Effect of Nickel Coating on Fatigue Resistance of Carburized AISI 301 Stainless Steel

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Abstract

The present research deals with the study of the effect of Nickel Coating on the fatigue resistance of carburized and uncarburized AISI 301 stainless steel. Six groups of bending fatigue specimens were prepared for fatigue test.

Two groups of the carburized specimens were precoated with Nickel. The Nickel coated specimens were then case carburized at a temperature of (540°C) for 90 minute. The other Nickel coated specimens were then case carburized at a temperature of (950°C) for 120 minute.

Experimental results revealed an increase in fatigue resistance by (25%) for Nickel coated specimens which are carburized at low temperature of (540°C) as compared with the as received specimens.

The surface hardness was increased by 79.4% for those specimens that have been carburized at a temperature of (540°C), while the specimens that have been coated by Nickel then carburized at low temperature of (540°C) showed a 34.3% increase in surface hardness.

Keywords: AISI 301Stainless Steel, Low temperature carburization, High temperature carburization, Nickel coating, Fatigue resistance.

تأثير الطلاء بالنيكل على مقاومة الكلال للفولاذ الغير قابل للصدأ AISI 301 المكربن

الخلاصة

تناول البحث الحالي دراسة تأثير الطلاء بالنيكل على مقاومة الكلال لعينات من الفولاذ الغير قابل للصدأ AISI 301 المكربن والغير مكربن .

تم تحضير ستة مجاميع من عينات الكلال الانحنائي الدوار لإجراء اختبارات الكلال. أجري الطلاء المسبق بالنيكل لمجموعتين من العينات المكربنة. تم كربنة أسطح العينات المطلية بالنيكل عند درجة حرارة (540°م) لفترة زمنية مقدارها 90 دقيقة, بينما كربنت العينات الأخرى المطلية بالنيكل عند درجة حرارة (950°م) لمدة 120 دقيقة.

أظهرت نتائج الاختبارات العملية زيادة مقاومة الكلال بنسبة (25%) للعينات التي طليت بالنيكل ثم كربنت عند درجة كربنة منخفضة (540°م) مقارنة بالعينات المستلمة.
ازدادت الصلادة السطحية بمقدار (79.4%) للعينات التي تم كربنتها عند درجة حرارة (540°م), بينما أظهرت العينات التي طليت بالنيكل ثم كربنت عند درجة حرارة (540°م) زيادة في الصلادة السطحية بمقدار(34.3%).

INTRODUCTION

Fatigue failures were widely studied because it accounts for 90% of all service failures due to mechanical causes. It occurs when materials are subjected to a repetitive or fluctuating stresses and failure occurs at a stresses which are much lower than their tensile strength, without any plastic deformation (no warning) [1].

The fatigue behavior of mechanical components coated with thin hard corrosion-resistant coatings such as the physically or chemically vapor deposits was studied, and some models and theoretical-numerical procedures were developed for fatigue behavior of coated components. It is found that a combination of good fatigue and anti-corrosion properties could significantly increases the mechanical component performance that have been working in an aggressive environment [2]. The effects of Aluminum thermal spray coating for stainless steel 304 were evaluated with the point of microstructure and electrochemical property. It was concluded that electrochemical properties with the increasing of coating thickness give good results[3].

Fatigue properties of 316L stainless steel coated with different TiNx deposits approximately 3µm thickness were studied and investigated [4]. It has been found that the applications of such coatings to the steel substrate have been led to a significant increase in the fatigue properties of the composite material due to well adherent of such films to the substrate during fatigue testing which was associated with the intrinsic higher mechanical properties of deposits as compared to the uncoated steel.

The effect of dynamic ion mixing coating condition for fatigue properties of stainless steel with TiN film have been studied and found that the fatigue limit was increased by the deposition at a appropriate conditions. [5]. Fatigue and deformation of HVOF sprayed WC-Co coatings and hard chrome plating was studied. The results showed that the fatigue life distributions of coated AISI 4340 steel specimens demonstrated that the HVOF coated specimens exhibited higher fatigue lives compared to the uncoated specimens [6].

The high-cycle fatigue properties of graded (Ti, Al)N- and $Ti_{0.7}Al_{0.3}N$-coated 1Cr11Ni2W2MoV at 500 °C have been investigated using a rotating bending fatigue testing machine. The results showed that fatigue strength and life of 1Cr11Ni2W2MoV stainless steel were increased by the presence of $Ti_{0.7}Al_{0.3}N$ coating ,and the graded coating was found to improve the fatigue life and strength at high stress levels (475 MPa–525 MPa) [7]. Low-temperature (450°C –500°C) Para-equilibrium carburization technique has been developed for introducing carbon into stainless steel surfaces without formation of carbides, and found that this surface carburization method was improved fatigue resistance [8].

Fatigue behavior of carburized AISI 316 austenitic stainless steel was studied with stress concentration factors, K_t of 2.08, 3.55 and 6.50, the fatigue strength have been decreased with an increase in K_t [9].

The aim of the present research is to investigate the effect of Nickel coating on high and low carburizing temperature of AISI 301 stainless steel alloy, in an attempt to evaluate the fatigue resistance.

Experimental Work

Rotating bending fatigue specimens were machined and prepared from AISI 301 stainless steel material according to ASTM designation standard: E6-02a, [10]. The chemical composition of the material used, was analyzed by (Brucker SDI Alloy Analyzer, Germany) and listed in Table (1).

Table. 1: Chemical composition of AISI 301 stainless steel, as analyzed by Brucker SDI alloy analyzer, %.

C	Mn	P	S	Si	Cr	Ni	N	Fe
0.15	2.00	0.045	0.03	0.75	17	7	0.1	Balance

Six groups of rotating bending fatigue specimens were prepared and surface treated as described in Table (2).

Table. 2: Surface treatments for fatigue test of AISI 301 stainless steel specimens.

Group 1	As Received
Group 2	Specimens were coated by Nickel solution ($NiSO_4$ 180g/litter, H_3BO_3 30g/litter, and Ammonium Chloride NH_4CL 25g/litter) using 0.03Amp current , at 50°C for 30 minute ,(Layer thickness 32 microns).
Group 3	Specimens were vacuum carburized at 950 °C for two hours by using Carbon powder (Charcoal) 50%, barium salt ($BaCO_3$) 40% and Sodium Carbonate (Na_2CO_2) 10% as a carburization medium. The carburized specimens were then heated to 950 °C for two hours followed by quenching in oil and then tempered at 500°C for one hour, (Carburized layer 211 micron).
Group 4	Specimens were coated by Nickel, then Carburized at 950°C for two hours by applying the carburization procedures that cited in the third group specimens, (Coating layer thickness 300 micron).
Group 5	Specimens were carburized at 540 °C for 90 minutes using a Carbon powder (Charcoal) 65%, and 35% Sodium carbonate (Na_2CO_2). The carburized specimens were heated to 760 °C for 10 minutes then quenched in NaOH solution to room temperature, (Carburized layer 56 micron).
Group 6	Specimens were coated by Nickel, then Carburized at 540 °C for 90 minutes, by applying the carburization procedure for the fifth group specimens, (Coating layer thickness 78 micron).

Nickel coating was performed by Nickel solution ($NiSO_4$ 180g / litter, H_3BO_3 30 g /litter and Ammonium Chloride NH_4CL 25g/litter) at 0.03Amp current , at 50°C for 30 minute by using the Nickel coating electric cell shown in Figure (1) [11].

Figure. (1) Nickel electroplating cell.

Carburization processes were performed by packing the specimens in a mixture of Charcoal 50%, barium salt ($BaCO_3$) 40% and Sodium Carbonate (Na_2CO_2) 10% as a carburization medium at 950 °C for two hours in a vacuum furnace model TF-3 (Australian Thermoline of 2.84kW). Carburization process at 540°C was performed in a vacuum furnace for 90 minutes by using a carbon powder (Charcoal) 65%, and 35% Sodium carbonate (Na_2CO_2).

All the specimen groups that have been described in Table(2) were subjected to rotating bending fatigue tests up to fracture under different stress levels by rotating bending fatigue apparatus type (HSM19mk3 Hi-Tech Ltd., UK), as shown in Figure (2).

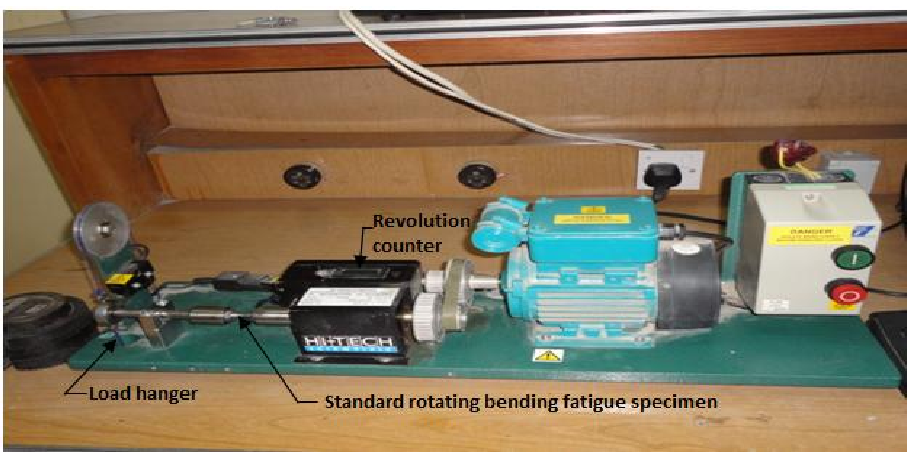


Figure. (2) Rotating bending fatigue apparatus type (HSM19mk3 Hi-Tech Ltd., UK)

Three tests were conducted for each applied stress and the average values were considered. The Stress versus Number of cycles curves (S-N) were then plotted, and the surface and core hardness were measured by (OTTO WOLPERT-WERKE, GMBH) hardness tester, as listed in Table (3).

Table. 3: Surface and core hardness for the six groups of tested specimens.

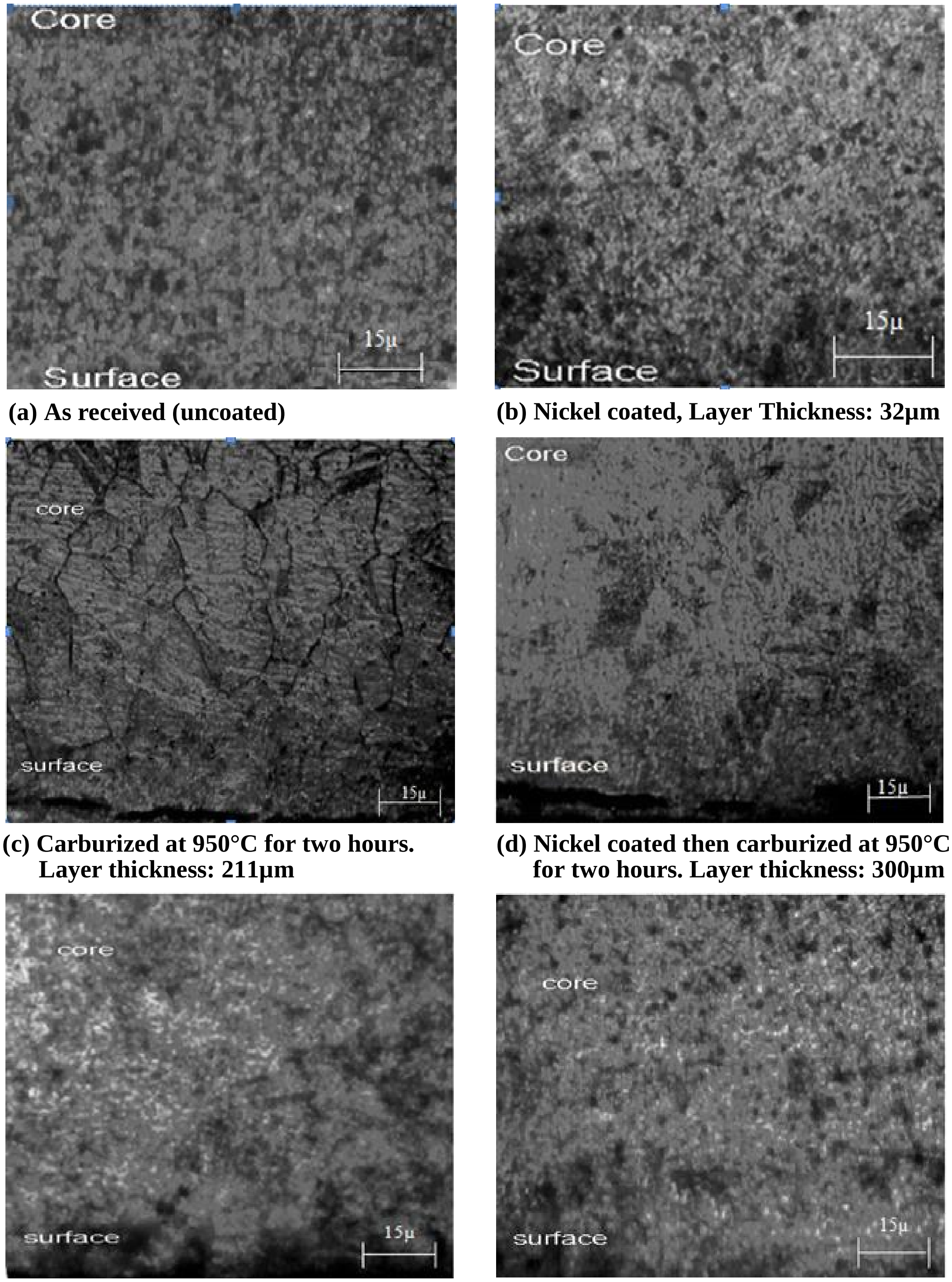
	Surface hardness, Hv	**Core hardness, Hv**
Group 1 (As received)	224	224
Group 2 (Nickel coated)	205	225
Group 3 (Carburized at high temperature 950°C)	225	211
Group 4 (Nickel coated and Carburized at high temperature 950°C)	232	221
Group 5 (Carburized at low temperature 540°C)	402	224
Group 6 (Nickel coated and Carburized at low temperature 540°C)	301	225

Results and Discussion

The microstructure of as received and other treated specimens were photomicrographed by Union Metallurgical Microscope, (Union ME-312S, Japan). Figure (3) shows the microstructure of as received AISI 301 stainless steel alloy and for the specimens of other groups.

Plate "a", from figure (3) reveals the microstructure of as received 301 stainless steel, which consists of carbide (dark) formed in austenitic matrix. Plate "b", shows the structure after being Nickel plated to a layer of 32 microns. In plate c, the pack carburizing layer has a depth of 211 microns, hence sensitization occurred due to formation of Chromium carbides at grain boundaries impairing fatigue resistance. The coating layer increased to 300 micron at plate "d", due to both Nickel and Carbone diffusion toward the core. Plate "e", shows that a layer of only 56 microns formed on specimen surfaces due to low temperature carburization at 540 °C, while plate "f" shows that this layer decreased to 78 microns as compared to plate "d" due to the Nickel plating which impedes the diffusion of carbon during low temperature carburization.

Figure (4) represents the S-N curves for both uncoated (as received) and Nickel coated AISI 301stainless steel. The curves show that fatigue resistance of Nickel coated AISI 301 stainless steel decreased by 17.3% as compared with uncoated specimens. The reduction in the fatigue resistance of Nickel coated AISI 301stainless steel can be attributed to the residual tensile stresses that have been developed on the surface layers due to Nickel plating which decreased the fatigue resistance of Nickel coated specimens[12].



(a) As received (uncoated)

(b) Nickel coated, Layer Thickness: 32μm

(c) Carburized at 950°C for two hours. Layer thickness: 211μm

(d) Nickel coated then carburized at 950°C for two hours. Layer thickness: 300μm

(e) Carburized at 540°C for 90 minute. Layer Thickness: 56 μm

(f) Nickel coated then carburized at 540°C for 90 minute. Layer Thickness: 78 μm

Figure. (3) The microstructure of the six groups of AISI 301stainless steel specimens.

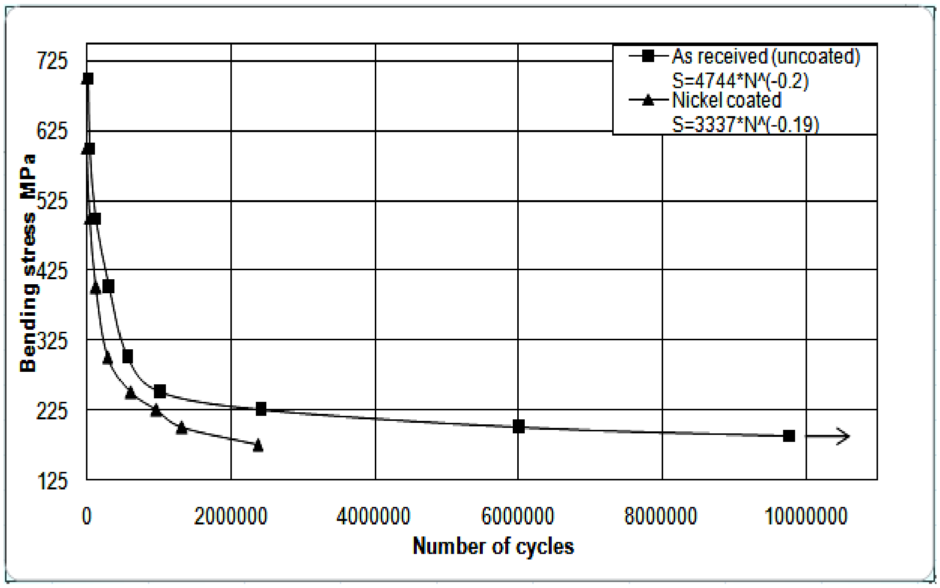


Figure. (4) The effect of Nickel coating on fatigue resistance of AISI 301stainless steel.

The S-N curves, plotted in Figure (5) show a decrease in the fatigue resistance by 6.9% for the specimens carburized at low temperature (540°C), while the fatigue resistance was decreased by 33.5% for specimens carburized at high temperature (950°C) as compared with the uncoated (as received) specimens. The figure also reveals that the fatigue resistance for the specimens that have been carburized at low temperature (540°C) was higher than those specimens that have been carburized at high temperature (950°C). That decrease in the fatigue resistance of high temperature carburization can be attributed to the microstructure changes and grains coarsening that have been resulted due to high temperature in the AISI 301stainless steel as shown in Figure (3c), which led to a degradation in the fatigue resistance. Hardening by high temperature carburization was not suitable to chromium-containing alloys such as stainless steel, due to chromium carbide formation, which is in agreement with Natishan [8].

The fatigue resistance of AISI 301 stainless steel specimens coated by Nickel, then carburized at both low (540°C) and high (950°C) temperature, are shown in Figure (6). The results clearly show a 25% improvement in the fatigue resistance for those specimens that have been Nickel coated then carburized at low carburizing temperature (540°C), while the Nickel coated specimens that have been carburized at (950°C) show 4.19% decrease in fatigue resistance, as compared with the as received specimens.

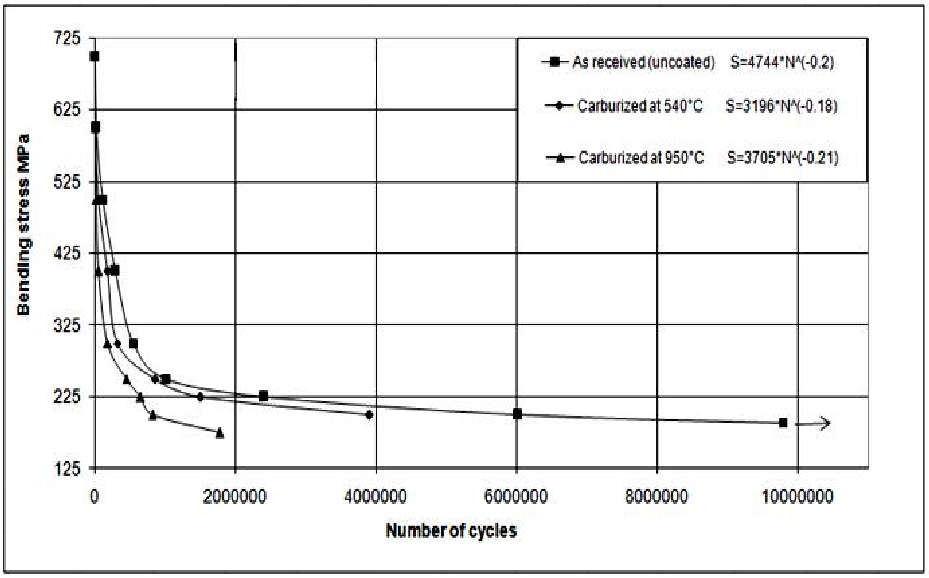


Figure. (5) The effect of carburization at temperatures 950°C and 540°C on fatigue resistance of AISI 301 stainless steel.

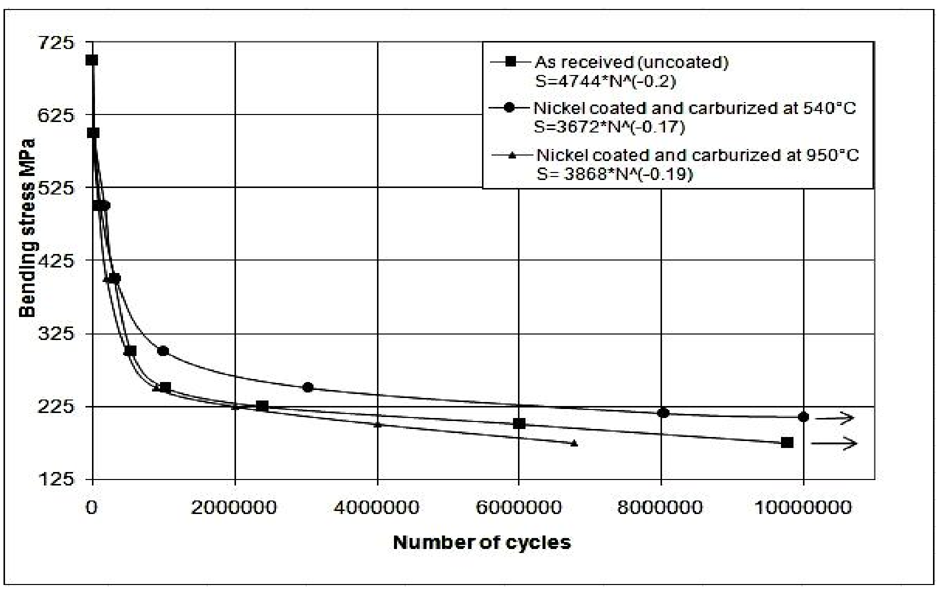
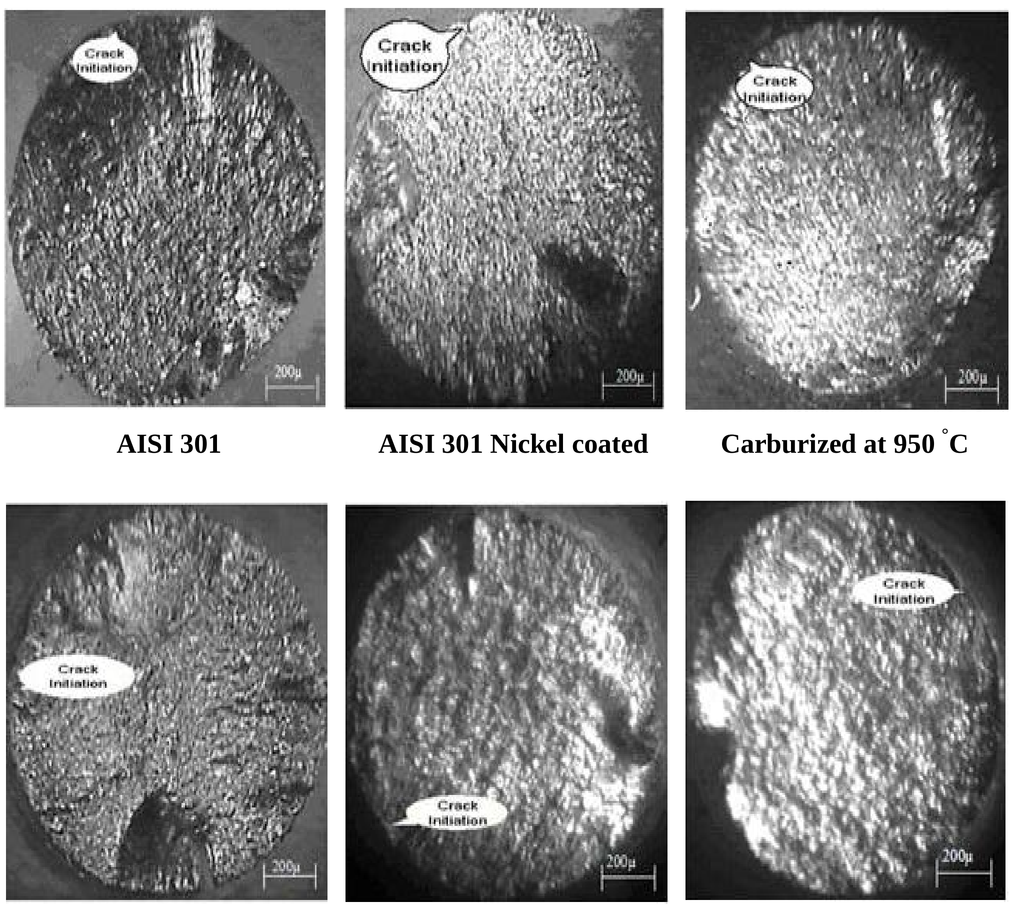


Figure. (6) The effect of Nickel coating and carburization at temperatures 950°C and 540°C on fatigue resistance of AISI 301 stainless steel.

The increase in the fatigue resistance of the specimens coated by Nickel then carburized at low temperature (540˚C) was due to Nickel coating layer that have been deposited on the specimen surfaces which reduced the diffusion of carbon across the surface towards the core of AISI 301stainless steel specimens. As a result chromium carbide formation was decreased , as well as the carburization layer has favorable compressive residual stresses that help the part to withstand cyclic loading to which it was exposed [1].

The fractured regions were photographed by Stereo- Microscope, as shown in Figure (7). Examination of the fractured surfaces shown in Figure (7), show that fatigue cracks were initiated at a Racket mark, where progressive flat fatigue fractured with cross beach marks, until fast over load fracture had taken place ending with shear lips.



AISI 301 **AISI 301 Nickel coated** **Carburized at 950 ˚C**

Nickel coated and Carburized at 950 ˚C **Carburized at 540 ˚C** **Nickel coated and Carburized at 540 ˚C**

Figure. (7) Fractured regions micrographs of the six groups tested under 20N load.

Table (3) represents the surface and core hardness measurements of the six groups of specimens. It is clear from the results that the specimens coated by Nickel then carburized at low temperature (540°C) ,exhibited 34.3% higher surface hardness, while a 79.4% increase in surface hardness was recorded for the specimens carburized at (540°C) without Nickel coating.

CONCLUSIONS

Rotating bending fatigue tests applied to the as received, coated by Nickel, carburized at high temperature (950°C), coated by Nickel then carburized at high temperature (950°C), carburized at low temperature (540°C) and coated by Nickel then carburized at low temperature (540°C) AISI301 stainless steel specimens tested under different stress levels led to the following conclusions:

1. The fatigue resistance was increased by 25% for Nickel coated specimens then carburized at low temperature (540°C),while surface hardness was increased by 34.3% as compared with the as received specimens.
2. Fatigue resistance was decreased by 4.18% for specimens that have been Carburized at low temperature (540°C), while surface hardness was increased by79.4% as compared to the as received specimens.
3. Fatigue resistance was decreased for Nickel coated, carburized at high temperature (950°C) and Nickel coated then carburized at high temperature (950°C) as compared to the as received specimens.

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