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Optimization On Material Removal Rate And Surface Roughness Of Stainless Steel 304 Wire Mesh Cut Wedm By Topsis Methodology

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Abstract

Wire electrical discharge machining (WEDM) is an important technology, which demands high-speed cutting and high-precision machining to realize productivity and improved accuracy for automotive, manufacturing of press stamping dies, prototype parts etc. In this present work, investigations of cutting performance with pulse on time, pulse off time, servo voltage, wire feed, current and cutting speed were experimentally investigated in wire electric discharge machining (WEDM) process.The EDM wire research currently focuses on achieving higher machining speed and surface integrity. In this regard, US patent 20100012628A1 presents a hybrid wire embedded with electrically nonconducting abrasives This investigation involves using Glass (G), Kevlar(k), and carbon (C) fibres in the Hybrid Synthetic Fibre Polymer (HSGKC) composites for different applications. Synthetic Fibre WireMesh Composite (SFWMC) plates were fabricated using woven G/K/C along with Stainless Steel Wire Mesh (SSWM),. The samples were fabricated using hand-layup and through compression moulding techniques. The Experimental trial-I samples were prepared with G/K, K/G, C/G and G/K/C combinations along with LY556 and HY951. In trial-II the samples were prepared by adding $BaSO_4$ in various weight ratios (1%, 3%, 5% and 7 %). The optimum results were obtained for sample with 5% of $BaSO_4$ addition, and hence the samples uses in the first trial combinations with 5% of $BaSO_4$ were preferred for trial-III. Finally, along with 5% of $BaSO_4$ the experimental trial-IV samples were fabricated using stainless steel, aluminium wire mesh. This results in a remarkable improvement in removal rate and ensures better recast surface layer when compared to an equivalent WEDM process. Moreover, the need for advanced machining techniques like AWJM is inevitable to produce complex components in the field of automobiles. A study of the (SFWMC) composite was made with special reference to the TOPSIS method for optimizing the cutting parameters of WEDM while minimizing the surface roughness. Each trial was led at varied stand-off distance (D), transverse speed (S), and degrees of water jet pressure (P). For this study, the Material Removal Rate (MRR), Kerf Taper Angle (KTA), and surface roughness (R_a) were taken as multi criteria characteristics. There was negligible recast material present on the machined surfaces. A majority of this process is dedicated to machining steel. The cutting performance outputs considered in this study are material removal rate (MRR) and surface roughness. Experimentation has been completed by using Taguchis L16 orthogonal array under different conditions of parameters. The aim of the present investigation is to develop the selection of an optimal combination of WEDM parameters for proper machining of SS 304 to achieve better surface roughness and Materials Removal Rate (MRR). However, it may be useful in machining (such as polycrystalline diamond), which are usually hard to process with WEDM. The abrasion can negatively affect the machining performance, which makes such a process suitable for roughing sequences. Therefore, it is usually developed in a twin-wire machine tool. Although diamond wire can be effective in such work, wire with aluminium oxide abrasives can provide better performance at a lower cost.

Introduction

WEDM, also called as “spark,” is a machining technique that employs electrical output to obtain a variety of shapes. WEDM is a unique variation of the traditional EDM technique that starts the electrical sparking process using an electrode. The thin continuous brass, copper, or tungsten made wire electrode with a diameter of 0.05-0.3 mm moves constantly, which makes use of that may attain a better tiny corner radius of WEDM. Using a series of rapidly recurring current outputs among the two electrodes separated by a dielectric solution and placed at an electric voltage, the material is removed from the workpiece. The tool-electrode, or simply the “tool” or “electrode,” is one of the electrodes, whilst the workpiece-electrode [1, 2], or just the “workpiece”, is the other electrode.

As the distance between the electrodes decreases, the intensity of the electric field in the volume between them exceeds the strength of the [3–5] dielectric (at least at few point(s), that breakup the allowed current to flow among the two electrodes). This is analogous to the breaking of the capacitor. From this, the material is removed from the two electrodes [6].

When the current flow slows (or stops—based on the generator), fresh solution-based dielectric is frequently introduced into the internal-electrode volume, allowing solid elements to be removed and the dielectric’s insulating characteristics to be recovered [7]. Flushing is the process of replenishing the interelectrode volume with a new liquid dielectric. Additionally, following a current flow, the potential differentiation among the two electrodes [8] is recovered to its prebreakdown state, allowing for another liquid dielectric breakdown. Wire EDM is used in various manufacturing industrial applications: soft armors shaping, hybrid composite, and mainly in the coating industries (thermal spray processes) for cutting the base materials into the desired shape [9–20].

The mechanism of wire EDM process parameters is most similar to conventional EDM. The conventional EDM process will create an erosion effect on the sample surfaces to remove the material. The basic mechanism involved in the electric discharge machining (EDM) process is that the tool electrode is the cathode and the sample material is the anode. The developed voltage is passed between the two electrodes, and dielectric medium is passed between them to create a strong electrostatic effect. This effect produces a spark gap between the tool and sample. Huge thermal energy is created, and it melts material and vaporizes the material from the sample. The modification of pulse energy and current durations in the dielectric medium can determine the dimensional accuracy and quality of the machining samples [21–25].

To improve the dimensional accuracy and quality of the wire EDM process, it has many working parameters: surface roughness, metal removal rate, wire feed rate, pulse on time, pulse off time, peak current, pulse current, applied voltage, etc.

These all parameters mostly influence the performance of wire EDM machining processes. The proper selection of optimal parameters plays a very important role in the wire EDM machining process; it leads to dimensional accuracy and a quality surface finish. The improper selection of process parameters will lead to dimensional inaccuracy, poor quality, and surface finish; it also leads to wire breakage in the continued machining process; and it affects the performance of the process [26–29].

The most accurate optimization technique is the response surface methodology (RSM) based linear regression model is used in this work. The popularity and simplicity of this technique needed to control various parameters in the wire EDM process. In the present work, surface roughness, MRR, pulse on time, pulse off time, and peak current values are chosen for performance measurement. The selected parameters are the most essential things to get dimensional accuracy and quality finishing in the WEDM process. Many researchers have proved that using the RSM technique is most helpful in carrying out experiments with this technique, which leads to minimal experimental effort [30–33].

Wire Electrochemical Discharge Machining

An extension of machining with electrochemical discharges to wire machining, called travelling wire electrochemical discharge machining (TW-ECDM), was first proposed by Tsuchiya et al. [105] and studied further by Jain et al. [58,91] and Peng and Liao [92]. TW-ECDM is particularly interesting for slicing glass fibre composites [58,59,102,103], but may also be used for 2D contour cutting [105].

In TW-ECDM, a wire is used as the tool-electrode in a similar manner as in wire electrical discharge machining (WEDM). Copper wires [59,92], stainless steel wires [92], or brass wires [100,105,106] are typically used. The wire speed is a trade-off between high speed, in order to allow the cooling of the wire (avoiding overheating and breaking), and low speed for economical reasons [58]. Typical wire speeds vary from a few millimetres per minute [58] to a few centimetres per minute [105] depending on the set-up used. The wire may be guided horizontally or vertically.

Similar to hole drilling and 2D structuring, several materials can be machined using TW-ECDM: glass, quartz, alumina [91,92,105], piezoelectric (PZT) ceramics [100,106], and various composites (glass- and Kevlar-epoxy) [58]. NaOH is generally the preferred electrolyte. The applied voltage may be a direct current (DC) or pulsed voltage. Compared with hole drilling or 2D structuring the voltage is generally higher, which is due to the different geometry of the wire (larger surface area) compared with a cylindrical tool-electrode.

Workpiece feeding is done by gravity-feed, by constant speed (typically a few millimetres per minute for glass and 0.1 mm/min for ceramics), or by gap control [92]. In the last configuration the gap is controlled optically by asensor. The thickness of the workpiece can be in the range of 1 mm to 1 cm (for glass). The gravity-feed mechanism generally results in poor cut shapes [133].

The stabilisation of the temperature during machining by appropriate flushing of the electrolyte is possible. However, too high flushing rates can destabilise the discharge activity.

The material removal rate and the machining over-cut increase with the machining voltage [100,105] and electrolyte concentration [105,133], which also increases the probability of wire breaking [105]. Polarising the wire as a cathode generally results in higher material removal rates than for a wire polarised as an anode.

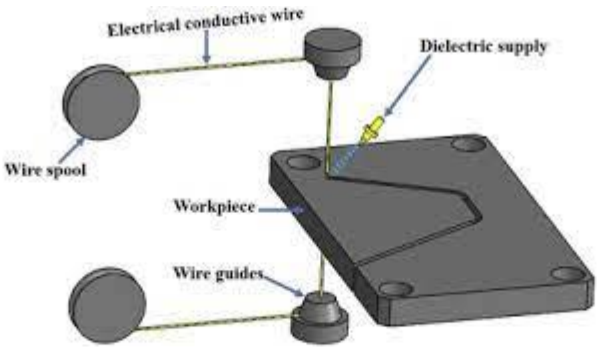
An efficient method to decrease the machining over-cut involves adding abrasive particles into the electrolyte [133] or the use a pulsed voltage supply. At the same time surface roughness is decreased and can reach values below 1 μm. Recently, replacing metallic machine parts with composite material has been seen as a potential alternative to various issues, including high metal costs, rusting, and the weight of the components. In the modern machining industry, composite materials that possess similar or even enhanced physical and mechanical properties compared to metals are highly encouraged [1,2,3]. Polymer composite materials (PCMs) are recognized as a group of difficult-to-machine materials [4]. The development of light-weight PCMs plays a significant role in aviation and many critical industrial applications. These materials are economically efficient and reduce the CO_2 emission load [1]. The binders used in PCM have good strengths and are heat resistant, resulting in high elastic strength and operational stability. In contrast, the matrix phase in the PCM is the ductile phase that transfers the external load stress to the filler phase. The filler/reinforcement used in a PCM determines its mechanical properties, such as strength, stiffness, and deformability. The filler used may be carbon/ceramic fibers. These fibers have good physical and mechanical properties. These fibers are converted into fabrics by weaving [5,6,7]. A typical PCM is shown in **Figure 1**a, and the weaving pattern of the fibers forms the reinforcement phase and the possible defects in conventional machining.

EXPERIMENTAL DETAILS

Experimentation

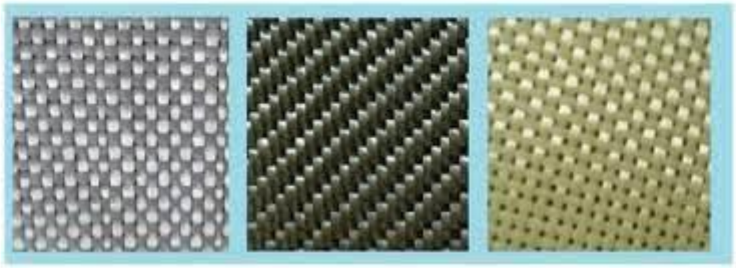
3.1 Materials, machine tool and measurement Wire EDM is a very complicated process consisting of complex interactions between a large numbers of variables such as machine tools, workpiece materials and operating parameters. However, to facilitate experimental data collection,only six dominant factors were considered in the planning of experimentation. A sprint-cut high-precision fouraxis CNC wire EDM was used to machine the high-speed steel (M2, SKH9) pieces of size 230×25×10 mm, having cut in length with 12-mm depth along the longer length. The composition of high-speed steel (M2, SKH9) workpiece material used for experimentation in this work is as given in Table 1. The parameters, selected for experimentation,were as shown in Table 2, along with their limits, units and notations. The photographic view of the machine and machining zone has been shown in Fig. 3a, b, respectively. The other details of experimentation have been shown in Table 3. A 0.25-mm-diameter stratified wire (zinc-coated copper wire) with vertical configuration was used and discarded once used. High metal removal rate in WEDM without wire breakage can be attained by the use of a zinc-coated copper wire because the evaporation of zinc causes cooling at the interface of the workpiece and wire and a coating of zinc oxide on the surface of the wire helps prevent short circuits [30]. The two most important performance measures in WEDM are metal removal rate and workpiece surface roughness. The material removal rate (g/min) was calculated by weight difference of the specimen before and after machining using high-precision balance. The surface roughness was measured with Talysurf-6 at three different locations (at 0.8 μm cutoff value) on the workpiece after machining and the average value has been taken in the present study. The resolution of surface roughness measuring instrument is 0.8 . This means that the 0.8 is the minimum value of surface roughness that can be measured by the surface roughness measuring instrument. However, the differences in the readings of surface roughness are much higher than the resolution of the surface roughness measuring instrument.So, the instrument will be able to distinguish between

Experiment Setup The machine used for experiments is electronica sprint cut Wire cut EDM, Model-ELPULS-40 A DLX, incorporated with molybdenum wire technology which is installed at Darshan Wire Cut, Odhav, G.I.D.C., Ahmadabad, Gujarat as shown in Figure.

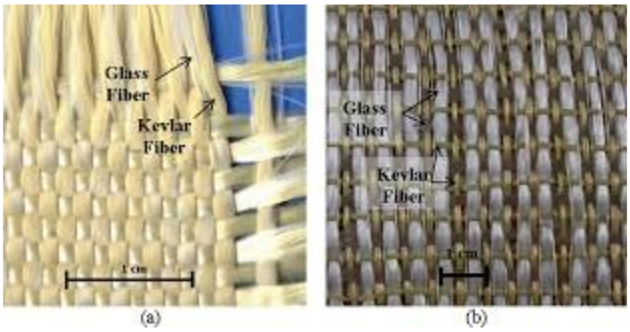


Process Parameters Selection

The experiments were carried out on a Wire Electro Discharge Machine (WEDM) ELECTRONICA ECOCUT of M/S Electronic Machine Tools Ltd. Installed at Precision Engineering Lab of Manufacturing Engineering Department , College of Engineering, ANNA UNIVERSITYGuindy,Chennai-25, Tamil Nadu, India. The discussions related to the measurement of WEDM Experimental Parameters, material Removal Rate (MRR), Surface Roughness are presented in the following.



WOVEN GLASS/ KEVLAR/ CARBON



SI. No	Parameters	Range
1	Wire Material	Diffused Brass Wire
2	Wire Size (mm)	Ã˜ 0.25
3	Wire tension (gm)	1600

4	Dielectric	Deionised water
5	Table feed rate (mm/min)	80
6	Work Piece	SS 304

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Taguchi design experiments in MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates. A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of eighteen numbers of experiments to be conducted and hence the OA L16 was chosen. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L16 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler. This project makes use of Taguchis method for designing the experiments. Hence L16 mixed orthogonal

array was selected for the present investigation. Parameters and their levels selected for final experimentation has been depicted in Table. Experimental analysis using pooled ANOVA predicts the significant process parameters and to establish the optimal parameter set of combinations for Wire- EDM of (SFWMC)

chapter are related about influences of MRR, TWR, Surface Roughness finding the result which factors discharge current, pulse duration, diameter of brass tool, is most important with help of Taguchi method. The response table for MRR Surface Roughness is shown in Table 4 along with the input factors. In this investigation, the effects of WEDM essentials parameters such as peak current (A), Pulse on time (Ton), Pulse off time (Toff) and gap voltage (V)

were varied to determine their effects on material removal rate (MRR) and surface roughness (SR). In addition, the experimental data were transferred to grey relational grade and were assessed by analysis of variance (ANOVA) to determine the significant machining parameters and to obtain the optimal combination levels of machining parameters for multiple performance characteristics. Therefore, the optimal machining parameters of the WEDM were established to achieve a high MRR along with a good surface roughness for the difficult to machine materials.

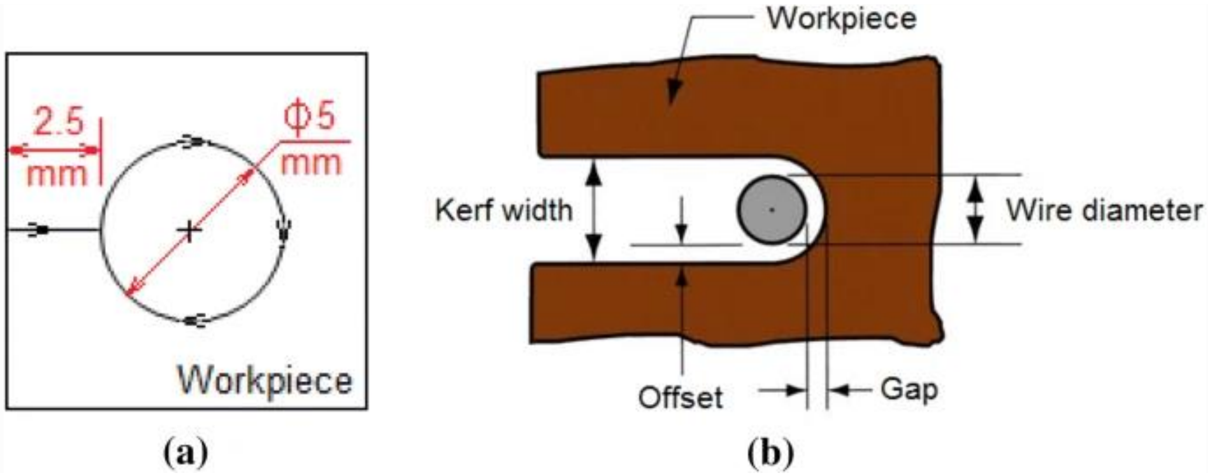
RESPONSE TABLE 4

Sl.No	T(on) (Âμs)	T(off) (Âμs)	Wire feed (m/mim)	Voltage (V)	Current (A)	M/c speed (mm/min)	Time (min)	Kerf width (mm)	Ra (Âμm)	MRR (mm3/min)
1	10	1	1	45	2.9	2.1	8.19.61	0.308	2.52	20.4

2	10	2	2	50	2.5	1.9	9.33.32	0.294	2.01	17.6
3	10	3	3	55	2.1	1.5	11.07.38	0.319	1.82	15.2
4	10	4	4	60	1.9	1.2	14.10.30	0.339	2.5	12.8
5	9	1	2	55	2.5	1.7	9.46.63	0.297	1.75	16
6	9	2	1	60	2.1	1.5	12.00.29	0.29	2.72	13.7
7	9	3	4	45	2.5	1.9	9.28.04	0.308	2.23	18.4
8	9	4	3	50	2.1	1.7	10.48.86	0.299	1.88	16
9	8	1	3	60	2	1.5	11.42.96	0.307	1.95	14.5
10	8	2	4	55	2.1	1.6	10.46.04	0.305	3.11	15.4
11	8	3	1	60	1.9	1.2	12.34.67	0.311	1.84	11.7
12	8	4	2	45	2.1	1.7	9.44.80	0.302	1.88	16.2
13	7	1	4	50	2.1	1.7	9.28.38	0.307	1.67	17
14	7	2	4	45	2.2	1.7	9.14.87	0.336	1.64	18
15	7	3	2	60	1.9	1.2	13.21.78	0.291	1.71	11

16	7	4	1	55	1.9	1.6	11.50.56	0.307 1.8	15.2

Kingred CNC wire cut EDM machine



Response surface methodology modeling results

MINITAB software is used during the RSM modeling. Equations 6 and 7 represent the predicted response equations for MRR and SR respectively. Figure 3 illustrates a statistical evaluation of the MRR and SR, which confirm the equation's accuracy and good fitness between the experimental and predicted results

Taguchi Method

A statistical technique of Taguchi method used for analyzing and optimizing the process parameters. The Taguchi analysis uses orthogonal arrays from the design of experiments, theory to study the power of a large number of variables on responses with a small number of experiments. In this method, the experimental results are changed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing the desired values [6] . Taguchi classified the quality characteristics into three categories such as Lower the better, Higher the better and Normal the better. These formulas used for calculating S/N ratio is as follows. The characteristics that lower value represents better machining performance, such as surface roughness is called "lower is better (LB)" and that higher values represent better machining performance, such as the material removal rate is called "higher is better (HB)" in quality engineering. The S/N ratio (signal to noise) could be an effective representation to find the significant parameter by evaluating the minimum variance. The equations for calculating the S/N ratio are, "Lower is better" (LB) S/N ratio = - 10 log (1/r (y1 2 + y2 2 + y3 2 +..........+ yn 2)) (1) "Higher is Better" (HB) S/N ratio = - 10 log (1/r (1/y1 2 + 1/y2 2 + 1/y3 2 +.........+ 1/yn 2)) (2) Where, y1 , y2 ,...yn = observed response values and n=

number of replications. By applying the equation 1, the S/N values of the obtained Ra values are computed. By applying the equation 2, the S/N values of machining performance of the obtained MRR values are computed. In order to obtain the effects of machining parameters for each level, the S/N values of each fixed parameter and level in each machining performance were summed up.

Process Parameters Selection In this analysis, WEDM parameters such as Ton, Toff and WF were considered. According to Taguchi's design of experiments, for three parameters and three levels L9 Taguchi orthogonal array [L9 OA] was selected. The number of factors and their corresponding levels are shown in the Table 1 and the basic Taguchi L9 (33) orthogonal array used for this work is shown in Table 2. Table.1 Levels of factors used in the experiment Sl.No. Symbol Cutting Parameters Levels Units 1 2 3 1 A Pulse on-time (Ton) 1 5 8 μ Sec 2 B Pulse off-time (Toff) 10 5 2 μSec 3 C Wire feed rate (WF) 1 2 3 m/min Table.2 Standard L9 Orthogonal array Experiment No. Levels Pulse ontime(Ton) Pulse offtime(Toff) Wire Feed Rate (WF) 1 1 1 1 2 1 2 2 3 1 3 3 4 2 1 2 5 2 2 3 6 2 3 1 7 3 1 3 8 3 2 1 9 3 3 2 1.3 Experimental Set up Table.3 Chemical composition of grade 304 stainless steel Grade Wt.% C Mn Si P S Cr Mo Ni N 304 0.08 2 0.75 0.04 0.03 20 - 10 0.1 Fig.1 Experimental setup 24 The experiments were conducted on a CNC WEDM. The trials conducted based on the settings shown in the L9 orthogonal array. Stainless steel (grade 304) materials were used as the workpiece. The surface roughnesses are measured on the machined surface using surf test 211 machine. The surface roughness-measuring device is slid on the workpiece and readings are taken in the middle of each test specimen. The material removal rate is calculated by loss of weight / time taken for each trial. The work material, electrode and other machining settings are as follows Work piece (anode) : stain less steel. (Grade 304) Electrode (cathode) : 0.25 mm diameter brass wire. Work piece thickness : 10 mm. Voltage : 80 V

3.1. Material removal rate and workpiece damage All of the tests achieved the 12 mm cut distance with machining times varying from 13.3 to 49.1 minutes. This resulted in MRR's of between 0.43 and 2.41 mm3 /min for the range of tests performed. Corresponding analysis of variance (ANOVA) revealed that ignition current and pulse off-time were both statistically significant factors at the 5% level, with percentage contribution ratios (PCR) of 48.5% and 24.3% respectively. The main effects plot in Fig. 2 showed that MRR increased with ignition current and pulse on-time due to the greater discharge energy, whereas higher pulse off-times reduced MRR due to the lower spark efficiency/frequency. Surprisingly, operating at the larger open gap voltage level (140 V) generally led to a reduction in mean MRR. A possible reason for this was the rise in molten resin material in the gap caused by the elevated discharge energy leading to unstable machining. Fig. 2. Main effects plot for MRR. Fig. 3 details optical micrographs of the machined kerf on the top and bottom of the workpiece from the test achieving the highest MRR. Aside from a relatively uneven edge profile, there was no evidence of major damage such as delamination, matrix burning or uncut fibres on the kerf periphery in any of the workpieces examined. There was however bronze coloured patches of suspected adhered debris/contamination visible around the bottom surface of the workpiece, see Fig. 3b, which may be deposits of re-solidified wire electrode material. This was possibly due to the differences in flushing efficiency/conditions between the top and bottom sides of the workpiece. Fig. 3. Sample micrographs of machined kerf on the (a) top and (b) bottom surfaces from the test achieving the highest MRR. 3.2. Kerf width The kerf width results highlighted discrepancies between measurements at the top and bottom surfaces of the CFRP workpiece. Average Wt was found to vary between ∼256 and 289 μm while Wb was generally smaller, ranging from ∼243 to 277 μm. The ANOVA shown in Table 3 for Wt demonstrated that the ignition current was the only significant factor with a corresponding PCR of 56.6%, while none of the variable parameters were found to be statistically significant with respect to the bottom kerf width. The main effects plot in Fig. 4 revealed that mean Wt decreased with increasing current and pulse off-time whilst increasing voltage enlarged the kerf width as expected due to the larger spark gap generated. In terms of Wb, both open gap voltage and pulse off-time exhibited similar effects compared to the top kerf, however the trends for ignition current and pulse on-time were reversed as shown in Fig. 5. Table 3. ANOVA table for top kerf width. Source DF Seq. SS Adj. MS F P PCR% Voltage, V0 1 40.18 40.18 1.91 0.197 4.1% Current, IAL 2 559.73 279.78 13.31 0.002* 56.6% On-time, A 2 32.19 16.10 0.77 0.490 3.3% Off-time, B 2 146.65 73.33 3.49 0.071 14.8% Residual error 10 210.21 21.02 21.3% Total 17 988.97 100% *Significant at the 5% level The relatively smaller mean Wb (∼261 μm) compared to Wt (∼282 μm) when operating at the lowest current level of 3 A was possibly due to greater machining instability at the bottom side of the workpiece. However, the disparity between the top and bottom kerf width was found to reduce significantly as ignition current increased to 5 A, which suggests that the wire advanced more uniformly through the workpiece, most likely as a result of the higher discharge energy. 198 Ramy Abdallah et al. / Procedia CIRP 77 (2018) 195–198 4 Author name / Procedia CIRP 00 (2018) 000–000 Fig. 4. Main effects plot for top kerf width. Fig. 5. Main effects plot for bottom kerf width. 3.3. Confirmation tests Confirmation trials were carried out to validate the preferred combination of operating parameter levels to achieve maximum MRR and minimum top/bottom kerf widths. Although the recommended parameter combinations for MRR and Wt were undertaken as part of the orthogonal array, confirmation trials for all 3 responses were carried out to verify the results. Table 4 details the predicted and experimental values of the mean and signal to noise (S/N) ratio for the respective confirmation trials. The percentage error between the experimental and predicted data did not exceed 5% for all of the responses evaluated, which indicates that the accuracy of the Taguchi experiment was acceptable. Table 4. Predicted and experimental values of mean and S/N ratio. Response Mean S/N ratio (dB) Error % Pred. Exp. Pred. Exp. MRR 2.17 2.28 7.79 7.16 4.95 Wt 262.14 263.67 -48.37 -48.42 0.58 Wb 255.72 262.97 -48.15 -48.43 2.75 4. Conclusions • All of the trials were successfully completed to a cut length of 12 mm. This suggests that the process parameters and electrode material selected were suitable for enabling the wire electrical discharge machining of unidirectional CFRP composites. • The highest MRR of 2.41 mm3 /min was achieved when utilising an ignition current of 5 A, pulse on-time of 1 μs, open gap voltage of 120 V and pulse off-time of 4 μs. • Ignition current and pulse off-time were statistically significant factors with regard to MRR while current was the sole parameter influencing the kerf width on the top surface. The difference in measured kerf width between the top and bottom surfaces of the workpiece was possibly due to the variation in flushing conditions/efficiency at the respective locations. • None of the machined workpieces showed any indications of thermal damage or serious defects around the vicinity of the kerf, apart from rough edges and some minor adhered debris on the bottom surface of the workpiece

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