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Experimental Investigation on Mechanical Characterization of Electrodeposited Shot Peened Copper Coated and Un-Coated Mild Steel

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Abstract

The fatigue strength of fabricated copper coating on mild steel specimens under repeated loading and the overall number of cycles to failure has been investigated. The specimens of copper coating on mild steel substrate are fabricated by using an electro deposition shot peening method. The hardness behaviour of fabricated specimens studied and the experimental work has been carried out by using Vickers Micro Hardness under the load of 20N force. The specimen's surface morphologies are examined using a scanning electron microscope (SEM). S/N ratio analysis is used to investigate the effects of process factors on the micro hardness of copper coated and shot peened specimens. The design of experiment is used to evaluate in order to rank the parameters. The micro hardness of the copper coating is found to be primarily influenced by the voltage and speed of the depositions. Analysis of Variance (ANOVA) test is used to evaluate the influence of variables in this experimental work. Statistical tools like S/N ratio and ANOVA enhance the reliability of conclusions by ensuring that findings are robust and data-driven. This systematic approach provides valuable insights for improving the performance and reliability of materials treated with processes like copper coating and shot peening, which are widely used in industries such as aerospace, automotive, and electronics.

Keywords: Electro deposition, shot peening, hardness, taguchi approach, analysis of variance (ANOVA)

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INTRODUCTION

Copper coating is a mechanical technique commonly employed to cover the surface of an object. The application of this coating serves ornamental, practical, or both purposes, depending on the specific requirements. Besides aesthetics, the coating technology also offers practical benefits by modifying the mechanical characteristics and surface properties of the object. The process of copper coating involves the deposition of a thin layer of copper onto the surface of another material. One effective method for achieving this is electro deposition, which utilizes an electric current to facilitate the plating process. In the case of copper coating on mild steel, the primary objective is to provide a protective layer that prevents corrosion of the underlying material. Electro deposition not only safeguards the original material from corrosion but also enhances its mechanical qualities. The deposited copper layer can improve properties such as adhesion, corrosion resistance, wear resistance, wettability, and even lower the temperature of the coated material. Several factors influence the quality and characteristics of the electrodeposited material [1-2].

The radiation and corrosive effects, which can lead to a decrease in performance and permanent failure of devices and component parts made from that material. In response to these issues, current research aims to enhance the hardness of the coated material and investigate the surface morphology of specimens with copper coatings. One technique being explored in this context is shot peening. Shot peening involves bombarding the surface of a material with small metallic particles (shots) to induce compressive residual stresses and improve its mechanical properties. In the case of case hardened steel, shot peening is being studied to understand its effects on the material [3-5]. Copper electroplating is indeed a well-known and widely used industrial surface finishing method [6].

It involves the deposition of a layer of copper onto the surface of a material using an electrochemical process. This technique offers various benefits, including improved aesthetics, enhanced corrosion resistance, and increased durability. Surface treatments play a crucial role in improving the fatigue life of materials. Fatigue is the process of progressive and localized damage caused by cyclic loading, which can lead to failure over time. Surface treatments aim to mitigate fatigue effects and improve the fatigue strength of materials [7-8].

In the experiment, the objective is to improve the mechanical properties of low carbon steel industrial waste by electro coating it with copper. One of the factors considered in the electro deposition process was the current density. Current density refers to the amount of electric current passing through a unit area during electroplating. It plays a significant role in determining the characteristics of the coating matrix. The anodic area and cathodic area in the coating matrix are directly affected by the current density [9].

Intensity refers to the measurement of the indentation-making power of the media used in shot peening. It is influenced by various parameters, including the velocity of the shots, the angle of impact, and the hardness of the media. Higher intensity generally leads to deeper and more pronounced indentations on the surface, resulting in increased compressive residual stresses and improved mechanical properties. Coverage is the ratio of the indented area to the target material's entire surface area. It represents the percentage of the surface that has been impacted by the shots. Achieving the desired coverage ensures that the entire surface is treated uniformly, avoiding any untreated areas. Proper coverage is crucial for obtaining consistent and predictable results in terms of surface integrity and mechanical performance. The media size refers to the diameter of the shots used in the shot peening process. The size of the media affects the depth and shape of the indentations created on the material's surface. Finer media will produce shallower indentations, while larger media will create deeper and more aggressive indentations. The selection of media size depends on the specific application, the material being treated, and the desired outcome [10]. Using standardised Almenstrips intensity is measured [11]. The static indentations caused by stresses are identical to those produced by drop experiments [12]. The plastic elongation of the surface layer at the maximum shear stress depth is due to high pressure [13].The residual stresses are often assessed using X-ray diffraction or hole drilling techniques [14]. Shot peening was performed on a variety of steel and aluminium alloys by Wang et al. [15]. The depth of the compressive residual stress maximum as a function of the peening intensity, yield strength, and tensile strength of the material [16].

Harada et al. investigated compressive residual stresses up to 2000 MPa in a case-carburized steel SCM420 [17]. Menig et. al. [18] experimentally demonstrated the uniform distribution of tensile stresses that has undergone shot peening on both sides using neutron diffraction. The width of the X-ray diffraction will be peak at half of its highest value as the full width [19–21]. Same behaviour for annealed 42CrMo4 steel was observed by Zinn and Scholtes [22]. The three key shot peening effects on gear fatigue life are residual stresses, microstructure, and surface roughness [23].

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MATERIALS AND METHODS

Shot peening and electro deposition are two different techniques used in surface treatment to improve the mechanical properties of surfaces. Shot peening is a mechanical surface treatment process in which small spherical particles, called shot, are propelled at high velocity onto a material's surface. The impact of the shot creates compressive residual stresses on the surface, which helps to increase the material's resistance to fatigue and stress corrosion cracking. Shot peening is commonly used in industries such as aerospace, automotive, and manufacturing. On the other hand, electro deposition, also known as electro deposition or electroplating, is an electrochemical process in which a metal coating is deposited onto a substrate material. In the case you mentioned, copper is deposited onto a mild steel.

Preparation of Specimen

The mild steel metal sheet is trimmed to the desired dimensions of 14 mm x 5 mm to make the plate specimen. The fine emery paper is used to clean the surface area of fabricated specimen. Then the specimens are washed with deionized water for removal of any impurities present on the surface of the specimens. Figure 1 shows the specimens used for experimental work.

Preparation of Electroplating Solution

The electrolyte solution of 600 ml is prepared. The elements added are 60g of copper sulphate, 0.75g sulphuric acid, 0.18g potassium sulphate, and a trace quantity of the urea is employed. The electrolyte solution is continually stirred using a glass stirrer.

Deposition Process and Shot peening

The electrolyte solution is rotated using a magnetic stirrer for stirring purposes. During the deposition process, a direct current (DC) power source at the necessary voltage is applied. The beaker with the ready-made electrolyte solution is set down on the magnetic stirrer platform. The copper metal and the mild steel specimen are joined to the DC power supply system and submerged in the electrolyte solution. The power supply's negative terminal (Cathode) is connected to the specimen of mild steel, while the positive terminal (Anode) is connected to the copper metal. Figure 2 shows the experimental setup used for the experimental work.

The stir bar is spun in the electrolyte solution at the desired speed for the predetermined amount of time. The copper deposition is ensured after the deposition process. Figure 3 shows the uncoated and coated specimen. The deposition parameters are monitored with different combinations of speed, duration, and voltage on additional mild steel specimens. Table 1 provides list of parameters preserved during the electroplating process for plate and round rod mild steel specimens.

The shot peeing is done after the electroplating procedure. The parameters blasting time, voltage, and blasting wheel rpm, are set in the control panel. The specimens are impeached using metal balls with extremely tiny diameters and high speeds. The component with a lower cross sectional area is shot peened in order to save weight. The test parameters for electroplated and shot-peened specimens for both case I and II are shown in Table 2.

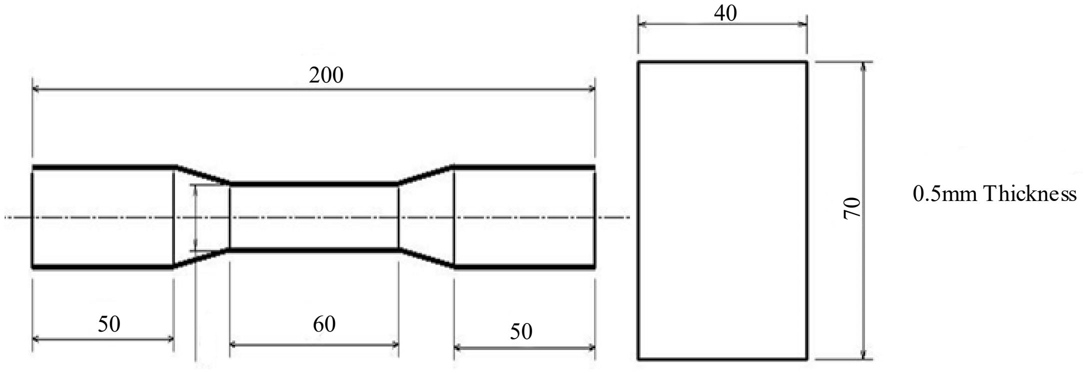

Figure 1. Mild steel Plate Test specimen and fatigue test rod specimen of 20 mm diameter.

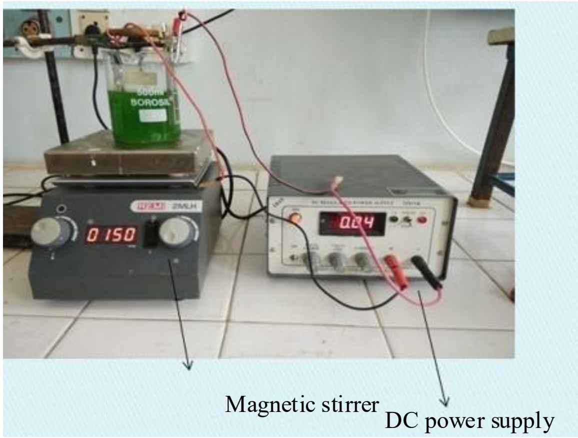

Figure 2. Electro deposition set up.

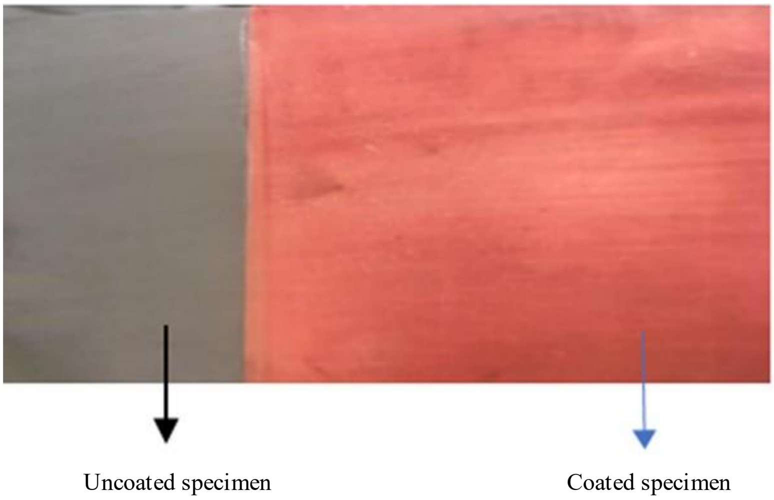

Figure 3. Copper coated mild steel specimen.

Electrodeposition Parameters

The voltage, current density, and deposition time were selected based on preliminary experiments and prior literature [3]. These parameters were optimized to achieve a uniform copper coating with desired thickness and adhesion properties. Specifically:

- *Voltage*: Chosen to balance deposition rate and coating quality, avoiding issues such as dendritic growth or poor adhesion.
- *Time*: Optimized to achieve a coating thickness which previous studies have shown to provide adequate protection and enhanced mechanical properties.
- *Electrolyte composition and temperature*: Controlled to ensure uniform deposition without excessive heating or agitation effects.

The voltage, speed, and time combinations were chosen through a trial-and-error approach to optimize the electrodeposition process. By systematically varying these parameters, we identified the most effective conditions for achieving uniform coating, optimal thickness, and improved mechanical properties of the copper-coated mild steel.

RESULT AND DISCUSSION

Here is a summary of all results from the whole investigation and how process factors affected each case are Specimens made of standard mild steel round rod and plate, only mild steel specimens shot-peened, and Mild steel specimens electroplated and shot peened.

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Table 1. List of parameters maintained in the electroplating process.

Trials	Voltage (Volts)	Speed (rpm)	Time (sec)
1	0.3	250	25
2	0.3	350	25
3	0.3	450	25
4	0.3	250	20
5	0.3	350	20
6	0.3	450	20
7	0.3	250	15
8	0.3	350	15
9	0.3	450	15
10	0.6	250	25
11	0.6	350	25
12	0.6	450	25
13	0.6	250	20
14	0.6	350	20
15	0.6	450	20
16	0.6	250	15
17	0.6	350	15
18	0.6	450	15
19	0.9	250	25
20	0.9	350	25
21	0.9	450	25
22	0.9	250	20
23	0.9	350	20
24	0.9	450	20
25	0.9	250	15
26	0.9	350	15
27	0.9	450	15

Table 2. Electrodeposited process parameters of fatigue test specimen (Case I & II)

Electroplated and shot peened (Round rod) specimens			
Trials	**Voltage (Volts)**	**Speed(rpm)**	**Time (sec)**
1	0.3	450	25
2	0.6	450	25
3	0.9	450	25

Composition Test

The thermo scientific Niton XL12 Analyzer is used for the composition test of mild steel specimens. This composition test is conducted before and after the electroplating procedure and the shot-peeing procedure. The parameters used during test are voltage (0.3 volts, 0.6 volts and 0.9 volts), speed (450 rpm, 350 rpm, and 250 rpm) and time (25 sec, 20 sec, and 15 sec).

The mild steel is composed of 98.6% (Fe), 0.156% manganese (Mn) and 0.312% silicon (Si). Table 3 shows the composition of normal mild steel specimen. Table 4. indicates composition of electrodeposited shot peened specimen conducted through thermo scientific Niton XL12 Analyzer

Table 3. Composition of Normal Mild steel specimen.

Cu%	Fe%	Mn%	S%	Si%	Co%	R%	Bi%
-	98.6	0.1	-	0.08	-	-	-

Table 4. Composition of Electroplated Shot peened specimen.

S N	Cu%	Fe%	Mn%	S%	Si%	Co%	R%	Bi%
i.	18	79.5	0.18	1.84	-	0.22	-	-
ii.	10.5	84.9	0.20	3.95	0.14	0.13	-	-
iii.	14	84.1	0.17	1.25	-	0.19	0.01	-
iv	18.8	79.3	0.18	1.25	0.13	0.13	.009	
v	17.4	80.3	0.17	1.57	0.25	-	-	-
vi	14.6	82.9	0.17	1.69	-	0.17	-	.009
vii	11.4	85.1	0.19	2.93	0.16	0.15	-	-
viii	10.7	85.6	0.16	3.13	0.17	-	-	-
ix	9.81	86.0	0.2	3.49	0.24	0.16	-	-

Fatigue Test

The fatigue test is conducted to examine specimen's behavior under various amounts of stress without failing. The four different specimen's endurance limit and the number of cycles before failure are recorded. The R R Moore bending testing apparatus is used to conduct the test. The three primary components of the machine are set for experimental work: spindle heads with drives, cycle's counters, and loading mechanisms. The test specimens are held by the spindle head with drive, which also transfers the testing load to the sample. The test specimens are held in place by the grippers on the spindle head, which is also linked to the electric motor via a belt and a single iron rod.

The spindle rotates at 4200 revolutions per minute. One of the crucial components of the fatigue test is the loading mechanism. It is utilised to provide the test specimens the necessary amount of bending moment. The table 5 shows the experimental results for both case I and Case II.

The shot peened specimen runs more cycles (64905) than the other specimens. Shot-peened electroplated specimens are subjected to the calculated number of cycle losses.

Table 5. Fatigue test values.

<table>
<tr><th colspan="3">Specimen type</th><th>No. of cycles to failure</th></tr>
<tr><td colspan="3">MS Specimen</td><td>50247</td></tr>
<tr><td colspan="3">Shot peened specimen</td><td>64905</td></tr>
<tr><td colspan="4">Case I: Electroplated- shot peened specimen.</td></tr>
<tr><td>Voltage</td><td>Speed</td><td>Time</td><td></td></tr>
<tr><td>0.3</td><td>450</td><td>25</td><td>39853</td></tr>
<tr><td>0.6</td><td>450</td><td>25</td><td>18003</td></tr>
<tr><td>0.9</td><td>450</td><td>25</td><td>17764</td></tr>
<tr><td colspan="4">Case II: Shot peened- Electroplated specimen</td></tr>
<tr><td>Voltage</td><td>Speed</td><td>Time</td><td></td></tr>
<tr><td>0.3</td><td>450</td><td>25</td><td>4075</td></tr>
<tr><td>0.6</td><td>450</td><td>25</td><td>4408</td></tr>
<tr><td>0.9</td><td>450</td><td>25</td><td>4421</td></tr>
</table>

SEM Analysis

To determine the morphology, SEM examination is carried out on four specimens at various magnifications. The pattern of element particle deposition in the normal mild steel specimen, as well as in the deposition for electroplated specimens before and after the shot peening, is seen and evaluated during the scanning at various magnifications. Particle deposition is affected by a variety of factors like voltage, speed, and time. Figure 4 illustrates a mild steel specimen's normal morphology picture during SEM investigation. Impurity particles are denoted by arrow marks.

The fabricated specimens' cross-sectional micrographs are examined. The dashed lines indicate the roughly defined boundaries between the coarse- and fine-grained zones. The surface particle arrangement in each specimen is visible by microscopy. Because of the impact on the surface, shot peened specimens' surfaces shows the distribution of embedded particles. The shot peened specimens can be seen in cross-sectional SEM observation in Figure 5, which shows the establishment of a dense structure and higher density of grain boundaries as a result of the applied peening's increased kinetic energy. The surface morphology of the typical mild steel specimen is shown in Figure 6 under various magnifications. The scanning pictures shows small impurities present on the surface of the specimens.

Shot Peened and Electroplated Shot Peened SEM Analysis

Figure 6 depicts the surface morphology of a Electroplated shot-peened specimen Increasing the kinetic energy of the shot peening process reveals the enhancement of the depth of the densely structured layer that was plastically deformed. Increased applied kinetic energy lowered the surface layer grain size up to nano-structure regime and resulted in considerable surface grain refinement in severe and overshot peening treatments. It is observed that excessive shot peening results in micro cracks and many surface flaws.

Analysis of Taguchi results for Micro hardness

The size or depth of the indentation indicates the material's micro hardness. The application of load to the specimen indentation is created. When a specimen is loaded during testing, elastic deformation developed in the specimen. The plastic deformation is created by the energy absorbed during the indentation, and any remaining energy raises the surface free energy. The results of the micro hardness test, S/N ratio calculations, and average surface roughness values are arranged according to the L27, orthogonal array, which is the most common type of standard orthogonal array and is employed frequently in design experiments. The micro hardness value is the primary responsible data, while voltage, speed, and time are considered to be the opposing components, as shown in the below table, which arranges all results in the form of an L27 orthogonal array.

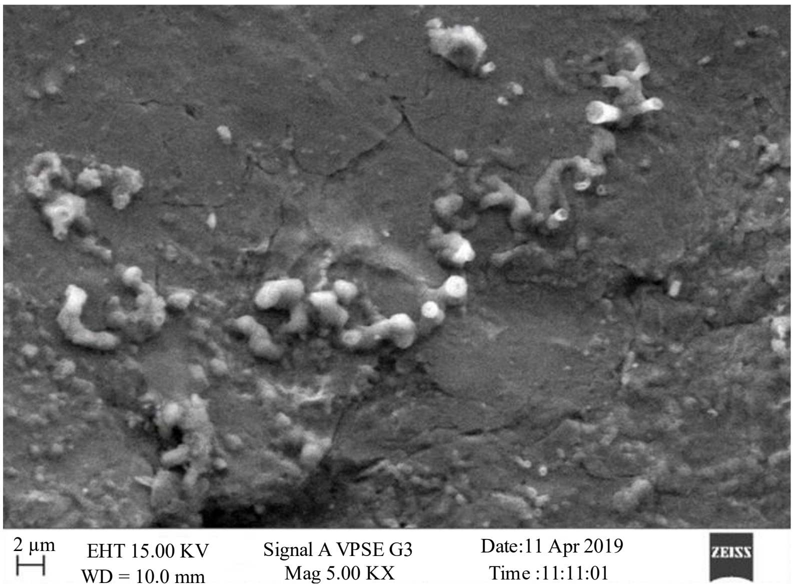

Figure 4. Normal Specimen Morphology image (1000X).

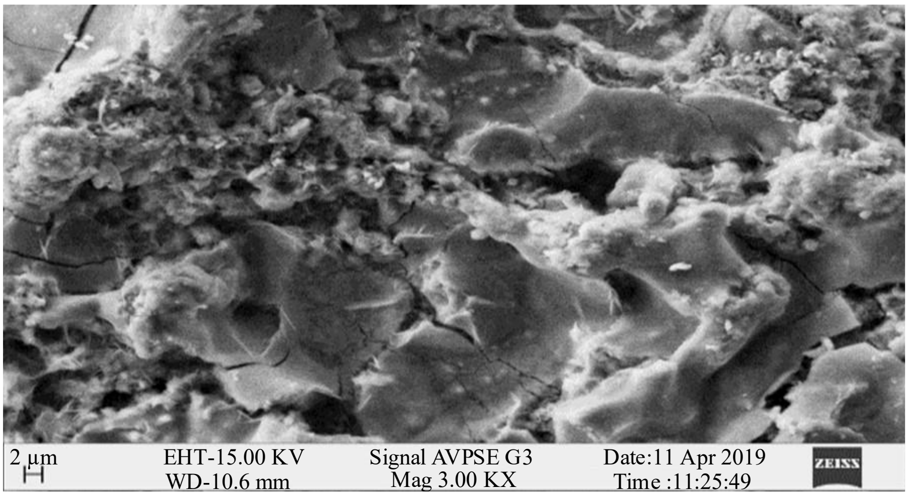

Figure 5. Shot peened specimen morphology image (5000X).

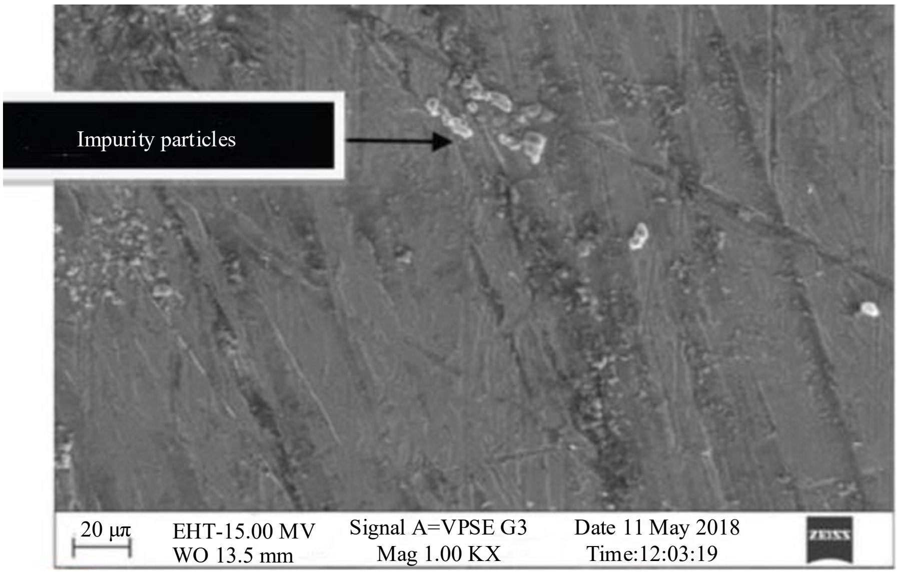

Figure 6. Morphology image of electroplated shot peened specimen under 3000X (V=0.3, S=450 rpm, T=25sec) and Morphology image under 5000X (V=0.3, S=450 rpm, T=25sec).

Table 6. Mean S/N ratio values for parameters on Micro Hardness.

Level	V	S	T
1	47.53	48.22	48.54
2	49.30	48.73	48.82
3	49.17	49.05	48.65
Delta	1.76	0.83	0.27
Rank	1	2	3

Table 7. Mean effects of parameters on Micro hardness.

Level	V	S	T
1	240	260.5	269.5
2	292.1	274.5	276.8
3	287.7	284.6	273.4
Delta	52.1	24.0	7.3
Rank	1	2	3

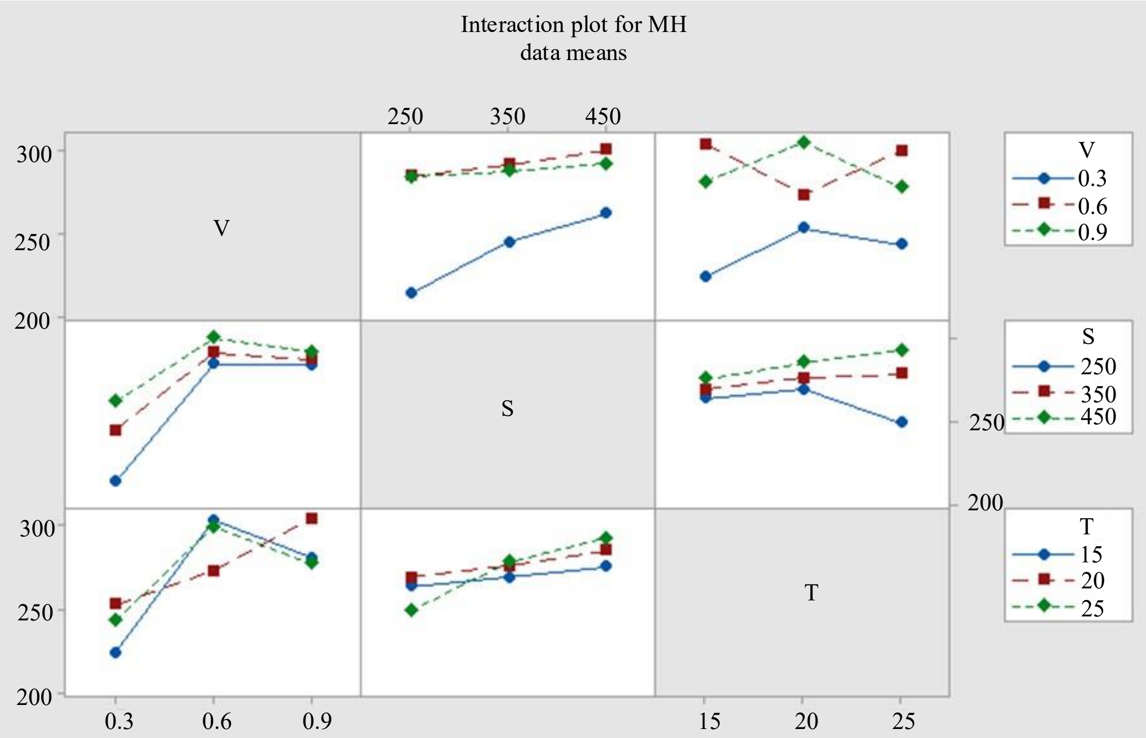

Figure 7. Interaction plot for micro hardness voltage and time.

The Tables 6 and 7 show the mean signal to noise ratio and mean effect parameter for microhardness for the fabricated specimens. The Figure 7 shows the importance of S/N ratio and the interaction mean plot of micro hardness, voltage, speed, and time.

CONCLUSION

The experimental investigation on mild steel plate coated with copper by electroplating and shot has been carried out to study the behavior of fabricated specimens. The fatigue test for these fabricated specimens reveals that shot peened normal mild steel specimens exhibits better results than shot peened electroplated mild steel specimens in terms of cycles before failure. As compared to standard mild steel specimens, shot peened electroplated specimens will have higher deposition mass, coating thickness, and average roughness values. SEM morphology reveals the surface particles are arrangement in a systematic order in all specimens. The impact on the surface of shot peened specimens' display the distribution of embedded particles. The process factors like voltage, speed, and time influence the electrodepositing process, Experimental data analysis using Taguchi reveals that the deposition's voltage and speed parameters are more significant in enhancing mechanical properties of the specimens.

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