

# Experimental Investigation and Image-Assisted Electrode Tool Wear in the EDM Process

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## ABSTRACT

The present experimental investigation proposes an image-based assessment method for the automatic detection and measurement of convex end wear in cylindrical brass electrodes used during Electrical Discharge Machining (EDM) of AISI 314 steel plate workpieces. Minitab was utilized to determine the total number of experiments required for this study. The MATLAB Image Processing Toolbox was employed to classify and process images of cylindrical brass electrodes for extracting the data required in the data acquisition operation. The main objective of this study is to utilize a non-contact measurement system, along with a relatively low-cost instrumentation, to compute and evaluate the wear in cylindrical brass electrodes. The obtained wear values demonstrated that there is a slight skewed between the wear determined using a digitized caliper tool and the proposed image-assisted wear measurement, which validated the introduced method. The percentage of deviation between the proposed method and the method used by the digitized caliper tool-assisted wear measurement is 0.06.

*Keywords-electrical discharge machining; brass electrode; noncontact measuring system; image processing technique; material removal rate; electrode tool wear*

## I. INTRODUCTION

EDM has many applications as it is considered an important industrial process due to its distinctive properties [1]. In addition, EDM exhibits a precise efficiency for the electrically

conductive materials that do not require contact with the electrode tool [2]. Moreover, this manufacturing process is used to the machining of brittle and hard materials that are difficult to manufacture using other traditional techniques [3]. The rate of material removal depends on the sparks formed in

the operating area, which generates a plasma channel between the electrode and the work-piece, and thus removal occurs due to high temperatures [4]. The evaluation of the electrode wear is crucial to the EDM process as it plays an important role in improving its performance [5, 6]. A new method to evaluate the copper electrode wear during the machining of the AISI 1005 carbon steel employing the EDM process was proposed in [7]. A 3D laser scanner that measures the lost volume of the electrode was utilized. The results of the proposed method were compared with those of the conventional method. Laser technology was deployed to accurately measure the dimensions and surface characteristics of the electrode by scanning the latter's surface and its view topology before and after the machining process. The results revealed that the Tool Wear Rate (TWR) obtained by the two methods showed a mean absolute deviation of 3.6%, with an insignificant error on the effect of the machining.

Authors in [8] adopted a brass electrode to operate SS316, where copper is combined with zinc to form a copper alloy. The TWR, Material Removal Rate (MRR), and Surface Roughness (SR) were chosen as indicators to measure the process performance, which significantly improved. In [9], holes were drilled using copper and brass electrodes by relying on the current, pulse on time, and pulse off time, and the MRR and TWR were determined as the performance measures. The results confirmed a significant improvement by increasing the MRR, decreasing the operation time, and minimizing the TWR. Authors in [10] investigated the cutting process of alloy steel X210, focusing on the parameter selection and the influence of the electrode angles on machining responses, such as MRR, Electrode Wear Ratio, and surface roughness. Electrode angles of 0° and 90° were selected for machining work-pieces using Wire Electrical Discharge Machining (WEDM). Models for regression and responses were developed to increase the productivity. Authors in [11, 12] employed EDM to study the product surface of alloy steel X210. The experiments were conducted on a copper electrode that included a horizontal hole. The electrode angle, peak current, pulse on-time, and pulse-off time were studied using the Response Surface Methodology (RSM). The lowest SR was reached during the machining with a 45° electrode angle. Authors in [13] used brass electrodes to machine Inconel 690 alloy, selecting the peak current, pulse-on time, and flushing pressure as the operating parameters. Authors in [14] used copper, brass, and graphite as electrode materials for machining IS2062 steel, while TWR, MRR, and SR were identified as the main performance parameters of EDM. Authors in [15] demonstrated that the performance of the EDM process significantly depends on the electrode material and that it has an influential role in improving the performance of the process. Various materials, such as copper, brass, copper-tungsten, and graphite, were utilized to study their effect and improve the performance of the process. Authors in [16] presented an experimental study on the effect of the electrode material on the EDM process performance. Authors in [17] studied the effect of operating parameters, such as current, pulse-on time, and pulse-off time, on EDM performance parameters, like TWR and MRR, using brass electrodes based on Taguchi's

method. The results identified optimal conditions, leading to an improved machining performance.

## II. METHODOLOGY

This study was conducted on a CHEMER EDM type CM 323C, as shown in Figure 1. A cylindrical solid brass electrode with a 10 mm diameter and a convex end was used as the tool material in the experimental work to cut a depth of 2 mm in an AISI 314 steel plate. Table I lists the main parameters adopted in the investigation.



Fig. 1. CM 323C EDM machine employed for the experimental work.

## III. DESIGN OF EXPERIMENTS

This study selected three parameters as response and control variables, as listed in Table I. Minitab was also used to determine the total number of the experiments adopted in this work, as illustrated in Figure 2.

TABLE I. MACHINING PARAMETERS USED IN THE STUDY

Code	Factor	Machining parameter	Level			
			1	2	3	4
A	I	Pulse-current (A)	2	6	10	14
B	Ton	Pulse-time (μs)	25	50	75	100
C	Toff	Pulse-time (μs)	18	37	50	75

### I. CAMERA ADJUSTING SYSTEM

The image-assisted setup consists of a digital camera (SONY DSC-HX50) connected to a computer via USB. The acquired data are recorded in image pixel units, while the brass electrode wear area is registered in mm. Therefore, the units were scaled to mm/pixel. MATLAB is adopted for processing the captured brass electrode images in the image-assisted wear evaluation.

### II. EXPERIMENTAL WORK

In this investigation, a total of twelve experiments were conducted. In each experiment, the length of the cylindrical brass electrode with a convex end was measured using a digital caliper before and after the cutting operation. The average electrode length was recorded, accordingly. The camera

captured images of the electrode along its length before and after the machining process. These images were then processed using the Image Processing Toolbox. The processed images were first converted to grayscale, and then to binary format to reduce the processing time and eliminate the unwanted background objects. Figure 3 depicts the captured cylindrical brass electrode with a convex end.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Current	Ton	Toff						
1	2	25	18						
2	2	50	37						
3	2	75	50						
4	2	100	75						
5	6	25	37						
6	6	50	18						
7	6	75	75						
8	6	100	50						
9	10	25	50						
10	10	50	75						
11	10	75	18						
12	10	100	37						

Fig. 2. Design of Experiments (DOE) generated using Minitab.

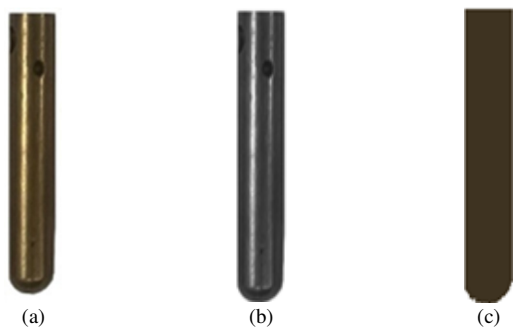


Fig. 3. The captured cylindrical brass electrode with a convex end: (a) colored image, (b) grayscale image, (c) binary image.

Table II lists the average electrode lengths measured before the cutting process, using a digital caliper and the proposed image-assisted electrode wear method, respectively.

After the EDM process, an image overlapping technique was applied to the images captured before and after the machining, creating a composite view, as illustrated in Figure 4(a). After the overlapping process was completed, the electrode image was scanned line by line to detect the intensity value of each pixel in the new electrode scene, starting from the left and proceeding to the right along the brass electrode. The results of this analysis for the cylindrical brass electrode with a convex end are presented. Figure 4(b) demonstrates a dark region indicating the wear on the tested brass sample.

TABLE II. MEASUREMENT OF THE CYLINDRICAL BRASS ELECTRODE LENGTH BEFORE THE EDM PROCESS

Sample	Length using the digital caliper (mm)	Length using the proposed image-based method (mm)	Error (%)
1	40.12	39.98	0.35
2	40.16	39.94	0.55
3	40.13	40.08	0.12
4	40.12	39.90	0.55
5	40.11	39.92	0.47
6	40.09	39.93	0.40
7	40.10	39.92	0.45
8	40.09	39.95	0.35
9	40.11	39.99	0.30
10	40.13	40.05	0.20
11	40.12	39.98	0.35
12	40.09	39.89	0.50
Average	40.11	39.96	0.38
Std. Dev.	0.02	0.06	0.13

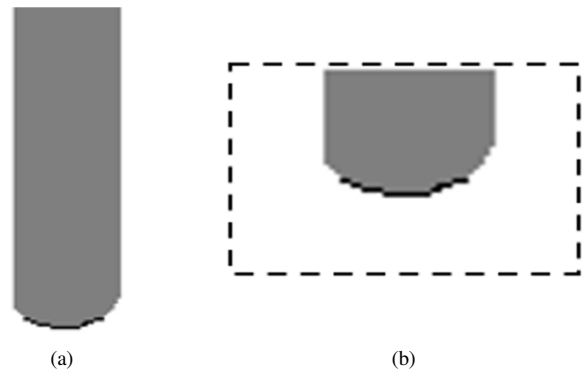


Fig. 4. Cylindrical brass electrode: (a) overlapped electrodes with convex end (b) enlarged view highlighting the worn region.

Table III and Figure 5 present the average length measurements of the cylindrical brass electrode obtained using a digital caliper and the image-assisted method, respectively, after the EDM process.

TABLE III. AVERAGE LENGTHS OF CYLINDRICAL BRASS ELECTRODES AFTER THE MACHINING PROCESS

Sample	Length using the digital caliper (mm)	Length using the proposed image-based method (mm)	Error (%)
1	39.51	39.35	0.40
2	39.47	39.40	0.18
3	39.45	39.35	0.25
4	39.43	39.34	0.23
5	39.52	39.46	0.15
6	39.56	39.46	0.25
7	39.47	39.43	0.10
8	39.61	39.56	0.13
9	39.59	39.55	0.10
10	39.62	39.49	0.33
11	39.58	39.53	0.13
12	39.53	39.46	0.18
Average	39.53	39.45	0.20
Std. dev.	0.06	0.07	0.09

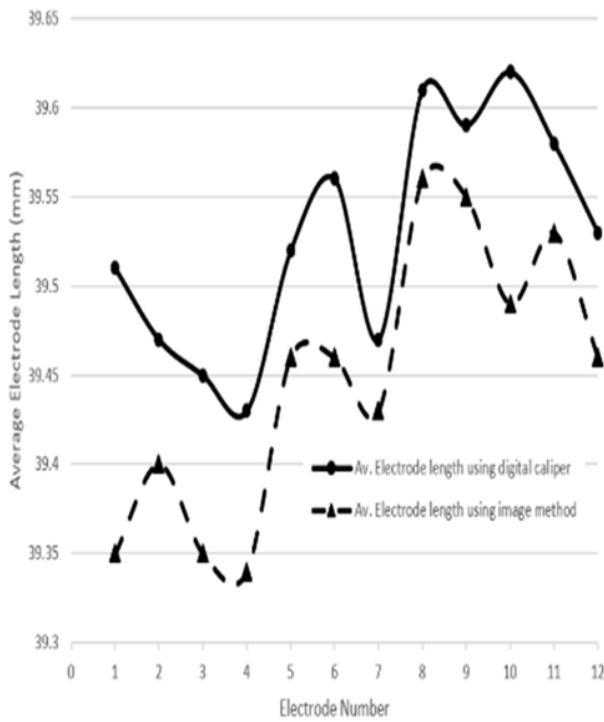


Fig. 5. The average cylindrical brass electrode lengths measured using the proposed methods.

III. RESULTS AND DISCUSSION

Table IV and Figure 6 illustrate the wear measurements of the cylindrical brass electrodes after the EDM process, which were attained using a digital caliper and the proposed image-assisted method, respectively. Obtaining wear values from a single captured image is a challenging task. Consequently, the proposed technique was successfully demonstrated and yielded good results.

TABLE IV. WEAR MEASUREMENT OF CYLINDRICAL BRASS ELECTRODES (mm) WITH ERROR (%)

Sample	Length using the digital caliper (mm)	Length using the proposed image-based method (mm)	Error (%)
1	0.62	0.63	0.62
2	0.67	0.53	0.67
3	0.65	0.71	0.65
4	0.69	0.55	0.69
5	0.60	0.45	0.60
6	0.52	0.46	0.52
7	0.61	0.50	0.61
8	0.50	0.40	0.50
9	0.54	0.46	0.54
10	0.52	0.58	0.52
11	0.51	0.46	0.51
12	0.58	0.42	0.58
Av.	0.58	0.51	0.58
Std. dev.	0.06	0.09	0.06

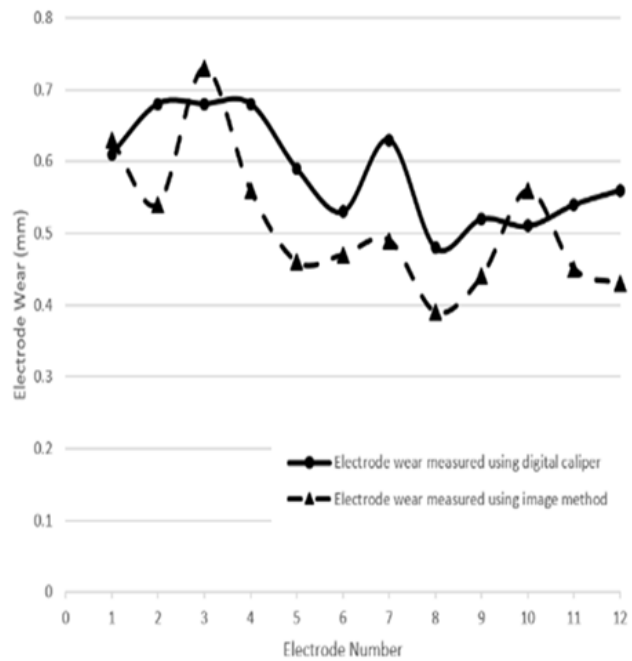


Fig. 6. Cylindrical brass electrode wear measured using the proposed method.

The comparison graph in Figure 6, showing the wear results measured using a digital caliper and the adopted image-based method, indicates that there was no significant deviation between the two measurement approaches. Based on the measurements attained through the digital caliper, the highest wear occurred in the electrode number 4 (0.69 mm), while the lowest wear was observed in the electrode number 8 (0.50 mm). Regarding the image-assisted wear measurement method, the highest wear value was recorded in the electrode sample number 3 (0.71 mm), while the lowest wear was observed in the electrode sample number 8 (0.40 mm).

These fluctuations in the cylindrical electrode wear measurements using the adopted image-assisted method are due to undesired background objects and image distortions, which result from the selected image threshold value.

IV. CONCLUSION

The present experimental investigation proposes a simple and effective method for computing the wear in cylindrical brass electrodes during the Electrical Discharge Machining (EDM) process. Consequently, the proposed image-assisted wear measurement method for the cylindrical brass electrodes successfully distinguished and computed the wear values close to the actual measurements. The resulting values were achieved owing to a proper camera adjustment and positioning, relative to the target scene, along with an effective image thresholding process. The resulted wear values demonstrated that there is a slight skewed between the wear determined using a digitized caliper tool and the proposed image-assisted wear measurement, which verified the introduced method. Based on the key findings of this experimental work regarding the use of inexpensive tools for the EDM electrode wear estimation, the

percentage of deviation between the proposed method and the digital caliper-assisted measurement method was found to be 0.06%. For future work, it is proposed to apply the introduced method to estimate the Material Removal Rate (MRR) and electrode wear rate for various electrode shapes and materials.

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