ti-6Al-4V by SiC abrasive-mixed EDM with magnetic stirring. *Materials and Manufacturing Processes, 32*(1), 83-86.

Li, Y., Cui, C., Lin, B., & Li, L. (2020). *Machining Characteristics of IN718 by EDM with Cooled Electrode and Vibration of the Workpiece.* Paper presented at the Materials Science Forum.

Lim, L., Lee, L., Wong, Y., & Lu, H. (1991). Solidification microstructure of electrodischarge machined surfaces of tool steels. *Materials Science and Technology, 7*(3), 239-248.

Lin, Y.-C., Chen, Y.-F., Wang, D.-A., & Lee, H.-S. (2009). Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method. *Journal of materials processing technology, 209*(7), 3374-3383.

Lin, Y.-C., & Lee, H.-S. (2008). Machining characteristics of magnetic force-assisted EDM. *International Journal of Machine Tools and Manufacture, 48*(11), 1179-1186.

Luo, Y., & Chen, C. (1990). Effect of a pulsed electromagnetic field on the surface roughness in superfinishing EDM. *Precision engineering, 12*(2), 97-100.

Mahendran, S., Devarajan, R., Nagarajan, T., & Majdi, A. (2010). *A review of micro-EDM.* Paper presented at the Proceedings of the international multi conference of engineers and computer scientists.

Mamalis, A., Vosniakos, G., Vaxevanidis, N., & Prohaszka, J. (1987). Macroscopic and microscopic phenomena of electro-discharge machined steel surfaces: an experimental investigation. *Journal of Mechanical Working Technology, 15*(3), 335-356.

Mao, X., Yang, X., Zhang, M., Zhu, Z., & Huo, M. (2020). Development of Multi Micro Holes Synchronous Rotating and Vibration EDM Machine Tool. *MS&E, 768*(4), 042051.

Marafona, J., & Chousal, J. (2006). A finite element model of EDM based on the Joule effect. *International Journal of Machine Tools and Manufacture, 46*(6), 595-602.

Ming, W., Shen, F., Zhang, Z., Huang, H., Du, J., & Wu, J. (2020). A comparative investigation on magnetic field–assisted EDM of magnetic and non-magnetic materials. *The International Journal of Advanced Manufacturing Technology, 109*(3), 1103-1116.

Murray, J., Sun, J., Patil, D., Wood, T., & Clare, A. (2016). Physical and electrical characteristics of EDM debris. *Journal of materials processing technology, 229*, 54-60.

Newton, T. R., Melkote, S. N., Watkins, T. R., Trejo, R. M., & Reister, L. (2009). Investigation of the effect of process parameters on the formation and characteristics of recast layer in wire-EDM of Inconel 718. *Materials Science and Engineering: A, 513*, 208-215.

Okada, A. (2004). Effect of Debris Accumulation on Machining Speed in EDM. *International Journal of Electrical Machining*, 9-14.

Pandey, A., & Singh, S. (2010). Current research trends in variants of Electrical Discharge Machining: A review. *International Journal of Engineering Science and Technology*, *2*(6), 2172-2191.

Pavan, C., & Sateesh, N. (2020). Taguchi analysis on machinability of Inconel 600 using Copper, Brass, and Copper tungsten electrodes in EDM. *Materials Today: Proceedings*.

Prakash, D., Tariq, M., Davis, R., Singh, A., & Debnath, K. (2020). Influence of cryogenic treatment on the performance of micro-EDM tool electrode in machining of magnesium alloy AZ31B. *Materials Today: Proceedings*.

Puertas, I., & Luis, C. (2003). A study on the machining parameters optimisation of electrical discharge machining. *Journal of materials processing technology, 143*, 521-526.

Qiang, H., Yong, H., & Wansheng, Z. (2002). Research of two-dimension EDM spark locations detection using electromagnetic method. *Measurement, 31*(2), 117-122.

Rajabinasab, F., Abedini, V., Hadad, M., & Hajighorbani, R. (2020). Experimental investigation of the effect of tool material on the performance of AISI 4140 steel in the rotary near dry electrical discharge machining. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, 0954408920922102.

Rajkumar, G. M., Giridharan, A., Oyyaravelu, R., & Balan, A. (2020). Investigation on Magnetic Field-assisted Near-dry Electrical Discharge Machining of Inconel 600 *Advances in Unconventional Machining and Composites* (pp. 671-684): Springer.

Rajurkar, K., & Pandit, S. (1988). RECENT PROGRESS IN ELECTRICAL DISCHARGE MACHINE TECHNOLOGY AND RESEARCH *Unknown Host Publication Title*: ASME.

Rajurkar, K., & Yu, Z. (2000). 3d micro-edm using cad/cam. *CIRP Annals-Manufacturing Technology, 49*(1), 127-130.

Ramasawmy, H., & Blunt, L. (2004). Effect of EDM process parameters on 3D surface topography. *Journal of materials processing technology, 148*(2), 155-164.

Rao, P. N. (2013). *Manufacturing technology: metal cutting and machine tools* (Vol. 2): Tata McGraw-Hill Education.

Renjith, R., & Paul, L. (2020). Machining characteristics of micro-magnetic field assisted EDM (μ-MFAEDM). *Materials Today: Proceedings, 27*, 2000-2004.

Rouniyar, A. K., & Shandilya, P. (2020). Optimization of process parameters in magnetic field assisted powder mixed EDM of aluminium 6061 alloy. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 0954406220959108.

Sahu, D. R., & Mandal, A. (2020). Critical analysis of surface integrity parameters and dimensional accuracy in powder-mixed EDM. *Materials and Manufacturing Processes, 35*(4), 430-441.

Satynarayana, K., Rajkiran, K., & Chakradhar, D. (2020). *A Role of cryogenic in Wire cut EDM process.* Paper presented at the E3S Web of Conferences.

Saxena, K. K., Agarwal, S., & Khare, S. K. (2016). Surface characterization, material removal mechanism and material migration study of micro EDM process on conductive SiC. *Procedia CIRP, 42*, 179-184.

Serway, R., & Jewett, J. (2013). *Physics for scientists and engineers with modern physics*: Nelson Education.

Seyedzavvar, M., & Shabgard, M. R. (2012). *Influence of tool material on the electrical discharge machining of AISI H13 tool steel.* Paper presented at the Advanced Materials Research.

Shabgard, M. R., Gholipoor, A., & Baseri, H. (2016). A review on recent developments in machining methods based on electrical discharge phenomena. *The International Journal of Advanced Manufacturing Technology, 87*(5-8), 2081-2097.

Shitara, T., Fujita, K., & Yan, J. (2020). Direct observation of discharging phenomena in vibration-assisted micro-electrical discharge machining. *The International Journal of Advanced Manufacturing Technology*, 1-14.

Singh Bains, P., Sidhu, S. S., & Payal, H. (2016). Study of Magnetic Field-Assisted ED Machining of Metal Matrix Composites. *Materials and Manufacturing Processes, 31*(14), 1889-1894.

Singh, G., Satsangi, P., & Prajapati, D. (2020). Effect of Rotating Magnetic Field and Ultrasonic Vibration on Micro-EDM Process. *Arabian Journal for Science and Engineering, 45*(2), 1059-1070.

Singh, J., Singh, G., & Pandey, P. M. (2020). Electric discharge machining using rapid manufactured complex shape copper electrode with cryogenic cooling channel. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 0954405420949102.

Singh, V., Bhandari, R., & Yadav, V. K. (2017). An experimental investigation on machining parameters of AISI D2 steel using WEDM. *The International Journal of Advanced Manufacturing Technology, 93*(1-4), 203-214.

Sommer, C., & Sommer, S. (2005). *Complete EDM Handbook: Wire EDM, RAM EDM, Small Hole EDM; Practical Information for Designers, Engineers, Machinists, Tool and Die Makers, Mold Makers and Others in the Metal Machining Fields*: Advance Publ.

Sundaram, M. M., Yildiz, Y., & Rajurkar, K. (2009). *Experimental study of the effect of cryogenic treatment on the performance of electro discharge machining.* Paper presented at the Proceedings of International Manufacturing Science and Engineering Conference.

Sundriyal, S., Yadav, J., Walia, R., & Kumar, R. (2020). Thermophysical-Based Modeling of Material Removal in Powder Mixed Near-Dry Electric Discharge Machining. *Journal of Materials Engineering and Performance*, 1-20.

Takezawa, H., Yokote, N., & Mohri, N. (2016). Influence of external magnetic field on permanent magnet by EDM. *The International Journal of Advanced Manufacturing Technology, 87*(1-4), 25-30.

Teimouri, R., & Baseri, H. (2012). Study of tool wear and overcut in EDM process with rotary tool and magnetic field. *Advances in Tribology, 2012*.

Thomson, P. (1989). Surface damage in electrodischarge machining. *Mater. Sci. Technol, 5*, 1153-1157.

Tomura, S., & Kunieda, M. (2009). Analysis of electromagnetic force in wire-EDM. *Precision engineering, 33*(3), 255-262.

Vishwakarma, U., Dvivedi, A., & Kumar, P. (2013). Finite element modeling of material removal rate in powder mixed electric discharge machining of Al-SiC metal matrix composites *Materials Processing Fundamentals* (pp. 151-158): Springer.

Wong, Y., Lim, L., & Lee, L. (1995). Effects of flushing on electro-discharge machined surfaces. *Journal of materials processing technology, 48*(1-4), 299-305.

Wu, K. L., Yan, B. H., Huang, F. Y., & Chen, S. C. (2005). Improvement of surface finish on SKD steel using electro-discharge machining with aluminum and surfactant added dielectric. *International Journal of Machine Tools and Manufacture, 45*(10), 1195-1201.

Xu, M., Wu, Z., Gao, F., Liu, L., & Song, E. (2020). Error modeling and accuracy optimization of rotating ultrasonic vibration assisted EDM machine tool. *Journal of Mechanical Science and Technology, 34*(7), 2751-2760.

Yadav, V. K., Kumar, P., & Dvivedi, A. (2020). Investigation on the Effect of Input Parameters on Surface Quality During Rotary Tool Near-Dry EDM *Recent Advances in Mechanical Infrastructure* (pp. 41-47): Springer.

Yeo, S., Murali, M., & Cheah, H. (2004). Magnetic field assisted micro electro-discharge machining. *Journal of Micromechanics and Microengineering, 14*(11), 1526.

Zhang, Q., Zhang, J., Deng, J., Qin, Y., & Niu, Z. (2002). Ultrasonic vibration electrical discharge machining in gas. *Journal of materials processing technology, 129*(1), 135-138.

Zhang, S., Zhang, W., Liu, Y., Ma, F., Su, C., & Sha, Z. (2017). Study on the Gap Flow Simulation in EDM Small Hole Machining with Ti Alloy. *Advances in Materials Science and Engineering, 2017*.

Zhang, X., & Uchiyama, K. (2017). *Improvement of EDM Machining Speed by Using Magnetic/Piezoelectric Hybrid Drive Actuator.* Paper presented at the MATEC Web of Conferences.

Zinelis, S. (2007). Surface and elemental alterations of dental alloys induced by electro discharge machining (EDM). *Dental materials, 23*(5), 601-607.