Journal of Techniques, ISSN: 2708-8383, Vol. 5, No. 3, 2023, Pages 194-201
DOI: https://doi.org/10.51173/jt.v5i3.1608

JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

RESEARCH ARTICLE - ENGINEERING

The Effect of Electroplated Ni Nanocoating on Fatigue Life of 1020 AISI Low Carbon Steel

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Article Info.

Article history:

Received
28 May 2023

Accepted
02 August 2023

Publishing
30 September 2023

Abstract

Low carbon steel 1020 AISI has been selected in this study to show the influence of Ni Nano coating on fatigue life of this metal under fatigue loading at room temperature with a stress ratio R= -1. The prepared specimens are exposed to electroplated process using Nano nickel with 40 nm at diverse situations to improve the fatigue limit of metal. (SCHENCK PUNN) rotating bending fatigue test, hardness, tensile strength, microstructure, surface roughness and SEM, XRD diffraction tests have been completed for base metal and electroplating treated metal. The experimental results indicate that Ni nano coating by electroplating improve the fatigue life at due to steel substrates are typically polished mechanically and chemically before deposition to enhance the fatigue properties and nano nickel have fair distribution on steel surface.

Publisher: Middle Technical University

Keywords: Electroplating; Low Carbon Steel 1020 AISI; Fatigue Life; Fatigue Strain; Nano Coating.

1. Introduction

Coating substances is done for a variety of purposes such as corrosion prevention, wear resistance, hardness, and attractive objectives. The metal coating techniques include electrochemical and electroplating. It is known that electroplating technology can be used to create coatings in complicated models (galvanic plastics) and to apply thin coatings to objects to protect metals, mostly from corrosion (galvanization), as it is previously noted. Metal coatings are made by electroplating method that uses electric current and electrochemical reaction [1]. Copper, nickel, chromium, zinc, tin, cadmium, silver, gold, and other metals can be used to make coatings. Electroplating is one of the most challenging surface improvement techniques for pre-treatment products [2, 3]. This is obvious as the defined phase contact is necessary for the transport of metal ions from solution onto the surface of cathode and their incorporation into the crystal lattice. Surface and technical equipment demonstrate the state of the electroplating cell. Nickel is one of the popular metals that is used in electro-deposition [4,5,6]. Low carbon steel is frequently nickel-plated in industrial settings because it reduces corrosion fatigue. One of the popular types of carbon steel is low carbon steel (also known as mild steel) which is employed because of its low cost and outstanding workability. This kind of steel typically contains less than 0.25 % weight of carbon. They cannot be heat treated to harden (to generate marten site), hence its hardening is often accomplished through cold work. It is commonly employed in the construction of bridges, beams, channels, and other structural shapes, as well as vehicle body parts [7].in this study Nano Nickel was used for electroplating process at different parameter of low carbon steel AISI 1020 and its effect on fatigue life, One of the first inventions, metal coating, also known as surface finishing, is notable for improving the appearance and functionality of the material it shields. By metallic and non-metallic items referred to as substrates, it can be employed as a surface protectant Nickel plating is undoubtedly of the most used metal finishing techniques. In a variety of engineering and non-engineering applications, these coating processes produce hard corrosion-resistant, and endurable surfaces. These methods are crucial from a martial perspective, for instance, U.S.A. fleet aircraft carriers encountered breakdowns of the aircraft flight mechanism after an interval of operation due to wear and corrosion [3].

2. Experimental Work

2.1. Marital used

AISI 1020 low carbon steel (LCS) is preferred and is utilized in numerous steel parts, including shafts, building structures, and bridges. Chemical evaluation is performed by ("Thermo ARL3460, optical Emission spectrometer"). Table 1 lists the results.

2.2. Categorization of Specimen

Specimens are divided into groups as shown in Table 2.

Nomenclature & Symbols			
Ni	Metal Nickel	LCS	AISI 1020 Low Carbon Steel
DPR	Disproportionation Reaction	PVD	Physical Vapour Deposition
XRD	X-Ray Diffraction	CEC	Composite Electrochemical Coating
SiC	Silicon Carbide	SEM	Scanning Electron Microscopy
Nf	Number of cycles until failure	σf	Fatigue Stress at Failure (MPA)

Table 1. Chemical Analysis of the used metal AISI 1020Carbon steel

item	C%	Mn%	P%	S%	Si%	Ni%	Cr%	Mo%	Cu%	V%
Actual value	0.196	0.65	-	0.014	0.019	0.004	0.004	0.024	0.022	0.002
Standard value	0.14-0.22	0.4-0.65	-	-	-	-	0.05	-	-	-

Table 2. Categorization of specimens

Specimen Symbol	**Condition**	**Categorization of specimen**					
A	As received	Without coating					
			B_1		B_2		B_3
B	Coating at (0.5wt%) Nano Ni	Current Density	0.25A/dm^2	Current Density	0.3 A/dm^2	Current Density	0.35 A/dm^2
			C_1		C_2		C_3
C	Coating at (1wt%) Nano Ni	Current Density	0.25 A/dm^2	Current Density	0.3 A/dm^2	Current Density	0.35 A/dm^2
			D_1		D_2		D_3
D	Coating at (5wt%) Nano Ni	Current Density	0.25 A/dm^2	Current Density	0.3 A/dm^2	Current Density	0.35 A/dm^2

2.3. Microstructure examination

The specimens for the test of microstructure on groups A in Table 2 in the first step grinding by emery paper with different grains size 220, 320, 600, 800, and 1000, Polishing with Alumina Al_2O_3 and special cloth. Then etching by Nital solution (2%) nitric acid (HNO_3) and (98%) of methyl alcohol for 20 seconds, and finally performed the microstructure test by using a microscope programmed kind ("Advanced Polarizing Dark–field, Metallurgical Microscope MTj Corporation") is carried out of base metal as it is shown in Fig. 1.

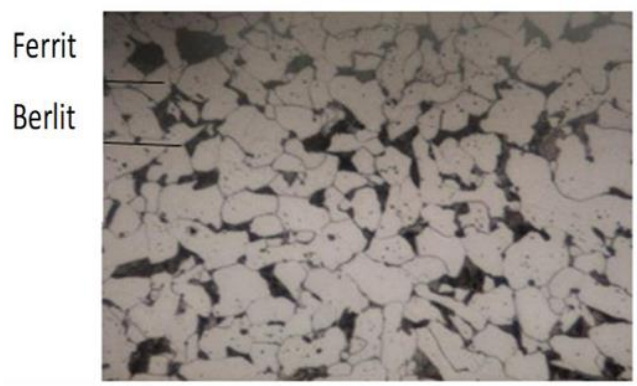


Fig. 1. Microstructure of base metal at 40X

2.4. Preparation of testing specimens

Many test specimens are prepared from used metal.

2.4.1. Tensile Tests Specimens

Many tensile tests specimens are produced using a CNC machine from low carbon steel (LCS) alloy in a circular cross section with required dimensions in compliance with the ASTM (A370-11) standard, as it is illustrated in Fig. 2.

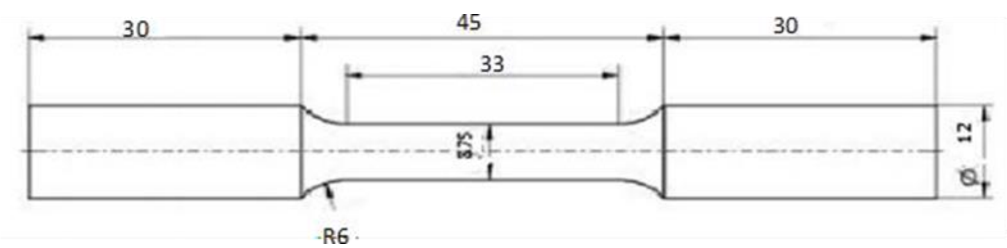


Fig. 2. Tensile test (dimensions in (mm))

2.4.2. Fatigue test specimens

Low carbon steel AISI 1020 fatigue samples are produced using CNC machines in accordance with the ASTM (E8 / E8M09) specification, as it is shown in Fig 3.

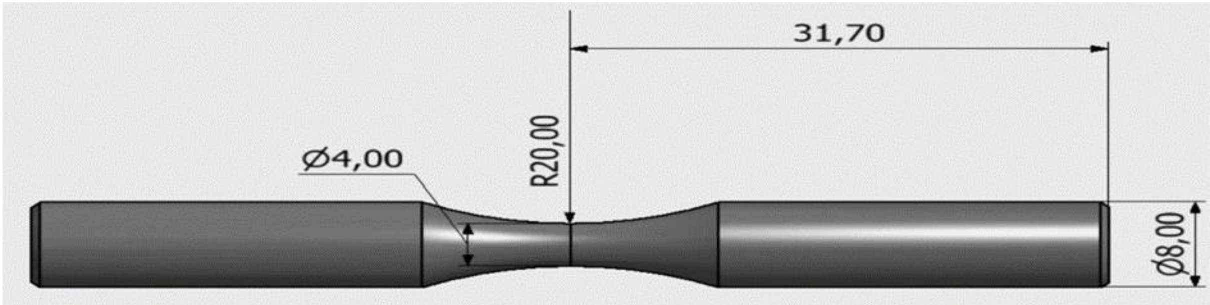


Fig. 3. Fatigue specimens (dimensions in (mm))

All specimens wear are prepared in two steps: grinding and polishing. Various grits of silicon carbide (SiC) emery paper and water are used to finish the grinding process (220,320,500, 800 and 1000). Al2O3 with a particular polishing cloth of (0.1µm) size is used in the polishing process after being cleaned specimens with alcohol and water. All samples are dried using hot air.

2.5. Surface roughness

A nickel-coated steel sample's (Ni-nHAP) surface roughness is assessed by using the (TR-100 surface roughness tester) to assess the surface roughness, as the instrument goes over the sample surface. The gadget features a sensor that measures the sample roughness of the surface and records the result directly on the display of the gadget. The precision of the instrument is (0.01m). The chosen results of the specimens are given in Table 3.

Table 3. Result of surface roughness

Specimens symbol	**A**	**B_1**	**B_2**	**B_3**	**C_1**	**C_2**	**C_3**	**D_1**	**D_2**	**D_3**
Surface Roughness(µm)	0.095	0.34	0.032	0.035	0.085	0.081	0.084	0.055	0.083	0.086

There is a variety in the results of roughness of the surface test according to the variety of specimen symbol condition concentrations coating at((0.5wt%), (1wt%), (5wt%))Nano Ni and current density at (0.25 A/dm^2, 0.3 A/dm^2, 0.35 A/dm^2).

2.6. Preparation of nickel electroplating solution

According to Watt's procedures [6] and using chemical reagents such as nickel sulphate, nickel chloride, boric acid, and formaldehyde as the brightener [2], nickel electroplating solution is created. By weighing each proportion in the weighing balance before dissolving it in a predetermined amount of distilled water, the chemical reagents composition in the solution is altered. A HANNA pH meter is used to measure the solution's pH. Table 4 presents the various concentrations.

Table 4. Modes of Electrochemical Deposition of CEC Based on Nickeled Alloy

Electrolyte composition, g/l	**Watts type g/l** **1**	**High chloride** **2**	**All chloride** **3**	**Floressin** **4**
Nickel sulfate, $NiSO_4$, 6H,0	300	240		
Nickel chloride, $NiCI_2$, $6H_2O$	45	90	240	
Nickel fluoborate,$Ni(BF_4)_2$	30-37.5	30-37.5		
Boric acid			30	
By analysis	77.0	75	75	55
Nickel pH range (electrometric)	2.0-2.5	2.0-2.5	0.9-1.1	
	3.5-4.0			
Low Medium High	4.8-5.2			3.0-4.0
	35-45	34-45	35-45	35-45
Non-pitter: I or II 1. Approved wetting agent to give dynes/ em at 21 ºC (70 F) II. Hydrogen peroxide to give free oxygen, ppm	5-10	5-10	5-10	5-10
For engineering applications as required				
Conditions: Temperature, ºC av.	55	55	55	5
(Practical range)	32-71	38-71	38-63	32-71
Current density A/dm^2 (asf)	1-6	1-6	5-10	5-10
(Possible range)				
Agitation: Cathode and (mild) solution preferred. Air effective in absolute	95-100	95-100	90-100	95-100
Cathode efficiency%				
Ratio anode to cathode area	1:1	1:1	1:1-(3:1)	1:1-(3:1)

(For high current density) Anodes: Nickel, bagged, cast, or rolled, depolarized or carbon type Filtration: Continuous, turn over once every 1 to 4 hr.	6-12	6-12	6-12	6-12
Filter aid and active volts: Suitable material construction	3,4,5,8,13,14	3,4, 8,13,14,15	8,9,12,13,14,15	3, 8,12,13,14

2.7. Preparation of nickel electroplating bath

The bath, which holds the ready electroplating solution, is a plastic bowl. A cathode electrode and an anode electrode are attached to the rectifier by using copper rod that is 6 mm in diameter. The nickel electrode is connected to the anode rod using copper wire as well. The bath is set up according to Watt's standard [6].

2.8. Samples pre-treatment operation

The samples are pickled in 0.5M H2SO4 solution for 2 minutes, rinsed in distilled water and degreased in electrolytic degreasing tank for another 2 minutes. Then, another rinse in distilled water is performed. An OHAUSR digital weighing device is used to obtain the samples' initial weights prior to their immersion in the electroplating bath.

2.9. Electroplating operation

The low carbon steel samples are immersed for constant concentration at a temperature of 50. 5°C during the electroplating runs, and 2 cm^3 of formaldehyde is added to the solution in the electroplating bath at the different bath concentrations as it is reported in Tables 2 and 3. Additionally, the voltage is maintained at 0.5V. The sample is electroplated, cleaned in distilled water, and dried in sawdust to absorb moisture and oils that cause corrosion and reduce fatigue limit so that by using sawdust important to dry the metal, before being finally weighed. The final dimension is measured using the fernier calipers. The plating is also carried out for Current density, voltage and bath volume variations (Tables 2 and 4) Fig. 4. Fatigue Specimens; (A) before nanocoating, (B) after nanocoating.

A B

Fig. 4. Fatigue Specimens; (A) before nanocoating, (B) after nanocoating

3. Testing and Examination

Many tests are conducted on specimens with and without coatings.

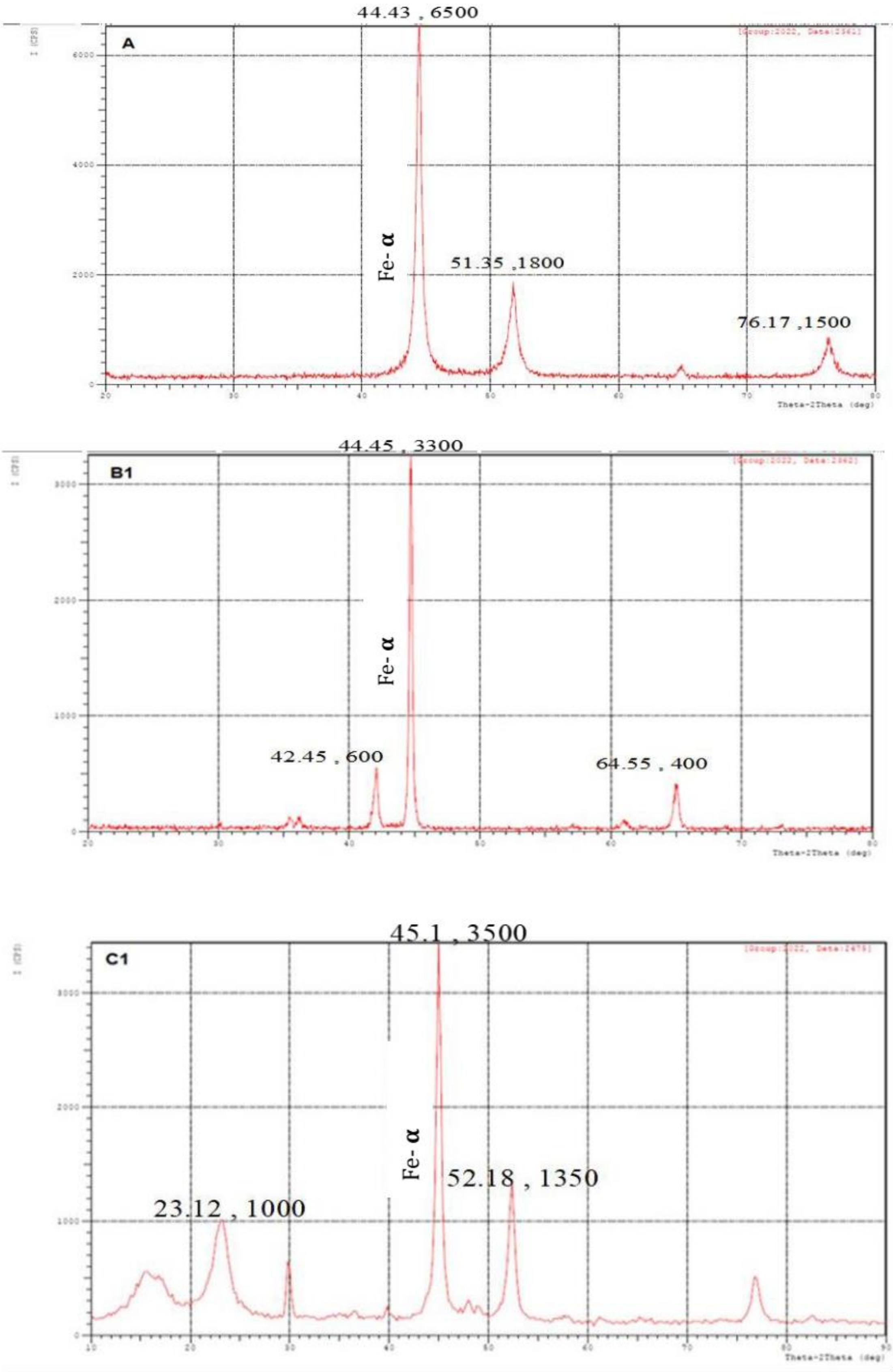
3.1. X-ray diffraction (XRD) tests

AISI 1020 low carbon steel (LCS) is subjected to XRD analysis to identify its phases by using Shimadzu 6000XRD device. It is complete in condition of its Cupper target Kα, (λ=1.541Å), (current= 30mA), (voltage= 40kV)and scan domain(20-80)degree. The result is shown in Fig. 5 and Table 5.

In the Fig. 5 indications the mark of XRD patterns of samples (A, B1, C1, D1) explain the XRD pattern of 2θ, intensity peaks indication to (**α-**Fe)peaks below X-ray count detection limit. This suggests that the lack of a peak is due to the regular distribution of Nano Nickel on surfaces. Fig. 5 shows the approving the existence of crystalline (Fe-α) in the samples (A, B1, C1, D1).

Table 5. Fatigue limit and S-N curve equation for uncoated and coated specimens

Specimens Symbol	Fatigue limit at $(10)^7$ cycle (MPa)	S-N curve Equation
A	232	$\sigma f = 1585Nf^{-0.122}$
B_1	235	$\sigma_f = 1754.3\ N_f^{-0.126}$
B_2	225	$\sigma f = 1227.8Nf^{-0.107}$
B_3	230	$\sigma f = 1591.98Nf^{-0.121}$
C_1	220	$\sigma f = 1486.2Nf^{0.117}$
C_2	225	$\sigma f = 1386.3Nf^{0.109}$
C_3	200	$\sigma f = 1864.6Nf^{-0.135}$
D_1	160	$\sigma_f = 2975.9N_f^{0.181}$
D_2	230	$\sigma_f = 458.83N_f^{-0.031}$
D3	225	$\sigma f = 1429.1Nf^{0.113}$


A
44.43 , 6500
Fe- α
51.35 ,1800
76.17 ,1500
B1
44.45 , 3300
Fe- α
42.45 , 600
64.55 , 400
C1
45.1 , 3500
Fe- α
52.18 , 1350
23.12 , 1000

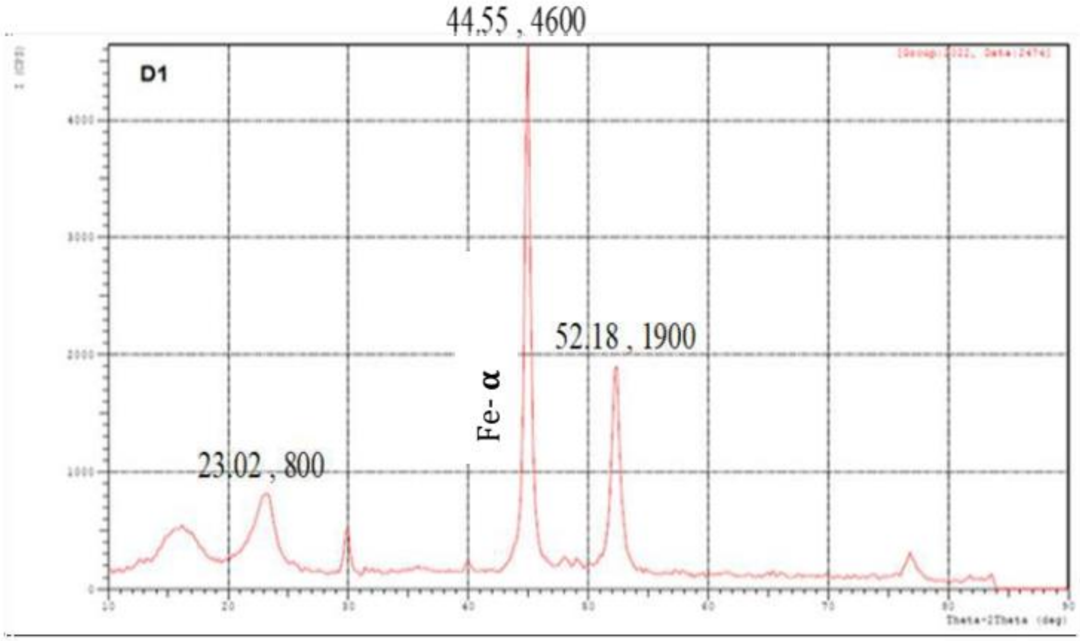


Fig. 5. XRD result of specimens (A, B1, C1, D1)

3.2. Tensile test

Tensile test is carried out at room temperature using the tensile test type (WDW-50) to determine mechanical characteristics including yield and ultimate strength, percent elongation, and Young's modulus. These characteristics are significant because they are utilized to select advantageous materials for suitable applications. The result is shown in Fig 6.

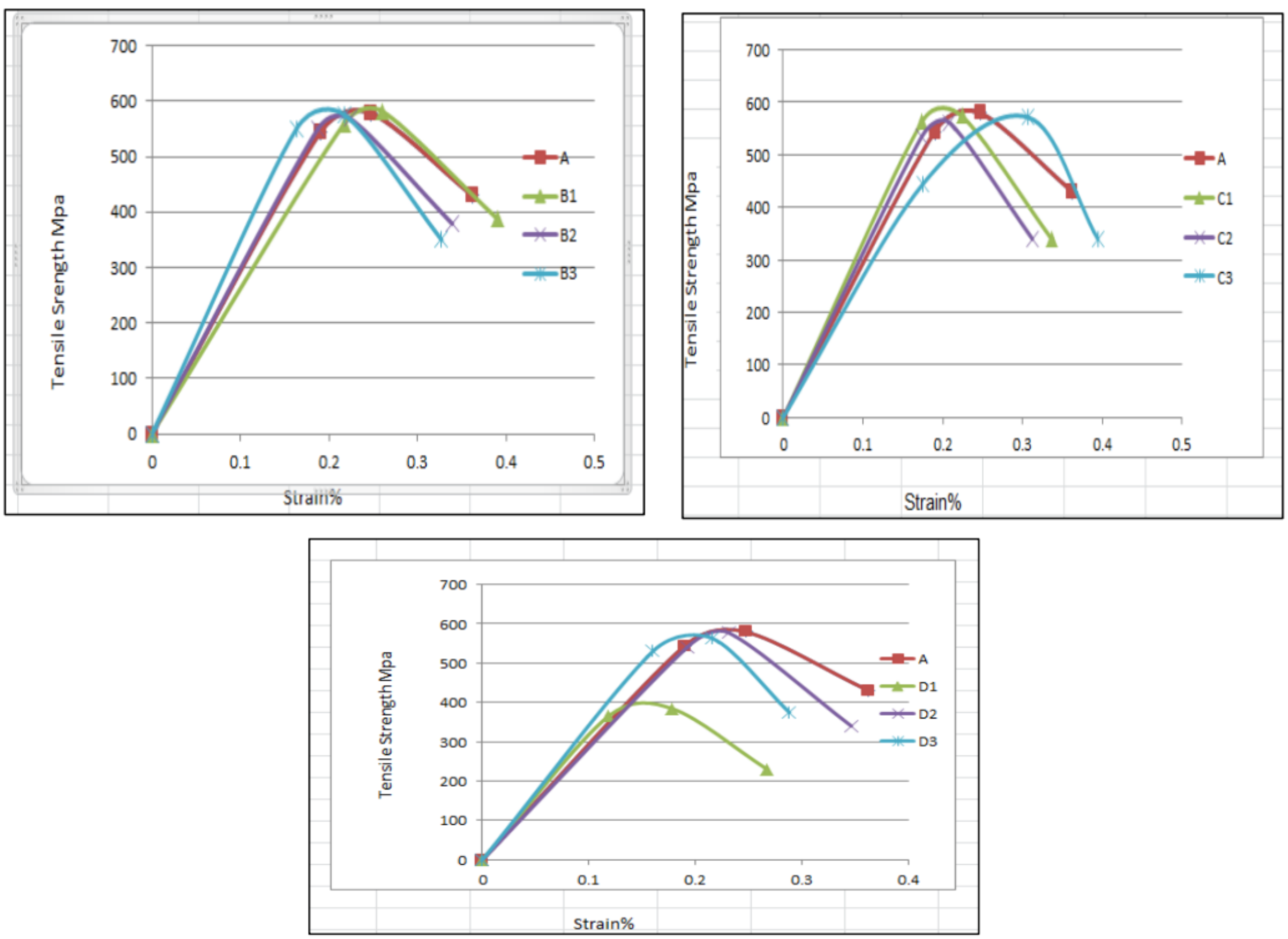


Fig. 6. Tensile test results for all specimens in Table 2

3.3. Fatigue test

Fatigue testing system of style (SCHENCK PUNN) rotating bending is used for all fatigue tests with constant ratio R (-1) A realistic load is applied to the sample from the specimen axis's right side, causing a moment of bending. As a result, when the specimen rotates, tension and compression stress are applied to the surface. The result is shown in Fig. 7 and Table 5.

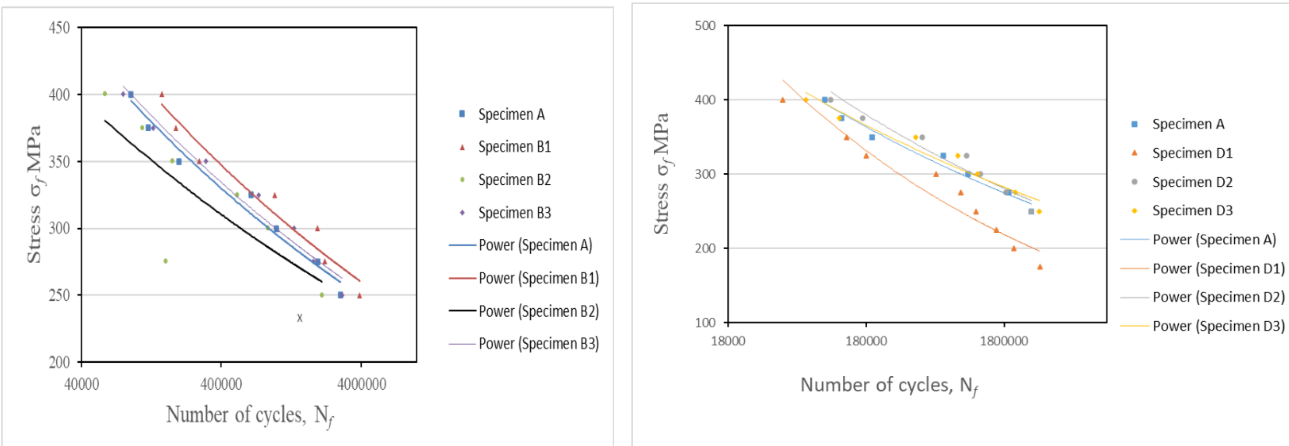


Fig. 7. S-N curves for all specimens at 0.5%nanonickel at different current density as compared with specimen(A)

3.4. Scanning electron microscopy (SEM) test

Scanning electron microscopy (SEM) of TESCAN kind (VEGA 3 LM) is applied , as it is shown in the Fig. 8, to recognize the breakage behavior in the AISI 1020 low Carbon steel(LCS)alloy specimens after the fatigue test is done.

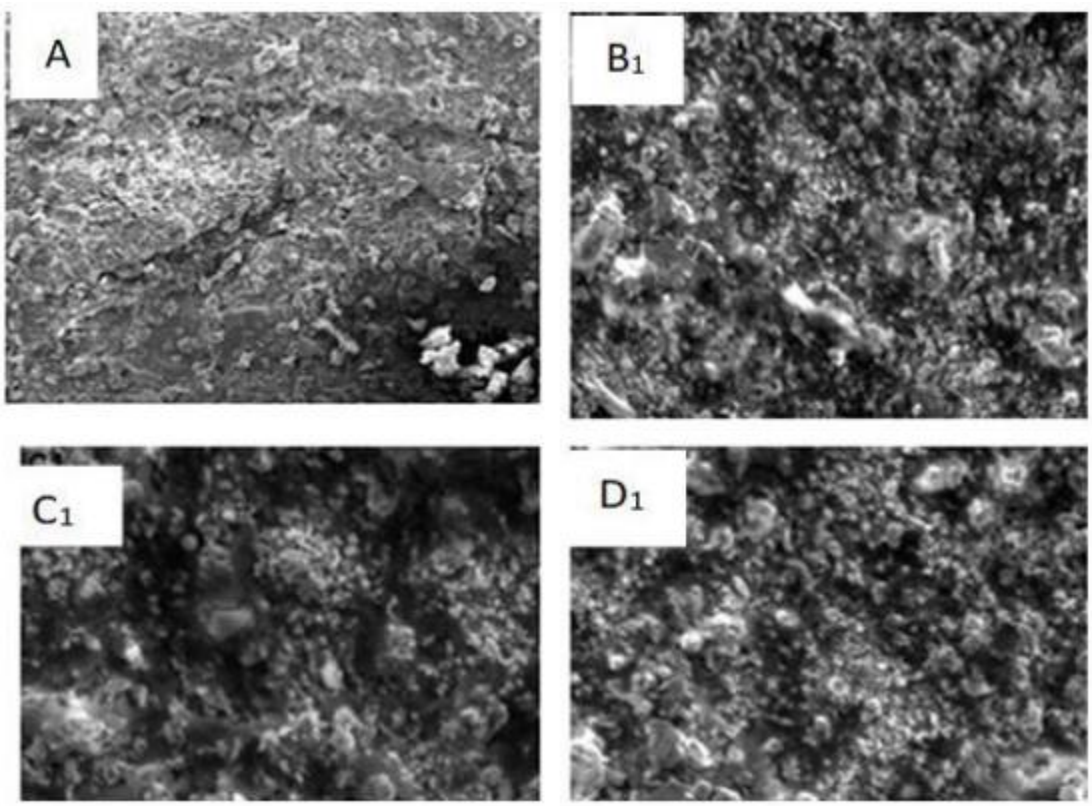


Fig. 8. SAM photograph for Specimens (A, B1, C1, D1) in a scale of (500nm)

4. Discussion

In Fig. 5 shows the consequence of X-Ray diffraction (XRD) patterns of samples (A, B1, C1, D1). Agreeing to 2θ, the intensity peak, referred to (**α**- Fe) peaks, the other element, are not clearly seen in the XRD. Nano Nickel element with (1 wt%) specimens (B1, C1, D1) show that few XRD peaks are seen. Fig. 5 also demonstrates that the Fe-α samples' XRD are exposed a peak at Bragg's angle 2θ=40.60, approving the existence of crystalline (F-α) in the samples (B1, C1, D1). Fig. 6 shows the tensile strength-strain curve for AISI 1020 low Carbon steel (LCS) specimens(A). According to that curve, the average values of yield stress and ultimate stress are 450.8MPa and 579.34MPa, respectively. The tensile test result is shown in Fig. 6; tensile strength is decrease by 5 % when Nano Nickel coating is carried out due to the Nano particular that is close by the porosity which is formed when grain size increase and causes and stress concentration. In Fig. 7 S-N curves for all specimens at 0.5% Nano Nickel at different current density compared with specimen(A), for all specimens fatigue limit are calculated by using Basquin technique as: $\sigma f = A\ Nf\ \alpha$, which is equal to (222MPa) at 107cycles. The microstructure of the base metal steel is related to Ferrite (phases), which served as the control phases, and perlite make up the microstructure. Mechanism of fatigue starts with the crack beginning in grain of ferrite and then propagates quickly, but the crack ends at Pearlite granule, which is different from the initiation of crack that occurs in pearlite granule and (SEM) image is clear. Comparison of fatigue curves are shown in Fig. 7 It indicates that fatigue limit of nickel coated specimen(B1) (235MPa) is higher by 5% than that of the uncoated specimen(A) (230MPa) due to steel substrates that are typically polished mechanically and chemically before their deposition to enhance the fatigue properties if it is compared to those that are achieved by machining and good distribution of nickel on steel surface which appeared by SEM microscopic as in Fig. 8. In general, careful substrate surface preparation seems to be crucial for minimizing the adverse influences of the coating deposition technique on component of the fatigue strength, and the result of the strength is influenced by the amount of applied stress amplitude [9]. During the fatigue experiments, the stress is controlled, at higher stress amplitudes coated specimens that exhibit a high fatigue resistance rather than of uncoated counterparts.

5. Conclusions

In this research, low carbon steel specimens nanocoating are created with nanoNi electroplating methods that had mechanically polished displayed good resistance of fatigue strength, nanoparticles decreased surface roughness, moisture penetration, and contact tension. However, nanoparticles have a larger surface area and improved their mechanical, optical, chemical, and magnetic characteristics. Moreover, nanoparticles increase resin absorption and decrease free surface, so that when the material is coated, the fatigue life of the it improves and are seen on fatigue curves because of the good distribution of nickel on steel surface which appeared by SEM microscopic.

Acknowledgement

Thanks, and gratitude to the staff in the laboratories at an Institute of Technology-Baghdad /Middle Technical University.

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