Review on WEDM on Surface Roughness and Material Removal Rate

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Abstract: Wire electrical discharge machining method was established as a non-conventional thermoelectric machining technique for machining the materials that are electricity conductors. Material removal method is the same as ordinary EDM operation. Wire-Electrical Discharge Machining (WEDM) is the non-contact machining methodology that has continuously developed from a pure manufacturing of geometrically complicated or hard material parts and die producing processes to a micro-scale design machining solution that attracts significant research interests. The cutting tools are electric sparks, mounted and powered by a generator. Because the wire electrode does not touch the workpiece completely, the electrical charge has generated a voltage that allows it to cross the gap between the electrode and the workpiece. The goal of this study is to examine the effect of different input factors on material removal efficiency, surface roughness value (Ra) using the response surface methodology (RSM) technique and to create Artificial Neural Network (ANN) model. This paper examinations the consequences of different WEDM process boundaries, for example, wire strain, servo voltage, beat on schedule, top weight, dielectric stream rate, beat off time, wire size, on different gadget response boundaries, for example, material removal rate (MRR), surface Roughness (Ra), business related development and wire wear proportion (WWR) of materials for wire terminals.

***Index Terms* - Process Parameters, Wire cut EDM, Material Removal Rate (MRR), surface Roughness (Ra).**

I. INTRODUCTION

Researchers are additionally demonstrating enthusiasm for cutting edge materials including clay molecule strengthened composites, blended composites; metal molecule covered artistic fortified MMCs for present-age creative item improvement. Traditional machining, for example, turning, boring, processing, and so forth shows wastefulness in the handling of earthenware strengthened MMCs [1]. Non-uniform appropriation of fortified particles, high hardness and expanded delicacy lead to helpless material evacuation rates, inordinate device wear and expanded surface unpleasantness [2]. Studies center around non-ordinary techniques for machining which can be utilized viably to process composite materials to create convoluted shapes in composite materials [3–4] Fig. 1. Non-ordinary types of machining are evaluated to the type of vitality expected to process the parts for the activity. For example (Ultrasonic machining, Water stream machining, Electron pillar machining, Laser bar machining, and concoction machining). A large number of these non-regular machining techniques presently can't seem to be concentrated to decide the "ideal" machining particulars and to accomplish savvy machining alongside great machine execution and reproducibility [2]. Wire Electrical Discharge Machine (WEDM) is a particular advancement of conventional EDM forms which utilize a cathode to trigger the starting cycle. WEDM turns out to be progressively significant in giving a non-contact machining strategy that is appropriate for viable machining of MMCs independent of the hardness and unbending nature of the forms over the segments [4].

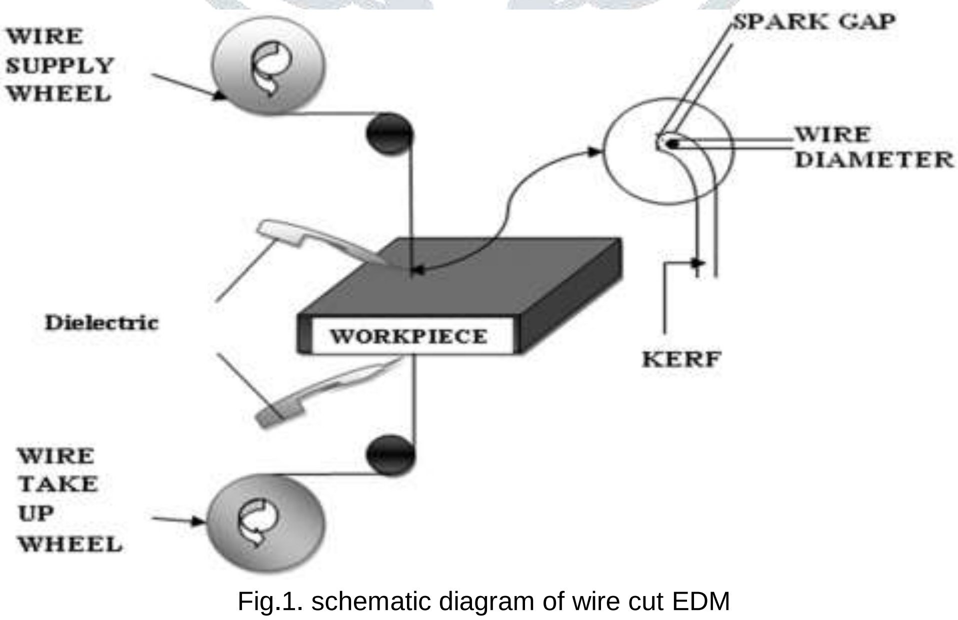

Fig.1. schematic diagram of wire cut EDM

WEDM utilizes an incessantly moving wire electrode constructed of thin 0.05–0.30 mm diameter copper, brass or tungsten, capable of producing very low corner radii, to be poured into the workpiece, which is immersed in a dielectric fluid tank like deionized water. The wire is placed between the upper and lower diamond guides and is continuously fed from a spool. The guides are normally operated by CNC and travel within the x – y axis. Filters and deionizing systems are used for the resistivity control and other electrical properties. The stream tends to wash the debris from the cutting field off. The flushing also assists in deciding the feed levels to be provided for a range of content thickness. The steel is battered in front of the wire during the WEDM process so there is no immediate interaction with the piece of work and even the metal, reducing the mechanical pressures during machining. The accompanying figure demonstrates conceptual configuration of the Wire cut EDM schematic diagram [5, 6].

Wire-EDM has been a significant non-conventional method of machining commonly utilized in the aerospace engineering, machine processing, dies, molding, metalworking and automotive industries. This is on the grounds that wire-EDM is a significant strategy for the machining of fragile shaped hard materials. Be that as it may, choice of cutting boundaries in wire-EDM for more prominent cutting proficiency or exactness is as yet not completely settled. WEDM is a thermoelectric procedure wherein material is dissolved between work piece and wire cathode by arrangement of sparkles. Wire bears one side of an electric charge during stage and occupation piece holds the opposite side of the charge. As the wire enters the component the interaction of electrical charges produces a regulated flame, melting and vaporizing small substance particles. The spark often eliminates a tiny chunk of the wire and after the wire goes through the job portion, the mechanism discards the discarded wire and then pushes fresh wire along. A constantly moving wire electrode made of thin 0.05-0.30 mm diameter steel, nickel, or tungsten. This paper centers principally around the major WEDM research exercises that include the various procedure boundaries, for example, wire size, wire width, beat on schedule, beat off time, top ebb and flow and wire pressure, wire feed rate, servo voltage, and dielectric liquid and flushing quality. Efficiency metrics such as the removal rate of substrates, surface roughness, wire wear rate, kerf width and dimensional variation have the largest effect on these parameters of the process.

The literature review segment offers details regarding the WEDM method machining function, and its features even include knowledge about the machining of the new composite material utilized in the automobile, aerospace and tooling industries. For the Wire-EDM process, create the neural network feed forward model. So as to tackle the ideal cutting boundaries utilizing a discretionary target work, a virtual tempering worldwide improvement calculation is then added to this system. It was seen that the beat on time is the significant boundary for surface harshness [7]. Attempted to control the parameter of machining, such as pulse-on time, table feed intensity, flushing strain, gap between wire periphery and workpiece top, pulse-off time, and experience of WEDM machining in finish cutting. This contrasts the method presented with that of a professionally skilled user. Clearly the preferred solution will obtain a higher consistency of the air [8].

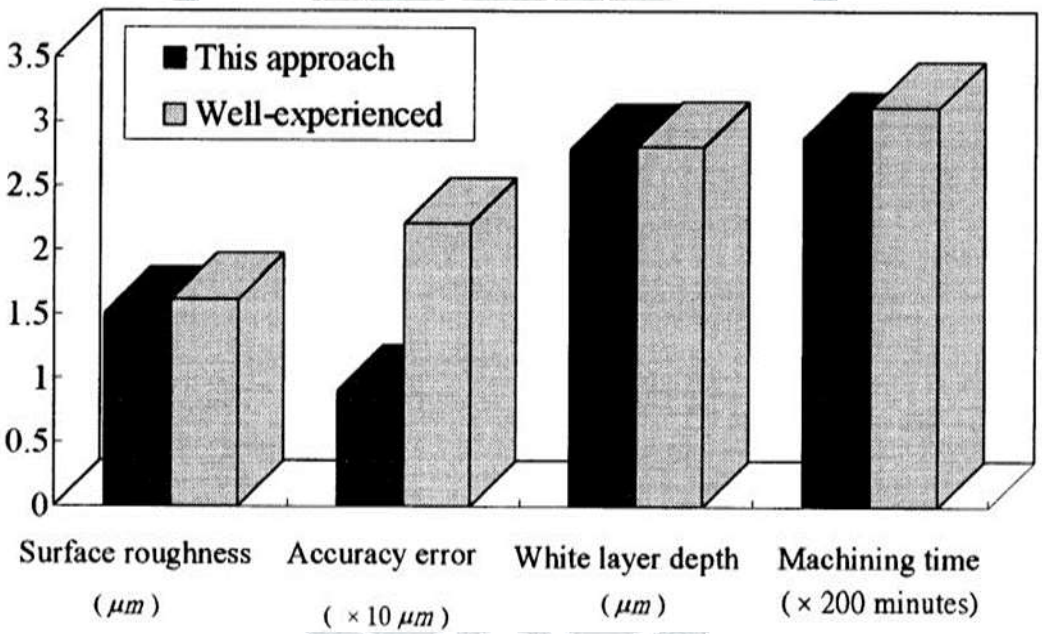

Fig. 2. Comparison of this approach with a well-skilled operation [8]

The characterize normal cutting pace, surface roughness; beat on time, beat off time and heartbeat top current during harsh cutting and heartbeat on schedule and consistent cutting rate during trim cutting are regularly affected by geometric mistake [9]. Test discoveries from Patil and Brahmankar show that expanded level of clay particulate issue in the MMC is causing diminished MRR. The MRR drop is roughly 12 percent with a 10 percent ascend in earthenware fortifications. While the current models and the procedure can be utilized to test the plan in more profundity all through the cycle [10]. Performed electrical release turning tests concentrated on Taguchi design picking AISI D3 Steel as working material and copper anode as gadget material. For seeking the best answer, using ANFIS to model the WEDT loop, NSGA. This also measures the consistency of all three methods used to measure surface roughness, as seen in figure 3 below, and the rate of material removal. From the graph, every one of the three models of destruction show results genuinely near one another, however in the ANFIS model there was a state of lower Ra and lower MRR away from the pattern line and it was discovered that the ANFIS model had a normal test mistake of about 27% [11]. Explains the creation of MROT using utility methods to predict and choose the opti Lastly, validation experiment was performed to test the feasibility of the suggested optimum setting [12].

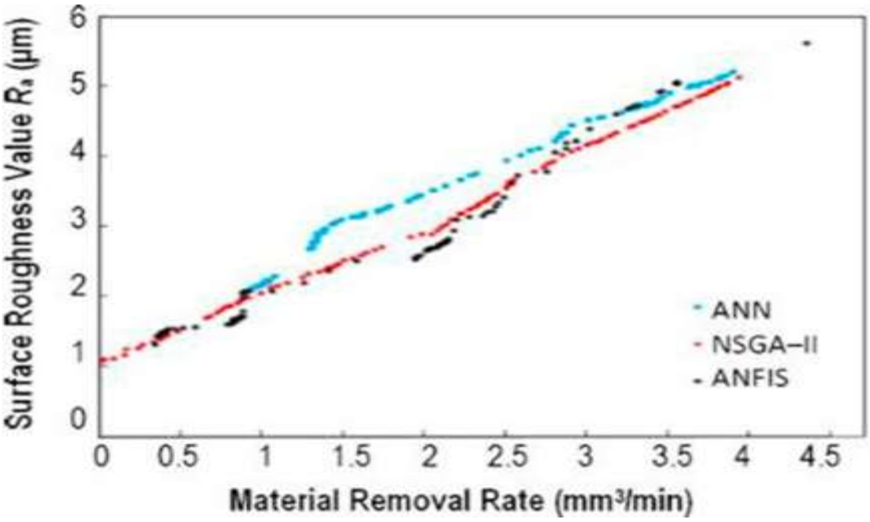

Fig. 3. Comparison of ANN, NSGA-II and ANFIS model [11]

The optimal cutting condition at a peak current of 2 A and a set distance of 772 µm. Because cutting speed did not impact any dimension or surface roughness, the pace was therefore set at the maximum of 5.5 mm / min to optimize the rate of output [13]. Tests were done by altering the molecule size, volume portion, beat on period, beat off period and pressure of the link. The principle part examination of multi-reaction streamlining strategy is utilized to determine the fundamental composite segment that goes about as the general quality record all the while [11]. The mathematical models to forecast output properties outcomes well in advance. The desirability feature method is used to determine the best set of parameters for single-objective optimisation as well as multi-objective optimisation. 8.1235 mm / min CV. The Ra of 1.2549 µm indicates that wire EDM can be successfully machined with the developed MMC [14]. Liao uses a neural network which, through the concept of SDE. The neural network, which is used in combination with the GAs optimization method, effectively involves variance of function component content to determine process design parameters. The framework permits clients to acquire a blend of machining boundaries which can accomplish the quickest conceivable machining speed while fulfilling the necessary nature of machining with various materials. This will also reduce the method of establishing machining criteria in method preparation, and save significant time and expense [15]. Zhang proposed solution will concurrently provide optimal process parameter settings for MS-WEDM machining SKD11 with maximum MRR and minimum 3D Sq. The affirmation explore demonstrated that the nature of the surface declines while the MRR increments with the heartbeat on time expanding. In view of the assembling engineer 's rules, the most appropriate procedure boundary mix can be browsed the pareto-ideal arrangements [16]. Kumar and Kumar performed deal with the pace of material expulsion and over-cutting of unadulterated titanium utilizing metal cathode in the WEDM cycle using response surface strategy. Dimensional demonstrating is utilized to build the semi-observational model, and the set up model was tried by standing out the model's forecasts from the MRR exploratory qualities, and a solid understanding was reached between the two [17]. The trial on close dry WEDM oxygen-fog utilizing test structure from taguchi. Relapse model was produced for expulsion pace of material and unpleasantness of the dirt. Multi-objective Artificial Bee Colony calculation is utilized to decide the ideal mix of the substance expulsion rate and surface unpleasantness boundaries [11].

II. WEDM PROCESS PARAMETERS

WEDM has revolutionized the tooling, die, molding and metalworking markets since its creation. Thanks to the efficient engines, modern wire electrodes, improved machine knowledge and better flushing conditions, the advancement of WEDM in the 1970s [18]. It is the most adaptable machine apparatus worked for assembling and has numerous advantages over customary machining. Whatever the unbending nature, it is conceivable to control electrically conductive articles with more noteworthy exactness and precision in this procedure, a persistently moving wire anode framework, made of metallic steel, is associated with a heartbeat generator to make electrical release between a wire terminal. The separation between the moving wire terminal and workpiece in a functioning machining setting must regularly be loaded up with a dielectric liquid that goes about as a cooling specialist and empowers the flushing of flotsam and jetsam expelled by release. Particles stream from each sparkle between the wire anode and the workpiece shaped under outrageous warmth and weight through an ionization channel because of a progression of quick electrical heartbeats delivered by the machine's capacity flexibly, a huge number of times each second. Active vitality, delivered as warmth, builds the channel temperature to a scope of 8000 C–12,000 C. The made temperature is higher than the breaking point, which in the long run expands the strain on the plasma channel to as much as 200 environments [18,19]. The method of machining includes repetitively shaping plasma and quenching it using dielectric fluid. This cycle occurs sequentially in several places in the cutting region of the workpiece at nanosecond intervals. Effective flushing is needed to avoid conductive particles from piling up in the void, which creates huge unwanted craters by transmitting massive quantities of energy due to electric arcs. Such vulnerabilities continue to get huge due to the deteriorating flushing conditions. Flaws produced by the sparks sometimes radiate from a sharp corner which leads to wire electrode failure or breakage. A material 's capacity for preventing crack-caused loss is termed fracture toughness. Typically, lower tensile wires have better fracture resistance than moderate tensile wires [21]. Consumers of WEDM expect optimum reliability, improved precision and reliable performance. Selection of the right wire electrode for WEDM is a daunting process in order to ensure a effective operation [22]. As a consequence, experimenting with various wire electrodes is necessary to obtain optimal performance. There must be three important criteria for the wire electrodes used in WEDM: high electrical conductivity; flushing and optimum spark properties; sufficient mechanical strength. The success of the WEDM is due to approximately six variables, as seen in Figure 4.

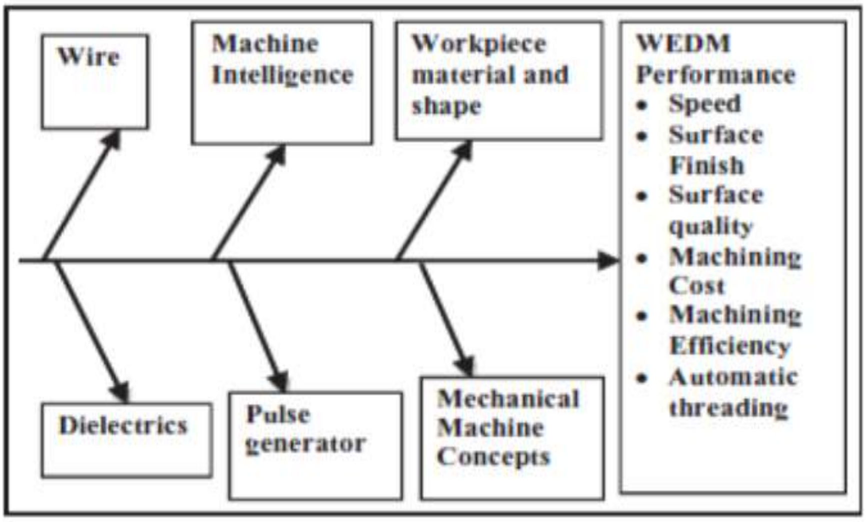

Fig 4. Effect of various factors improving the WEDM performance [23].

1 Pulse on Time-This is the span of time that permits the current to stream in each cycle. This is called Ton and it is estimated in small scale seconds (µs).
2 Pulse Off Time – It is the length of the two covering blasts. Now and again characterized as heartbeat length. It is marked Toff and it is estimated in miniaturized scale seconds (µs).
3 Spark Gap-The hole between the cathode and the bit of work during EDM stage. Pinnacle Current-For the given heartbeat, it is the greatest estimation of the current that experiences the terminals. This is represented in amperes (A) and denoted by IP.
4 Spark Gap Voltage-Common voltage for the genuine distinction between the substrate of the workpiece and the wire; The voltage of the sparkle hole is otherwise called open circuit pressure. SV speaks to it, and states it in volts (V).
5 Wire feed-The rate at which the wire goes along the wire manage way and is taken care of to produce the sparkles is known as wire feed.
6 Wire pressure the aggregate of wire to be stretched out between the upper and lower wire guides is directed by the quality of the link.
7 Pulse Peak Voltage-Pulse top voltage setting is with the expectation of complimentary hole voltage assortment.
8 Dielectric Pressure-Dielectric Stress is the dielectric liquid weight between the bit of work and the link. It's the rate this liquid is coursing in the tank at.

III. Effect of various parameters on MRR, RA and WWR

3.1 Effect of Pulse on Time:

MRR is straightforwardly corresponding to the entirety of vitality which is conveyed on time during beat. The higher the beat an incentive on schedule, the vitality yield will be higher and this will add to additionally warm vitality creation. Surface roughness (Ra) will in general be higher with higher estimations of Ton [24]. The pace of substance expulsion and the pace of wear of the wire (WWR) diminishes with time change in the beat [25]. Metal wire wear rate increments with increments in input vitality, bringing about wire breakage [26].

3.2 Effect of Pulse off Time

There are further releases over a predetermined period with a lower estimation of T off, bringing about an improvement in the pace of substance end. At the point when beat off time is expanded, the MRR diminishes as the dielectric liquid delivers the cooling impact on the wire terminal and work material with long heartbeat off time, along these lines decreasing the cutting pace. Surface toughness increments with heartbeat off time through. The Surface Roughness is solid at low heartbeat off time; this is on the grounds that there isn't sufficient opportunity to expel the liquefied small particles from the separation b/w of the wire terminal and workpiece with exceptionally restricted heartbeat off time. It is discovered that surface unpleasantness first abatements when beat off time rises, and afterward ascends with heartbeat off time rise. This is on the grounds that there is a requirement for more vitality to make the plasma channel and accordingly more prominent anode wear and higher surface strength [27],[24].

3.3 Effect of peak Current

Increasing the IP value would boost the energy from the pulse discharge and will in effect help enhance the cutting efficiency. Increases of average present value of MRR, Ra and WWR. It is observed that peak current is the main factor impacting Surface Roughness [28].

3.4 Effect of Servo Voltage

With servo voltage rising, the MRR rises and then begins to decrease. Due to the large dielectric ionization across the working gap, it is attributed to higher servo voltage resulting in higher discharge energy per spark; thus, the MRR is increasing [27]. At higher pulse-off time values, the variables analyzed in the analysis were maximum SR, wire feed, spark gap setting voltage, and lower pulse-on time values, input current, wire voltage [29]. Servo voltage has the largest effect on dimensional separation, and time off pulses and wire feeds are found in that order [30].

3.5 Effect of Wire Feed Rate

With variation in wire feed the material removal rate remains almost constant. Surface ruggedness decreases as wire feed rate increases, because new wire quickly comes into contact when wire feed rate increases. High Wire velocity threatens to snap the cable. But with the increase in wire supply, wire use is growing and the machining cost is also - [31],[32].

3.6 Effect of Dielectric Flow Rate

Effective machining is quite important. This fluid helps get the debris out of the machining area. This increases the surface quality and reduces the wire wear rate within the necessary range of flow. Fluid leakage decreases MRR [31].

3.7 Effect of Wire Tension

The wire remains straight because the wire stress is high enough because the wire drags behind. This helps hold the wire vibrating secure. This is that if there is an inappropriate stress, it will create noise through the tube, which would therefore contribute to the operation being successful. Wire breakage may also arise because of excessive stress of the cable. An rise in wire stress greatly improves the cutting pace and accuracy within substantial range [31].

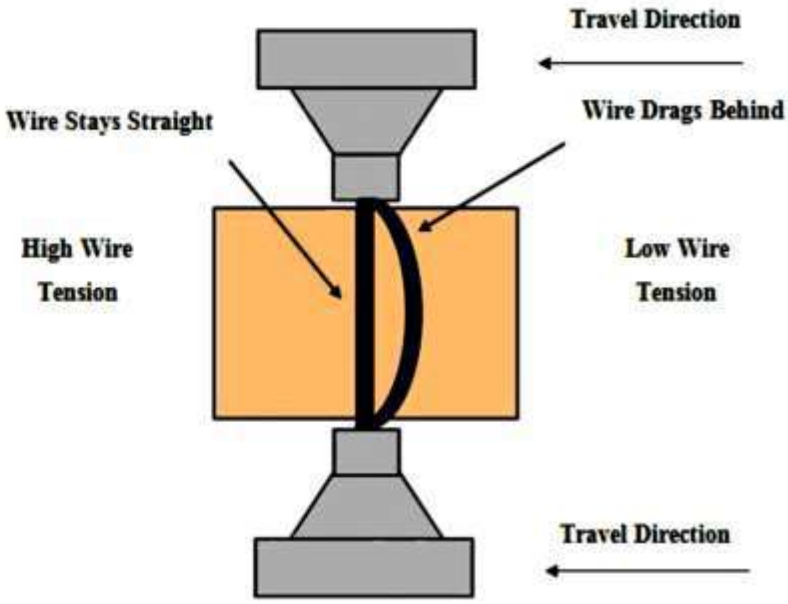

Fig. 5: Relation between Wire drag and wire tension [33]

IV. WEDM MACHINING FEATURES

The following are the WEDM features which need to be tailored for efficiency and improved results. These are Ground Roughness (Ra) [31], Metal Removal Ratio (MRR).

4.1 Metal removal rate (MRR)

MRR can be calculated by the ratio of the amount of substance removal to the machining period required. The performance of the machining method is heavily affected. It depends on the parameters on which the machining process is connected. Several scientists have experimented through various methods to optimize the pace of content elimination.

4.2 Surface roughness (Ra)

The square block's surface roughness (Ra) value is quantified in lm using an SJ-210 surface roughness tester and is a very critical parameter to minimize. The affecting parameters such as dielectric layer, substrate, and electrical parameters need to be regulated to achieve good surface finish. Several researchers have suggested that electrical discharge current must be controlled to achieve good surface finish.

V. PROPERTIES NECESSITATED FOR WIRE ELECTRODES

Figure 6 illustrates the performance of WEDM wire electrodes. The properties needed for the wire electrode are: spatial, mechanical, physical and electrical properties. Its electric resistance articulates the electrical properties. When utilizing two existing contacts and choosing with engineered settings high-conductivity electrode products such as steel, brass, aluminum and its alloys, energy losses are reduced. Conductivity defines how easily the energy is transmitted from the control feed to the real cutting point [34]. Improving the wire's surface area would allow for smoother cutting. Ultra-fine wires (with a distance across of under 30 mm) are utilized for miniaturized scale WEDM where low heartbeat energies prevail [35]. The covered layer structure is affected by the thermophysical properties of the anodes combined with their warm conductivity, dissolving and dissipation rate. Covering on the wire anode starts cooling of the wire terminal focus and gives sensible cutting execution [36]. The wire terminal 's critical mechanical properties are its rigidity (sY), lengthening, and straightness. Low elastic guarantees the wire anode can possibly suffer worry during machining. Extension clarifies how much the wire gives until it parts during cutting. Straightness is basic for proficient auto stringing [33]. For tighten cutting, delicate wires (sY=350–400N/mm2) are utilized, and high pliable wires (sY=750–990N/mm2) are utilized for high accuracy cutting [34]. Non-wire-related contemplations, for example, the advancement of mechanical gear, the use of upgraded drive generators and dielectric flushing procedures frequently assume a critical job in improving the WEDM procedure's machinability.

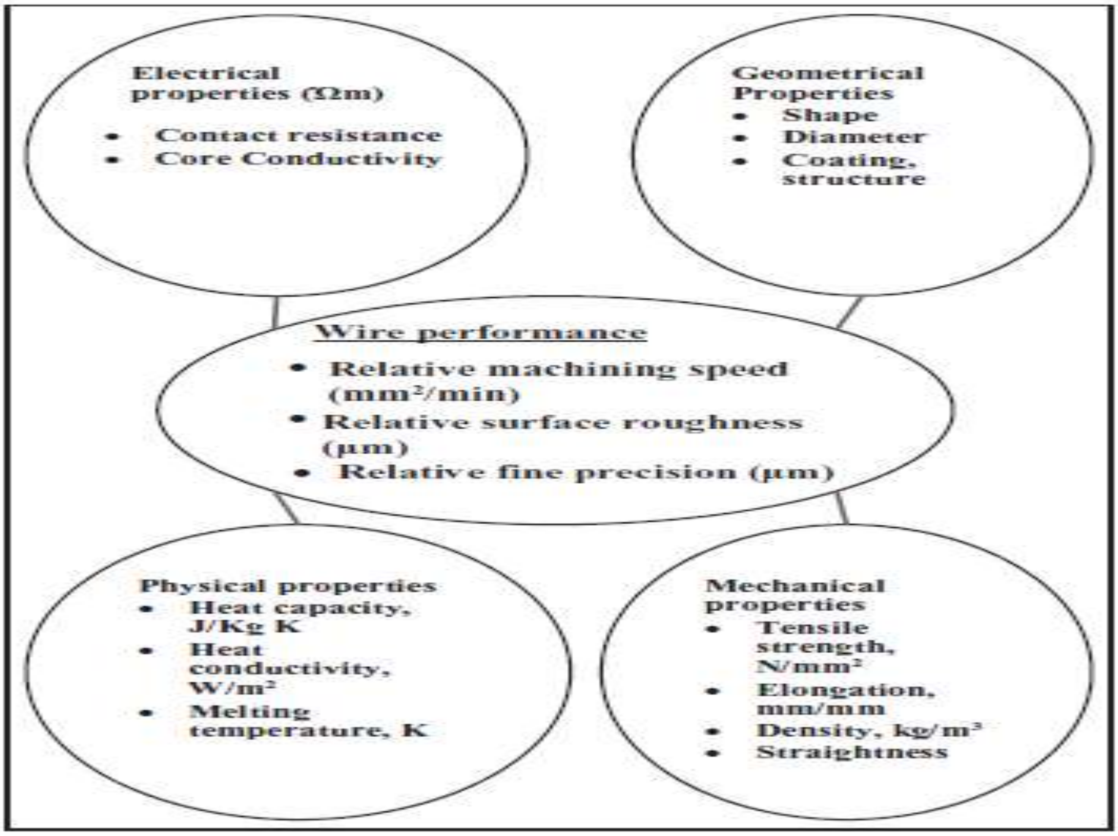

Fig 6. Wire electrode performance for WEDM [37].

VI. CONCLUSION

This can be concluded from the literature that

1 1 Researchers have been working on WEDM, but limited research on MMCs has been published.
2 2 The effect of different reinforcements (e.g. metal-coated ceramic strengthened MMC, composite MMC) on the machining properties of the MMCs on WEDM must be studied and optimized.
3 3 In most research papers, only electrical parameters were emphasized by past authors, but non-electrical parameters also influenced the machining characteristics.
4 Advances in the production of metal matrix composites include the feasibility of WED process machining in the potential machining environment. There is, however, plenty of room for machining work with the new technologies to boost efficiency.
5 The most important parameter influencing MRR is the pulse on time.
6 Decreased surface roughness as peak current and pulse on time rise, pulse off time doesn't have a significant effect.
7 The most important parameter is the pulse on time, while the pulse off time and the distance voltage are very noteworthy parameters to monitor the MRR.

REFERENCES

[1] Manish Vishwakarma, Vishal Parashar, V.K. Khare, Response Surface Approach for Optimization of Sinker Electric Discharge Machine Process Parameters on AISI 4140 Alloy Steel, Int. J. Sci. Res. Publ. 2 (3) (2012) 1–8.
[2] F. Müller, J. Monaghan, Non-conventional machining of particle reinforced metal matrix composite , Int. J. Mach. Tools Manuf. 40 (9) (2000) 1351–1366.
[3] Vishwa R. Surya, K.M. Vinay Kumar, R. Keshavamurthy, G. Ugrasen, H.V. Ravindra, Mater. Today. Proc. 4 (2) (2017) 203–212.
[4] Kashid D.V.1 , S.G. Bhatwadekar2 ,S.B. Sangale3 , P.R. Kubade4, Investigations of Effect of Process Parameters on Material Removal Rate in Wire-cut Electrical Discharge Machining of Steel Grade EN 9, International Journal of Emerging Engineering Research and Technology Volume 2, Issue 1, April 2014, PP 31-35
[5] Sachin Ashok Sonawane, M.L. Kulkarni, Optimization of machining parameters of WEDM for Nimonic-75 alloy using principal component analysis integrated with Taguchi method ,J. King Saud Univ.-Eng. Sci. (2018).
[6] Neeraj Sharma, Rajesh Khanna, Rahul Dev Gupta, WEDM process variables investigation for HSLA by response surface methodology and genetic algorithm. Sci. Technol. Int. J. 18 (2) (2015) 171–177.
[7] Y. S. Tarng, S. C. MA, L. K. Chung, Determination Of Optimal Cutting Parameters In Wire Electrical Discharge Machining, International Journal of Machine Tools & Manufacture,35(1995) ,1693-1701.
[8] Y.S.Liao, J.T.Huang, and H.C. Su, A study on machining-parameters optimization of wire electric discharge machining, Journal of Materials Processing Technology,71(1997), 483–493.
[9] A.B. Puri, and B. Bhattacharyya, An Analysis And Optimization Of The Geometrical Inaccuracy Due ToWire Lag Phenomenon In WEDM, International Journal of Machine Tools & Manufacture, 43(2003), 151 - 159.
[10] N.G.Patil, and P.K.Brahmankar, Determination of Material Removal Rate in Wire Electro-discharge Machining of Metal Matrix Composites Using Dimensional Analysis, International Journal of Advance Manufacturing Technology, 5(2010), 599-610.

[11] T.B.Rao, and A.G. Krishna, Simultaneous optimization of multiple performance characteristics in WEDM for machining ZC63/SiCp MMC, Journal of Advance Manufacturing, 1(2013), 265–275.
[12] R. Chalisgaonkar, and J. Kumar,Optimization of WEDM process of pure titanium with multiple performance characteristics using Taguchi's DOE approach and utility concept,Front. Mech. Eng, 8(2013), 201–214.
[13] Kanlayasiri, K. and Jattakul, P. (2013). "Simultaneous Optimization of Dimensional Accuracy and Surface Roughness for Finishing Cut of Wire-EDMed K460 Tool Steel, Journal of Precision Engineering, 37, 556 – 561.
[14] M.P.Garg, A. Jain, and G. Bhushan ,Multi-objective Optimization of Process Parameters in Wire Electric Discharge Machining of Ti- 6-2-4-2 Alloy, Arab Journal of Science and Engineering, 39(2014), 1465–1476.
[15] Y.S.Liao, J.T.Huang, and H.C. Su, A study on machining-parameters optimization of wire electric discharge machining, Journal of Materials Processing Technology,71(1997), 483–493.
[16] G.Zhang, Z.Zhang,J.Guo, W.Ming, M.Li, and Y.Huang, Modeling And Optimization Of Medium Speed WEDM Process Parameters For Machining SKD11, Materials and Manufacturing Processes, 28(2013), 1124-1132.
[17] A.Kumar,V.Kumar,and J.Kumar,Semi-empirical Model On MRR And Overcut In WEDM ProcessOf Pure Titanium Using Multi-objective Desirability Approach, Journal of Brazilian Society Of Mechanical Sciences And Engineering, 37(2015), 689-721.
[18] McGeough JA. Electro discharges machining. Advance methods of machining. London: Chapman & Hall, 1998, pp.130.
[19] Pandey PC and Shan HS. Modern machining processes. Tata McGraw-Hill Publishing Company Ltd, 1980, pp.79–80.
[20] Kern R. Improving wire EDM productivity. EDM Today 2007; March/April: 10–14.
[21] Kern R. EDM wire selection. EDM Today 2008; March/ April: 12–16.
[22] Aoyama S, Tamura K, Satoh T, et al. High-performance coated wire electrodes for high-speed cutting and accurate machining. Hitachi Cable Review 1999; 18: 75–80.
[23] Understanding the wire EDM process. Tooling and production Nov. 1999.
[24] Pujari Srinivasa Rao, Koona Ramji, Beela Satyanaraayana "Experimental Investigation and Optimization of Wire EDM parameters for Surface Roughness, MRR and White layer in machining of aluminum alloy" International conference on Advances in Manufacturing And Materials Engineering, AMME vol. 5, (2014), page. 2197-2206.
[25] Sreenivasa Rao "Review on wire cut edm process" International journal of advanced trends in computer science and engineering vol. 2, (2013), page 12-17.
[26] Ravindranadh Bobbili, V. Madhu, A.K. Gogia "An experimental investigation of wire electrical discharge machining of hot-pressed boron carbide" Science Direct, Defence Technology 11, (2015), page 344-349.
[27] Kumar Sandeep,"Current Research Trends in Electrical Discharge Machining: A Review" Research Journal of Engineering Sciences, Vol. 2(2), (2013) page 56-60.
[28] Brajesh Kumar Lodhi, Sanjay Agarwal "Optimization of machining parameters in WEDM of AISI D3 Steel using Taguchi Technique" 6th CIRP International Conference on High Performance Cutting, HPC2014, Procedia CIRP 14, (2014), page 194-199.
[29] Amitesh Goswami, Jatinder Kumar "Optimization in wire-cut EDM of Nimonic-80A using Taguchi's approach and utility concept" Engineering Science and BTechnology, An International Journal, (2014), page 236-246.
[30] Pradeep Singh, Arun Kumar Chaudhary, Tirath Singh, Amit Kumar Rana "Experimental Investigation of Wire EDM to Optimize Dimensional Deviation of EN8 Steel through Taguchi's Technique" International Research Journal of Engineering and Technology (IRJET) ISSN: 2395 -0056 Vol. 02, (2015), page 1753-1757.
[31] Sreenivasa Rao and Venkaiah "Review on wire cut edm process" International journal of advanced trends in computer science and engineering vol. 2, (2013), page 12-17.
[32] Navjot Singh, Parlad Kumar, Khushdeep Goyal "Effect of Two Different Cryogenic Treated Wires in Wire Electrical Discharge Machining of AISI D3 Die Steel", Journal of Mechanical Engineering, Vol. ME 43 No. 2, (2013), page 54-60.
[33] Danial Ghodsiyeh, Abolfazl Golshan, Jamal Azimi Shirvanehdeh "Review on Current Research Trends in Wire Electrical Discharge Machining", Indian Journal of Science and Technology, Vol. 6, (2013), page 4128-4140.
[34] Kern R. EDM wire selection. EDM Today 2008; March/ April: 12–16.
[35] Aoyama S, Tamura K, Satoh T, et al. High-performance coated wire electrodes for high-speed cutting and accurate machining. Hitachi Cable Review 1999; 18: 75–80.
[36] Masatada N, Naoyuki O, Hirokazu S, et al. Development of electrode wires ("CUT WIRE") for high-performance wire electro-discharge machining. Sumitomo electric technical review 1999; 154: 43–48.
[37] Aoyama S. Development of high-performance wire electrode for wire electric discharge machining. J Japan Soc Electrical Machining Engrs 2001; 35(79).