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Effect of Chromium Plating of AISI 321 Alloy at 1000°C on Fatigue Resistance

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ABSTRACT

The fatigue strength of the AISI 321 austenitic steel alloy was investigated in this study using chrome plating at 1000°C. Re-diffusion heat treatment at 1050°C for both coated and uncoated models' microscopic examination was also performed on the samples obtained from the coating and fatigue tests. Surface analysis of all samples was performed using an X-ray diffraction (XRD) device. We conclude that the fatigue life of chromium plating at 1000°C leads to a reduction in fatigue life. A possible explanation is that the phases of the coating layer consist of compounds that lack plasticity, which is due to the increased chromium content and the reduced area subject to stress. The fatigue life improved after heat treatment at 1050 °C, but the coating phases remained unchanged. The austenite phase, which is characterized by plasticity, tends to increase the fatigue life of alloys heat treated at 1050 °C. This phase can only be obtained if the temperature is higher than 925 °C. Chromium plating causes the austenitic structure to transform into the ferrite phase. The increase in resistance for the uncoated alloy was greater than that for the chromium-plated alloy.

Keywords: Chromium, aluminized coating, AISI 321 alloy, corrosion, metal corrosion.

INTRODUCTION

Austenitic steel is widely used because it is resistant to oxidation and corrosion at high temperatures. It has good mechanical properties because it contains a high percentage of chromium, which has the ability to form a protective oxide crust, but it is less effective in oxidative atmospheres containing sulfur compounds (Muayad *et al*., 2019). Aluminization techniques are widely used, by enriching the metal surface (coating) with aluminum, which is used industrially by cementation, because it works to spread the aluminum element into the metal and to a certain depth, inside the alloy, contributing to changing the structural composition (Pilone *et al*., 2008), to form compounds on the surface, which in turn form protective crusts. Rapid scientific progress in various industrial fields, such as aviation and power plant industries, has always led to research on how to improve machine and mechanic element reliability and life span (Hussam and Yahya, 2017). The answer to such questions is related to increasing the toughness of the surface layers and increasing the time life when different loads are applied, when the temperature rises, or when the hostility of the operating medium in which these parts operate increases (Yahya and Adel, 2018).

In stainless steel alloys, chromium is the most important element. Due to their good mechanical properties and resistance to oxidation and corrosion at high temperatures, austenitic steel alloys are widely used (Omed *et al*., 2021). Because it contains a high percentage of chromium, which has the ability to form a protective oxide crust in an oxidative atmosphere but is less effective in a sulfur-containing oxidative atmosphere. Because it spreads the chromium element into the metal and to a certain depth inside the alloy, it contributes to a change in the structural structure and forms compounds on the surface, which in turn form protective scales (Pilone *et al.*, 2008).

PRACTICAL PART

The preparation process was divided into three stages. The sample was first cut to the dimensions and diameters required for the fatigue tester i.e., 64 mm in length and 9 mm in diameter, as shown in Fig. (1), and then a notch with the indicated dimensions was created in the middle of the form. The second step is to remove oxides from the surface to varying degrees using silicon carbide (smoothing paper) (800-1200-2000). The samples were then cleaned with soap and water, and any remaining greasy substances were removed with alcohol. Creating a suitable surface for the coating process.

The well-known cementation technique was used to paint the models of the AISI 321 austenitic steel alloy's dimensions, as shown in Fig. (1), and the proportions of its weight elements, as shown in (Table 1). At a temperature of 1000°C, a number of models were coated with chromium. One of the samples was subjected to heat treatment (Re-Diffusion) at 1050°C. View the source for more information on the coating process and its mechanisms (Callister, 2005).

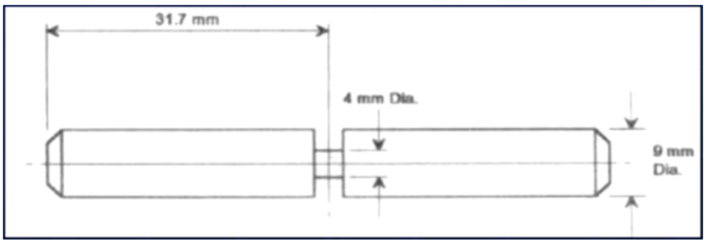

Fig. 1: Dimensions of the fatigue tester model.

Table 1: Weight percentage of alloy elements for AISI 321 austenitic stainless steel

Alloy Type AISI321	C%	Mn%	Si%	Ni%	Cr%	S%	Ti	Fe
Stainless Steal	0.0544	1.477	0.607	8.936	18.636	0.0015	0.21	Balance

The fatigue tester Fig. (2), was used using the rotating bending method. To determine the fatigue life of coated, uncoated, and thermally treated models. The loads ranged from 10 to 25 new tons. The samples resulting from the coating and fatigue tests were also subjected to microscopic examination. The X-ray diffraction (XRD) device was used to perform surface analysis on all of them.

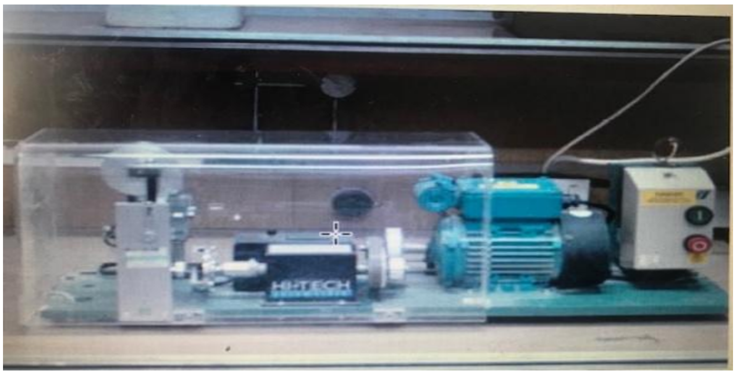

Fig. 2: Mechanical fatigue test device.

RESULTS AND DISCUSSION

The generated stresses were calculated during the examination of the fatigue of the uncoated AISI 321 austenitic steel ingot by the rotating bending method, using 10-25 Newton weights, and the number of cycles until failure was recorded, as shown in (Table 2).

Table 2: Stress values and average number of cycles to failure for AISI 321 austenitic steel alloy.

Weight (newton)	Stress (MPa)	AISI 321	Coating Cr 1000°C	Coating Cr 1000°C+H.T	AISI321+H.T 1050°C
10	200	850380	130642	375450	950166
15	300	410155	39800	105680	550122
20	400	135000	11690	31690	200650
25	500	12600	2980	6590	14560

As shown in Fig. (3), the alloy was subjected to a fatigue failure mechanism, which means that the number of cycles until failure gradually decreases with increasing stress, and thus the fatigue life decreases with increasing stress level.

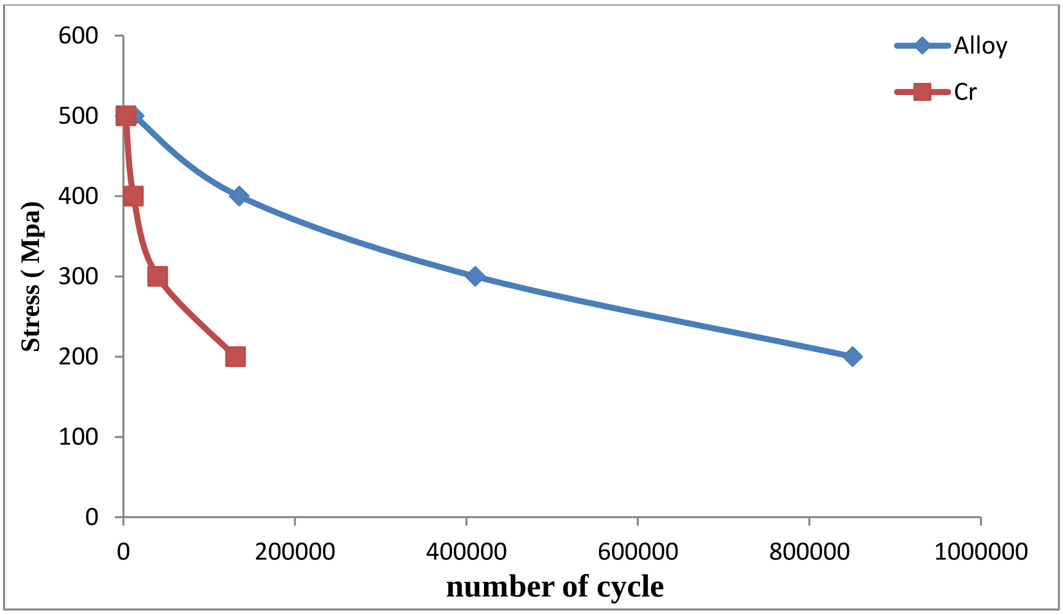

Fig. 3: Fatigue curve (S-N) of AISI 321, both chrome-plated and uncoated.

It is evident from Fig. (3) that the fatigue life of the chrome-plated alloy showed a decline in the fatigue strength compared to the uncoated alloy.

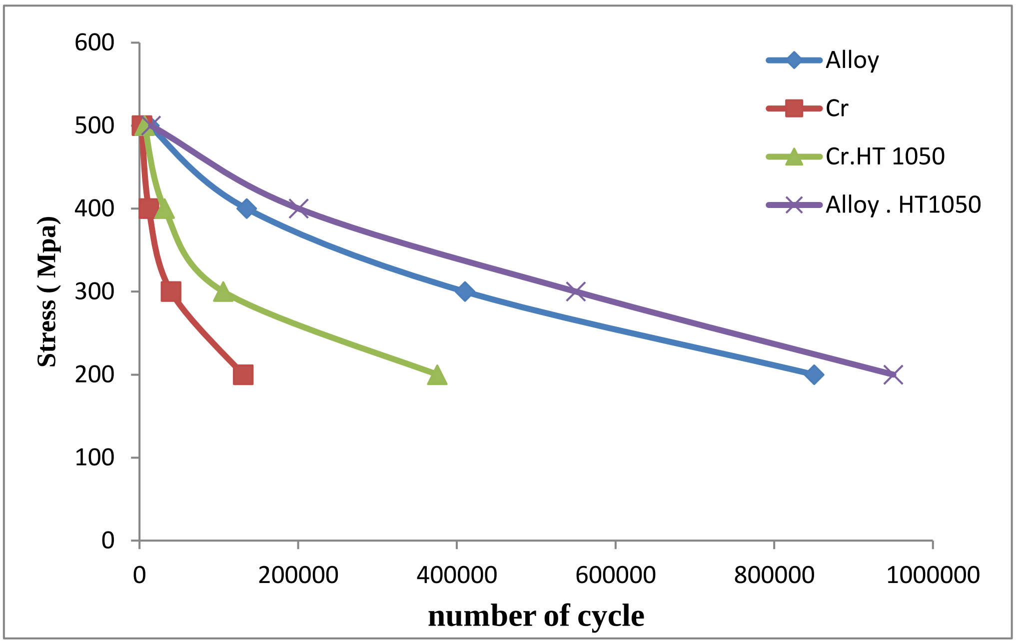

Fig. 4: Fatigue curve (S-N) of heat treated, uncoated and chromium-coated AISI 321.

While we notice from Fig. (4) the uncoated alloy that was heat treated at 1050°C, there was a clear improvement in the increase in fatigue life, compared with the uncoated alloy.

Fig. 5: Microscopic examination of uncoated AISI 321 (400X).

The microscopic examination of the uncoated alloy. Fig. (5) revealed that it has a structural composition of small grains and a variety of phases and structures. The alloy is composed of the austenitic phase (γ), which is the basic phase, according to Scheffler's scheme (Shanker *et al.*, 2003; Alabdullah, 2022). However, only a small percentage of the two phases exist (ferrite and martensite). At temperatures above 925°C, it is possible to obtain a single austenitic phase. (Sourmail, 2001; Al-Salih *et al.*, 2021). That is, the alloy's thermal treatment at 1050°C, followed by slow cooling inside the furnace, resulted in the formation of a single austenitic phase (γ), as shown in Fig. (6). It is known that the solubility of carbon in the austenitic phase is greater than its solubility in the other phases (ferrati and martensitic), implying that full annealing was performed, and this phase is characterized by being more ductile and softer than the other phases, making it more fatigue resistant.

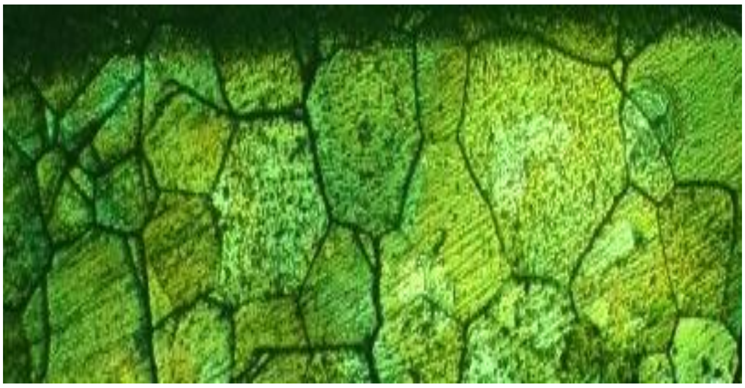

Fig. 6: Microscopic examination of the section of the AISI 321 alloy and heat treated at 1050C° (400X).

Fig. (4) demonstrates that the chrome-plated alloy and the alloy thermally treated at 1050°C outperform the chrome-plated alloy alone. The fatigue life of the chrome-plated alloy demonstrated a decrease in fatigue strength when compared to the uncoated alloy. (Moayad and Yahya, 2011), but its performance improved after heat treatment (Mohammed and Al-Abdullah, 2022).

The microscopic examination of a section of the chrome-plated model is shown in Fig. (7). This coating's structure consists of three areas, and its thickness exceeds 120 µm. The figure clearly shows that the base layer seems to be composed of carbide deposits inside the plating area, most of which are chromium carbides, indicating the spread of chromium to a limited depth inside the alloy, where its concentration increases due to the fact that the same alloy also contains chromium, as shown in (Table 1).

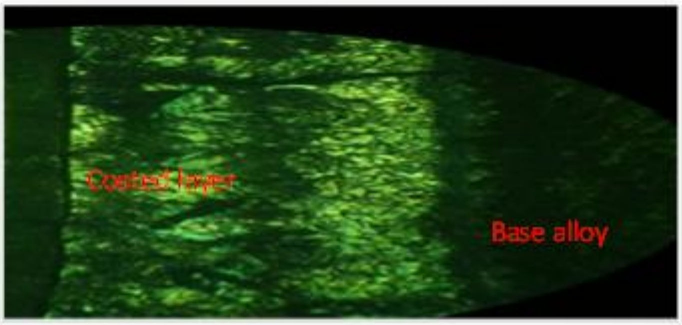

Fig. 7: Microscopic examination of the section of the chrome-plated model (400X).

Fig. (7) reveals that the coating layer is made up entirely of hard phases, which means it lacks ductility and is easily broken during fatigue testing. On the one hand, this is true, but the presence of carbide deposits is what makes the alloy less resistant.

The X-ray spectrum (XRD), Fig. (8) also proves the existence of phases (FeNi, FeCr, NiCr) with the presence of other carbides M_7C_3.

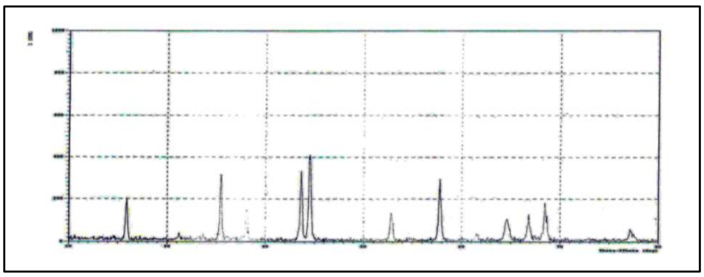

Fig. 8: X-ray diffraction (XRD) diagram of a chromium-plated alloy at a temperature of 1000°C.

Fig. (9) shows that the structural composition of the coating differs greatly between the coated and thermally treated alloys. Where two close areas in the thickness of the coating can be distinguished, the area of the alloy directly beneath the coating appears on its granularity traces and disappears when we go inside the alloy. In addition, since the heat treatment occurred in the absence of chromium, what might happen is the exchange of diffusion between the elements of the alloy and the elements of the coating layer, and from the analysis of the X-ray spectrum of the model in Fig. (10), it showed a kind of complexity because it contains peaks that belong to a number of phases, as confirmed by the presence of the -FeCr phase, which is more ductile. And the spread of iron towards the surface will leave a region rich in chromium and nickel, implying that the plating element affects the alloy components, at least to the extent that it affects fatigue life.

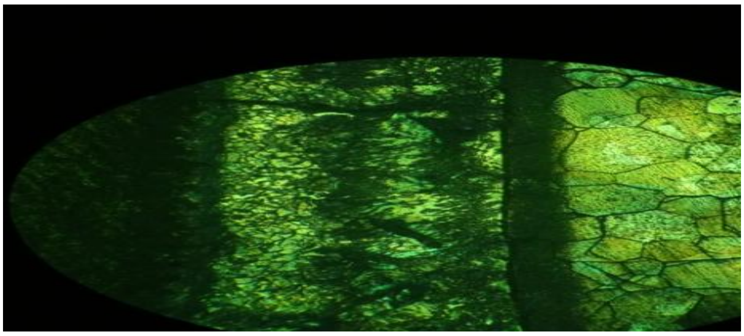

Fig. 9: Microscopic examination of the section of the chrome plated model and heat treated at 1050°C (400X).

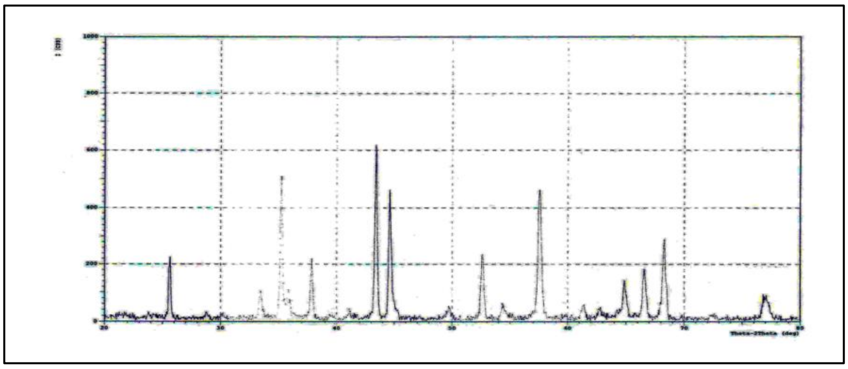

Fig. 10: X-ray diffraction (XRD) diagram of a chromium-plated alloy with a temperature of 1000°C and heat treated at a temperature of 1050°C.

That is, Fig. (9) may have been formed by the continuity of chromium diffusion, where the high concentration of chromium is towards the inside of the alloy, so this region is compensated by the diffusion of iron to it where the phase (-FerCr) is formed, and that the diffusion of iron towards the surface will leave the region rich in chromium and nickel. The reason for the region remaining in the xC (NiCr) phase, that is, the possibility of chromium spreading to the depth of the alloy, which led to the formation of the ferrite phase (-ferite), is that the chromium element is one of the elements that works to stabilize the ferrite phase, which has less strength than the austenitic phase. For this reason, it is less resistant to fatigue, but it has proven to be an improvement in fatigue resistance over the chrome-plated model alone.

CONCLUSIONS

Chrome plating at 1000°C reduces fatigue life. The possible explanation for this is that the phases of the coating layer are composed of compounds that lack ductility, and this is due to an increase in the percentage of chromium as well as a decrease in the area subjected to stress. The fatigue life improved after 1050°C heat treatment, but the coating phases remained unchanged.

The austenitization phase, which is characterized by ductility, tends to increase the fatigue life of the heat-treated alloy at 1050°C. This phase can only be obtained if the temperature is above 925°C.

Chromium plating causes the austenitic structure to be converted to the ferrite phase.

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تأثير طلاء الكروم لسبيكة الاوستنايتي AISI 321 عند 1000 درجة مئوية على مقاومة الكلال

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الملخص

تمت دراسة مقاومة الكلال لسبيكة الفولاذ الأوستنيتي AISI 321، في هذه الدراسة استخدام طلاء الكروم عند 1000 درجة مئوية. المعالجة الحرارية لإعادة الانتشار عند 1050 درجة مئوية لكل من النماذج المطلية وغير المطلية كما تم إجراء الفحص المجهري على العينات التي تم الحصول عليها من اختبارات الطلاء والتعب. تم إجراء تحليل سطحي لجميع العينات باستخدام جهاز حيود الأشعة السينية (XRD). نستنتج أن عمر تعب طلاء الكروم عند 1000 درجة مئوية يؤدي إلى انخفاض في عمر التعب. أحد التفسيرات المحتملة هو أن مراحل طبقة الطلاء تتكون من مركبات تفتقر إلى اللدونة، وهو ما يرجع إلى زيادة محتوى الكروم وانخفاض المساحة المعرضة للإجهاد. تحسن عمر التعب بعد المعالجة الحرارية عند 1050 درجة مئوية، لكن مراحل الطلاء ظلت دون تغيير. تميل المرحلة الأوستينيتية، التي تتميز باللدونة، إلى زيادة عمر التعب للسبائك المعالجة حرارياً عند 1050 درجة مئوية. لا يمكن الحصول على هذه المرحلة إلا إذا كانت درجة الحرارة أعلى من 925 درجة مئوية. يؤدي طلاء الكروم إلى تحول البنية الأوستنيتية إلى طور الفريت. كانت الزيادة في المقاومة للسبائك غير المطلية أكبر من تلك الخاصة بالسبائك المطلية بالكروم.

الكلمات الدالة: الكروم، الطلاء بالألمنيوم، سبيكة AISI 321، الكلال، تآكل المعادن.