INVESTIGATION OF FATIGUE BEHAVIOR USING SURFACE SHOT PEENED TECHNIQUE FOR 2024 – T4 AL-ALLOY

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ABSTRACT :-
The strength and fatigue lifetime of AL alloy 2024-T4 were estimated using flat fatigue specimen and stress ratio R=-1 at room temperature (RT). After fatigue testing,it was found that both fatigue region (low cycle fatigue and high cycle fatigue) was improved after the shoot penning of the surface .This improvement appeared due to the compressive residual stress established at the shoot penned surface . Also, the fatigue life improvement factor was obtained around (6) while the fatigue strength factor was found to be around 26.

KEYWORDS :-
2024-T4 Al-alloy, fatigue, life and strength, shot peening

دراسة تصرف الكلال باستخدام تقنية القذف بالكريات لسبيكة الالمنيوم 2024–T4

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الخلاصة :-
تم تقيم مقاومة وعمر الكلال لسبيكة الألمنيوم 2024–T4 باستخدام عينات الكلال المسطحة ونسبة إجهاد 1– =R عند درجة حرارة الغرفة باستخدام تقنية القذف بالكريات لعشرة دقائق . بعد الفحص تبين ان أداء الكلال لهذه السبيكة المشار اليها أعلاه لكلا منطقتي الكلال واطئ الدورات وعالي الدورات قد تحسن . ظهر هذا التحسن ربما لخلق اجهادات ضغطية متبقية على السطح . اعمار الكلال ازدادت بعامل تحسن الأعمار بمقدار 6 بينما عامل مقاومة الكلال النسبي (FSF%) وجد انه حوالي 26 .

INTRODUCTION AND REVIEW :-

Requirement to improve the fatigue life and fatigue strength of components are increasing year by year from the view point of environmental and energy conservation issues. There are mainly two popular ways to increase fatigue life (a) increase the hardness of material and (b) introduce compressive residual stress in components [G. S. Was et al. 1981]. Shot peening coverage at least 100% is thought to be necessary to achieve uniform surface compression and hence improved fatigue performance in metals. De los Rios et al. studied the effect of shot peening on (SP) the fatigue resistance of 2024-T35 Aluminum alloy using four points bending fatigue testing. The results show that the fatigue lives for peened specimen are longer than those for unpeened specimens over a wide range of applied stress. Fatigue life improvement due to SP is caused by dual effect provided by prolonging crack arrest and reducing the crack growth with both mechanisms being affected by residual stress relaxation profile [S. Currtis et al. .2003]. The largest increase in ultimate and yield strength were observed after different SPT (3, 5, 10, 15, 25 min) in2024-T351 aluminum alloy mechanical properties were increased 6.7% and 11.7% respectively , as a result of compressive residual stresses at 15 min [H.J. Alalkawi et al. 2009]. The effect of SP treatment come on change in surface residual stress can observed, for long treatment times the change to more compressive stresses is higher because processing time is increase the plastic deformation of balls increases too. The change to move compressive stresses reaches a stationary value at around 15 min [M. Benedetti et al. 2009].

Surface modifications produced by the shot peening treatment are (a) roughing of the surface (b) an increased near surface, strain hardening and (c) residual stress. Surface roughening will accelerate the nucleation and early propagation of cracks, strain hardening will retard the propagation of cracks by increasing the resistance to plastic deformation and residual stress profile will provide corresponding crack closure stress that will reduce the driving force for crack propagation [S. Khan et al.2010]. Development of crack growth after SP was measured and compared with crack growth in specimen without SP, the crack will be reliably arrested [L. Minghe et al. 2010]. Fine particle shot peening (FPSP) is a new technology using smaller media with higher blowing velocity compared with shot peening. (FPSP) created fine uniform dimples and high compressive residual stress very near surface. (FPSP) enhances fatigue life of Al- alloy compared with SP because of the high compressive residual stress at very near surface with low roughness [H. Y. Miao et al. 2010], the surface hardening of aluminum alloy 2024, when it was shot peening with Zn- based shot ball.

Shot peening process was carried out at variable loading, using compressed air. After shot peeing treatment, the surface hardness of AA2024 aluminum alloy increased up to about 140 HV from 65 HV of the base material at 180 sec [S. Khan et al. 2010]. Surface roughness behavior has studied as a function of peening parameters, the roughness profile as function of coverage, number of impacts or processing time. The ball impacting process the pv value increases initially with the processing time. Finally in the last phase, roughness stabilizes at constant value as the processing time increase because the rate of generating peak and valleys is in dynamic equilibrium with the rate of reducing the high of peaks [G. H. Majzoobi et al. 2009]. The improvement of fatigue life by shot peening has been attributed to the retardation of micro crack growth. This has been demonstrated by showing that the positive effect of the compressive residual stress field on fatigue life is greater than the negative effect of high surface roughness introduced by shot peeing.

Since the compressive residual stresses introduced into surface and subsurface layers to decrease the tensile stress, fatigue crack do not easily initiate or propagate. In addition, it is also well-known that SP with excessively high Almen intensities may not only result in small near surface compressive residual stress, but this process can also increase surface roughness and induce microcracks [M.Benedetti et al. 2009].The current investigation was focusing on the improvement of fatigue lifetime and strength created due to shot peening technique.

EXPERIMENTAL DETAILES :

Material :

The material used in this work is 2024-T4Aluminumally being partially the first heat – treatable alloy to be discovered (duralumin) still find wide application for many general engineering and aircraft structural purposes in the form of forgings, extruded bars and section sheets. The alloy has good fracture toughness ,and finds usage for service at temperature up to 120^{o}C [Wail Rasheed Al Naimy 1997].

Chemical Compositions:

The Chemical compositions of the alloy was tabulated in **Table 1**

The above results were obtained using XRF device in the state company for Inspection and Engineering Rehabilitation (S.I.E.R).

Testing

Tensile Test

The mechanical properties were obtained using Instron 225 testing machine that has maximum capacity of 150 KN. **Table 2** gives the average of five readings according to DIN 50123

Fatigue Test Specimen :

To get perfect dimensions of a fatigue specimen and to avoid mistakes, an accurate profile should be attained. All specimens were manufactured using programmable CNC milling machine. The test specimen is shown in **Fig. 1**, thickness of specimen is 10 mm.

Fatigue Test Machine

The machine “Avery fatigue crack testing machine” is designed to apply reverse loads with or without an initial static load for bend tests on flat specimens. The load was imposed at one end of the specimen by an oscillating spindle driven by means of a connecting rod. More details of this test rig can be found elsewhere [Mohamed Faycal Ameur 2002] while figure (2) shows the main parts of the fatigue machine “users instructions type 7305”.

Shot Peening Properties:

The peening operation was carried out in a shot peening device “Shot Tumblast control pommel model STB-OB. This device enables to do the operation of shot peening on round and flat specimens with the following properties given in **Table 2**.

Bending Stress Calculation

In order to achieve an accurate bending stress value in a specimen (Cantilever). The deflection at free end is:

$$\boldsymbol{\delta = \frac{WL^3}{3EI}} \qquad (1)$$

Where:

W : load on free end

E : modulus of elasticity

I : moment of inertia

L :length of specimen

Max. bending stress $\boldsymbol{\sigma = \frac{My}{I}}$ (2)

But $M = WL$ (3)

Substing equation (3) into (1) gives:

$$\boldsymbol{\delta = \frac{ML^2}{3EI}} \qquad \text{and finally} \qquad \boldsymbol{\delta = \frac{\sigma L^2}{1.5Eh}} \qquad (4)$$

Where: $y = \frac{h}{2}$ and h is thickness of specimen

From the calibration curve in **Fig.(4)** the bending stress can be determined for different angle using equation (4)
For more details, see Ref [Abdul Jabar H.A 2012], from deflection the bending stress can be calculated and from the applied angle in the wheel crack, the fatigue machine can be determined the deflection as in **Fig. (4).**

RESULTS AND DISCUSSIONS:

Constant S-N Curves:

The results of this group with shot peening at 10 min and without peening can be illustrated in **Fig. 5**, **Table 3** gives the improvements in fatigue lives at different stress level **based on ultimate stress of metal used.**

It was observed that the fatigue life was improved approximately seven times compared with based metal stress. These results are in good agreement with the findings of [Mohamed Faycal Ameur 2002]

In the case of 2024-T4 Al alloy, the effect of shot peening on fatigue life is most pronounced under conditions of low cycle fatigue $(\leq 10^4)$ and high cycle fatigue $(\geq 10^4)$. The reason for this is that probably because the surface layers of 2024 Al.alloy are heavily deformed during shot peening, and this will stop fatigue cracks and hence prevents fracture surface[Mohamed Faycal Ameur 2002].

Fatigue Strength :

Fatigue strength is divided into two groups, one for low cycle fatigue (LCF) and the other for high cycle fatigue (HCF) as given in **Fig. 6**

FSF% was calculated using the equation:

$$FSF\,\% = \frac{\sigma_{peened} - \sigma_{unpeened}}{\sigma_{unpeened}} * 100 \qquad (5)$$

According to **Table 4**, an Increase in fatigue strength is observed due to 10 min shot peening. The results indicate that the FSF% is around 26 for both regions, LCF and HCF. For the same alloy [Solis Romero et al. 1999] found that there is a little improvement in fatigue strength al LCF but a significant improvement was observed at HCF under shot Peening treatment.

Also it is found that the fatigue strength is improved by the same value as other strengths. An increase of 26.2 MPa in fatigue strength due to 10 min. shot peening.

The increase in the fatigue behavior is derived from compressive residual stresses that introduced into the near surface of the component [Arken J. Lu et al 1990].The integrity of surface changes by shot peening mainly include work hardening due to increase in the dislocation density, gives the surface layer higher mechanical properties but lower ductility [Robert L. Mott 2004].

Shot peening has improved the fatigue property of 2024-T4 Al alloy. This improvement is due to compressive stresses generated in the surface of the specimens [Mohamed Faycal Ameur2002 , Solis Romero et al. 1999].

The effect of shot peening on the fatigue property arises shot peening S-N curve level. The results are similar to that formed by British Aerospace [Solis Romero et al. 1999].

CONCLUSIONS :-

The fatigue S-N Curves behavior of Aluminum alloy 2024-T4 at 10 min. shot peening under reversed bending loading were investigated, the following conclusions may be derived from this work:

1-The fatigue life of 2024-T4 Al alloy is improved by shot peening surface treatment. This improvement may be due to the creation of compressive residual stresses at the surface.

2- The FSF% is found to be around 26% improvement in fatigue strength at both regions LCF and HCF,for a given No. of cycles to failure (Nf).

3- The shot peening process increased the fatigue strength by 26 MPa compared to unpeened fatigue strength.

Table (1) Chemical analysis of 2024-T4 Al alloy wt%

element	Cu	Mg	Mn	Zn	Si	Fe	Ni	Al
Value	4	0.245	0.45	0.43	0.12	0.27	0.1	remainder

Table 2 Mechanical properties of 2024-T4 Al alloy

	$\sigma_y (MP_a)$	$\sigma_u (MP_a)$	E(GPa)	Elongation %
experimental	388	472	75	16
Standard [17]	393	496	73	16.5
Speed	1 mm/min (all the tests were carried out at this speed)			

Table (2) shot peening properties

Ball material	Ball diameter (mm)	Rockwell hardness HRC	Velocity of ball (m/sec)	Average ball size (mm)	Pressure (bar)	Shoted Surface of specimen	Distance of Peening (cm)
Cast steel	1.2	(48 –50)	25	0.6	12	Front and back Faces	40

The details of the shot peening device can be seen in **Fig.3**.

Table (3) Fatigue lives improvements due to 10 min SP (Shot Peening)

Applied stress (MPa)	Life (cycles) before SP	Life (cycles) after 10 min SP	Fatigue live improvement
$0.8\ \sigma_u = 404$	132	918	6.95
$0.6\ \sigma_u = 303$	1396	9519	6.82
$0.4\ \sigma_u = 202$	38738	257185	6.64

Table 4 strength of 2024 –T4 Al at both LCF and HCF

Unpeened fatigue strength results			
LCF	**Fatigue strength (MPa)**	**HCF**	**Fatigue strength (MPa)**
10^2	418	10^5	180
10^3	315.6	10^6	136
10^4	238.3	10^7	102.6
10 min shot peening fatigue strength results			
10^2	530.65	10^5	227
10^3	400	10^6	171
10^4	301	10^7	128.8
Fatigue strength factor (FSF)*			
LCF	**FSF %**	**HCF**	**FSF %**
10^2	27	10^5	26.1
10^3	26.7	10^6	25.7
10^4	26.3	10^7	25.5

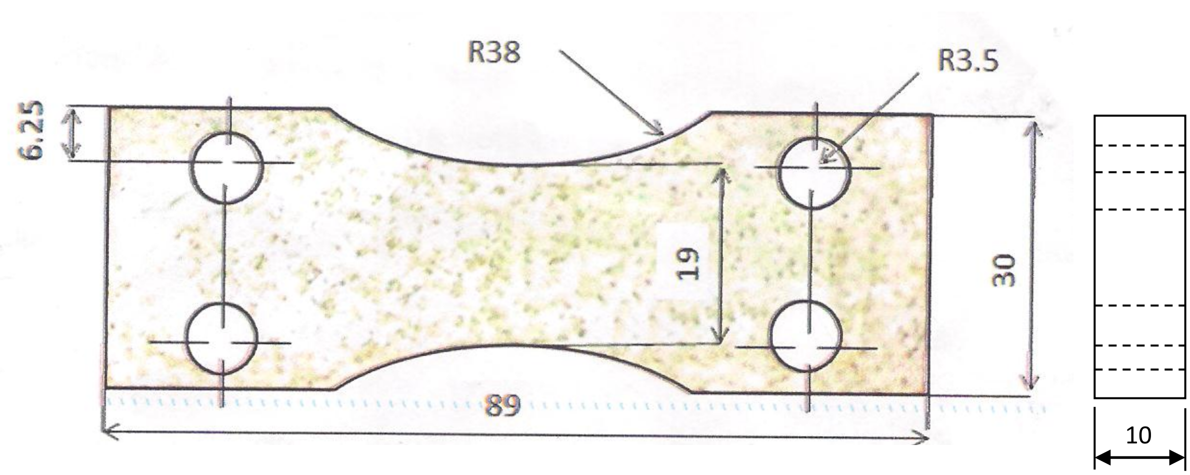

Figure 1.fatigue test specimen, shape and dimensions (mm) according to ASTM D3479/D3479M 96 standard

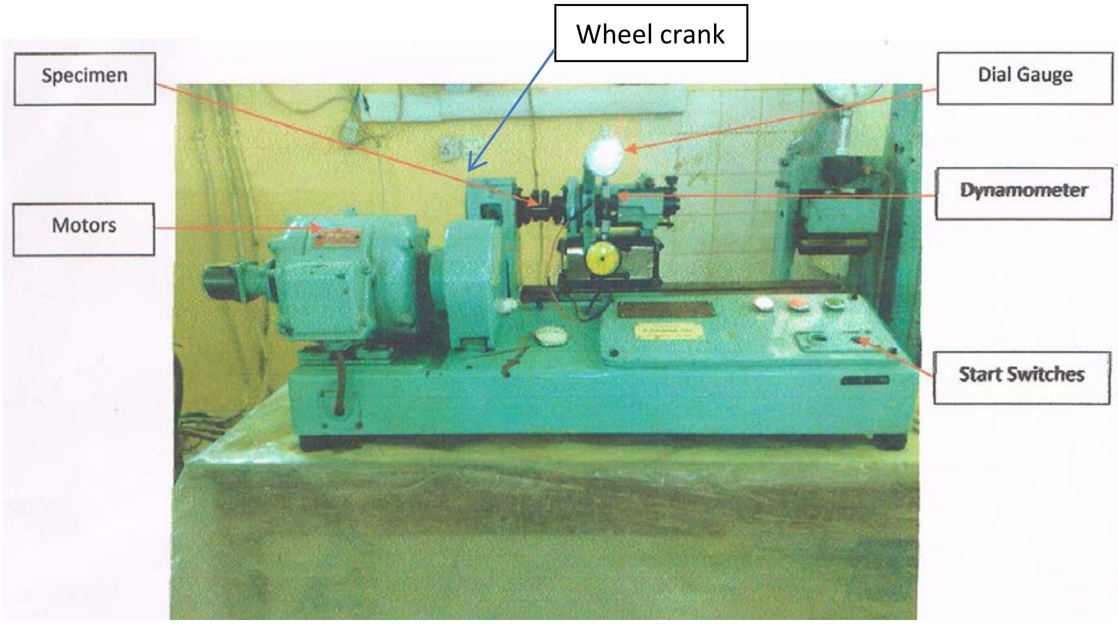

Figure (2) Reversed bending fatigue test rig

Figure 3. Shot peening device

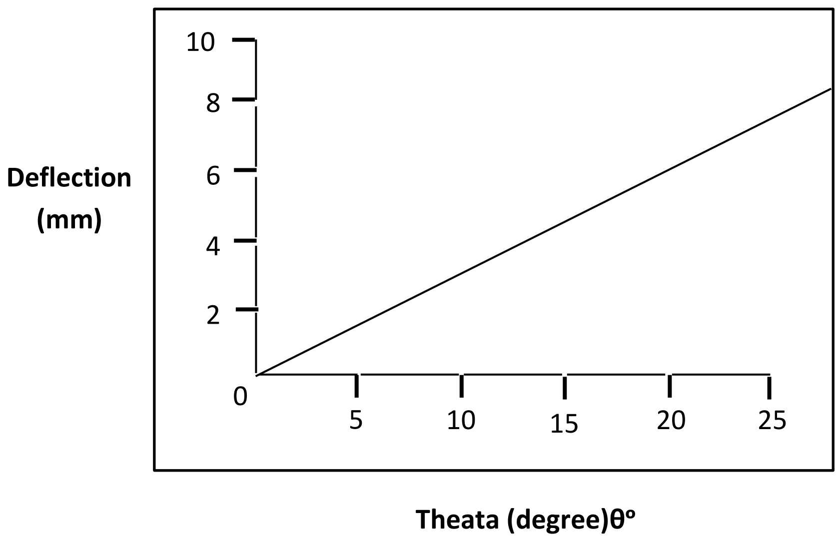

Figure (4) Calibration curve between θ^o and deflection

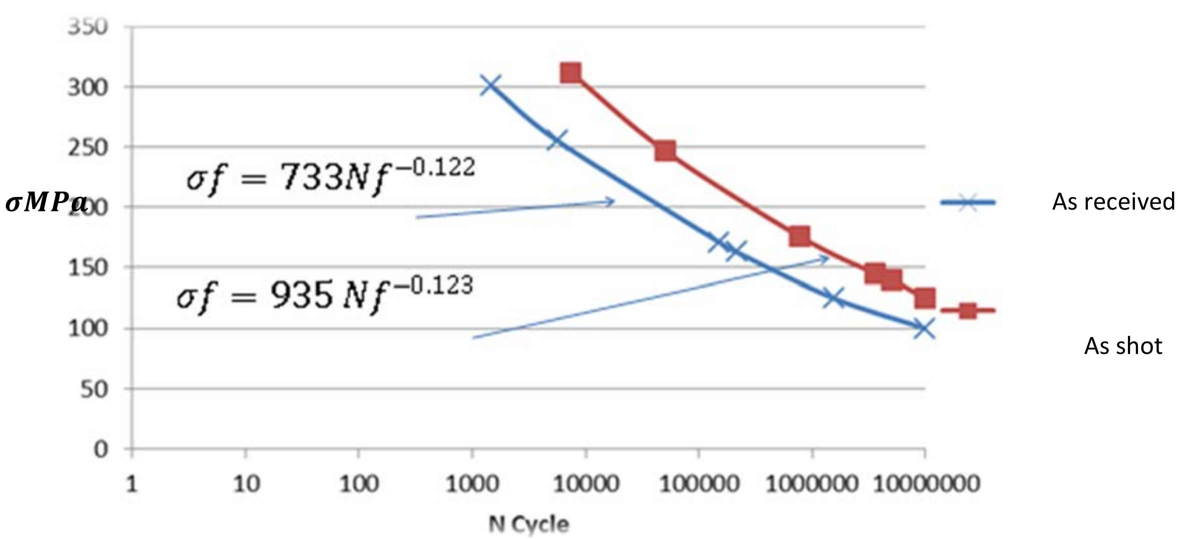

Figure. (5).S-N curves for unshot and shot peening

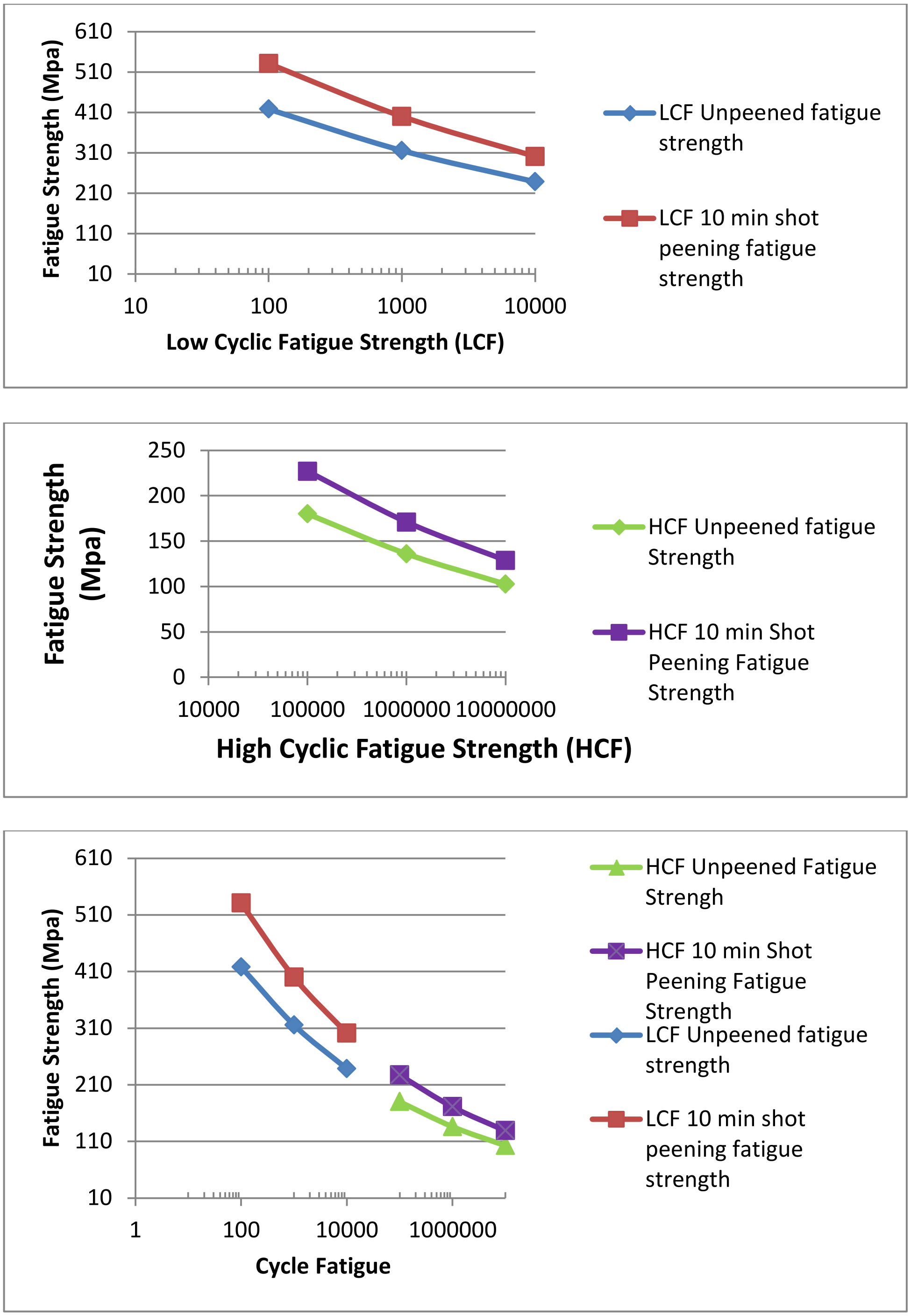

Figure (6). Strength of 2024-T4 Al at both LCF and HCF

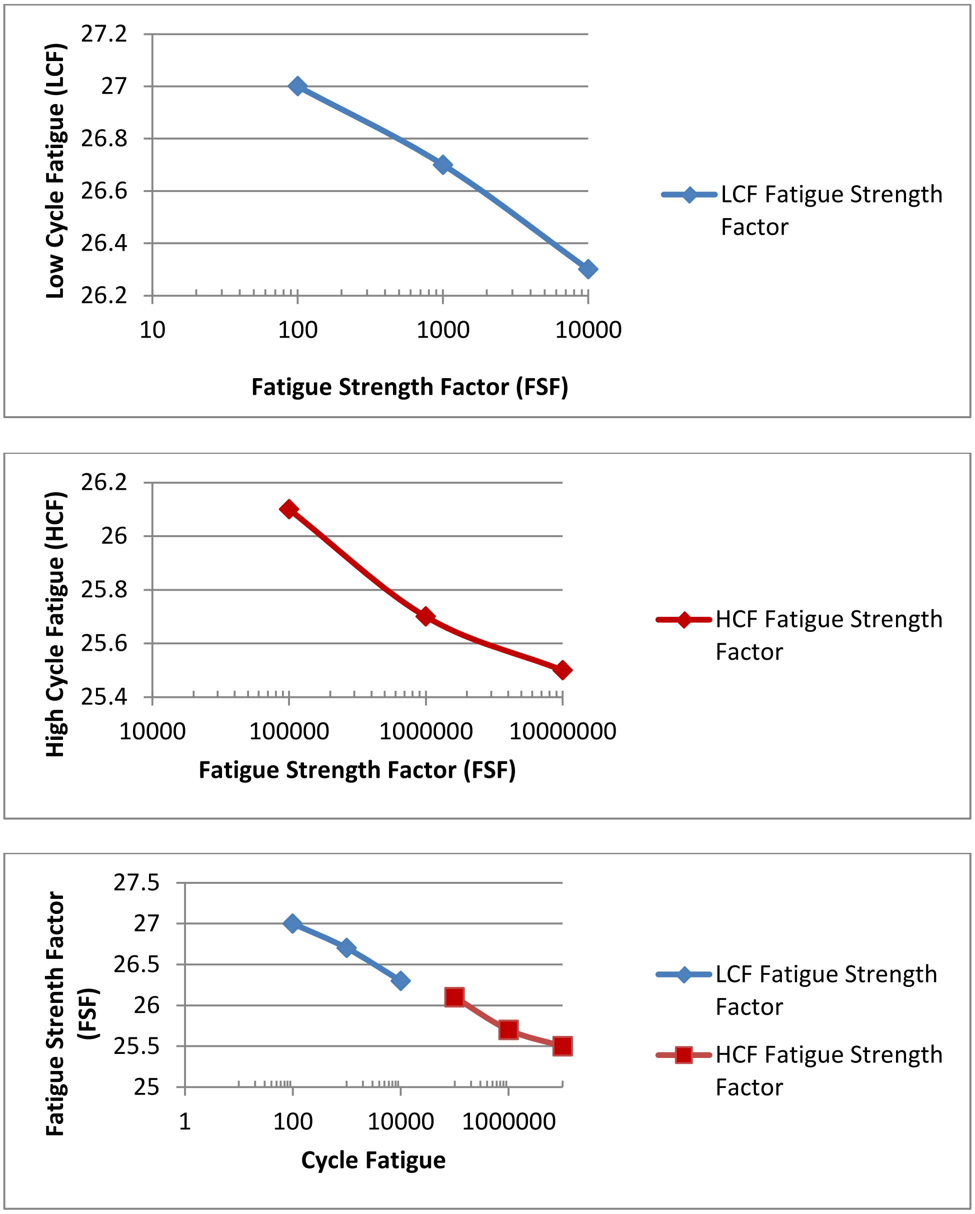

Figure (7). Fatigue Strength Factor of 2024-T4 Al at both LCF and HCF

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