Al-Khwarizmi Engineering Journal, Vol. 15, No. 1, March, (2019)
P.P. 82- 88

Al-Khwarizmi
Engineering
Journal

Study of Fatigue Fractography of Mild Steel Used in Automotive Industry

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(Received 27 February 2018; accepted 1 July 2018)
https://doi.org/10.22153/kej.2019.07.003

Abstract

Fatigue failure is almost considered as the predominant problem affecting automotive parts under dynamic loading condition. Thus, more understanding of crack behavior during fatigue can strongly help in finding the proper mechanism to avoid the final fracture and extent the service life of components. The main goal of this paper is to study the fracture behavior of low carbon steel which is used mostly in automotive industry. For this purpose, the fractography of samples subjected to high and low stress levels in fatigue test then was evaluated and analyzed. Hardness and tensile tests were carried out to determine the properties of used steel. Also, the samples were characterized by microstructure test and XRD analysis to examine the constitute phases. The fatigue test (S-N curve) was done at stress ratio (R= -1), and the fracture examination was perform using Scanning Electron Microscope (SEM). The results of microstructure and XRD analysis were indicating that the Ferrite and a little amount of pearlite are the dominant phases of this steel. Whereas, the fractography observations reveal that the void coalescence ductile fracture is the main failure mode in samples with high stress level, while the ductile fracture (void coalescence) with Transgranular Cleavage fracture was noticed in low stress fatigue mode for this alloy.

Keywords: *Automotive, fatigue, fracture, mild steel.*

1. Introduction

Automotive vehicles have become an important part of our everyday lives. Therefore, it is necessary to continually attempt to enhance their service life and design. Nowadays, with the fast progress in advanced technologies, the automotive industries become under grown pressure to produce vehicles which are more life service, safe and with best crash performance [1, 2]. Mild Steel have wide usage in automotive industry as a shafts, axles, gears, suspension and chassis parts.

However, a lot of these parts are very liable to fatigue failure, which happened without any prior warning, because of the elevation levels of cyclic loading that encounter normal use [2, 3]. Therefore, it is critical to understand the loading mechanisms and evaluation the fatigue behavior of the parts under dynamic loading conditions to ensure extend their service life and make it more safe. In the last decades there has been a growing interest in studying the mechanism of fatigue failure at different environments. So, many fatigue fractography investigation in last decade were made, Chang-Yeol Jeong [4] showed that fatigue life and the fatigue strength increased with higher yield and tensile strengths. The fatigue fracture behavior of AISI 1018 mild steel which expose to rotating bending- torsional fatigue were studied by M.W. Dewan et al [5]. They noticed that the small size dimples were due to high tensile stress. The effect of microstructure and short cracks in three groups of low carbon steel specimen subjected to tension-tension, rotating bending and pure bending loading on fatigue strength were investigated by Donka et al [6]. They noticed that the tension-tension fatigue specimen possesses the smallest crack growth rate due to lesser applied loading than other groups, while shorter fatigue life span were noticed for rotating bending specimen groups due to elevation fatigue load.

This work presents a systematic study of the mechanisms of fatigue damage in terms of initiation and propagation of fatigue cracks to failure of low carbon steel samples under low and high stress levels. The main goal is to provide greater insights into the alloy design of this steel and their subsequent engineering.

2. Experimental work

A. The Materials

The used steel in this study was (St 37) according to DIN standard which supplied as rods of 13 mm diameter and 1m long which were cut later to 150 mm long. The chemical composition was performed using Oxford X-Met 3000TX spectroscopy and the chemical compositions as shown in Table (1).

Table 1,
chemical composition of steel

Element	C	Mn	Si	S	P	Fe
wt.%	0.17	1.4	0.3	0.045	0.045	Rem.

B. Mechanical Tests

A Microhardness of a sample is tested by digital micro hardness tester (H.V.) under load of (9.8) N and dwell time of (15) second. A cylindrical shape specimen with (Ø 10mm× 6 mm) was used. The taken reading was an average of three reading.

The tensile test of specimen was carried out using WP 300 universal material tester device. The specimen was prepared according to (ASTM E8) standard.

A roughness test was performed using stylus probe type device to ensure the constancy of a tested surface subjected to fatigue. The average value of all samples were approximately R_a =0.5 (µm).

Fatigue tests were done using Gunt WP-140 fatigue testing machine with rotating bending load type and stress ratio (R= -1) at laboratory temperature. Cycles of 1×10^6 cycles were considering as a run out test. An average value of 3 specimens was adopted. Also Stress-Number of cycle to fail (S-N curve) was plotted and fatigue limit was concluded. A fatigue specimen dimensions is shown as in Fig (1).

C. Non Destructive Inspections

Microstructure examination were performed using BEL type optical microscope with 5 Mega pixel accompanied camera. Wet grinding was carried out using different grades of emery papers (320 up to 1200) followed with diamond paste 0.2 µm and its lubricant for polishing to get a high surface finish. Finally, the specimen was etched using Nital solution (2% HNO_3 and 98% Ethanol).

X-ray Diffraction analysis was used to ensure the contestant of ferrite and little amount of pearlite for the used alloy.

The fractured specimens from fatigue tests have been examined using scanning electron microscope TESCAN VEGA3 LMU. This inspection was done to fractured specimens subjected to low and high stresses with different magnifications. All the tests and measurements in this research were carried out at room temperature.

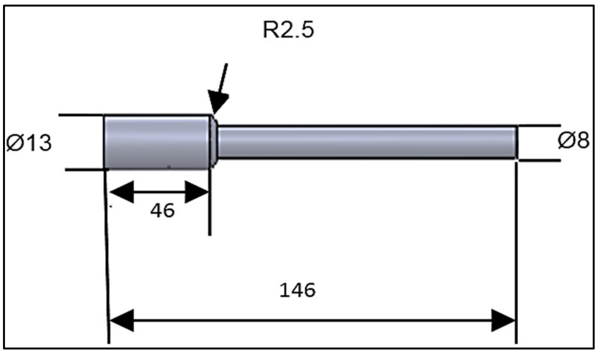


Fig 1. Fatigue test specimen dimensions (mm) .

3. Results and Discussion

A. Microstructure Examination

The microstructure of used steel is illustrated in Fig (2) with two magnifications. It is clear from Fig that the microstructure consists of pearlite regions (dark area) uniformly distributed with irregular shapes and imbedded in the matrix of ferrite (bright area). The percentage of pearlite content was about 17% (according to Image J software). More information can be concluded using X-ray Diffraction analysis which revealed the peaks of ferrite (pure iron) which it is the matrix of the used alloy as shown in Fig (3).

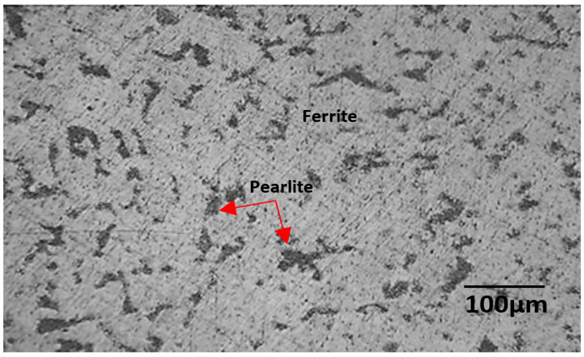
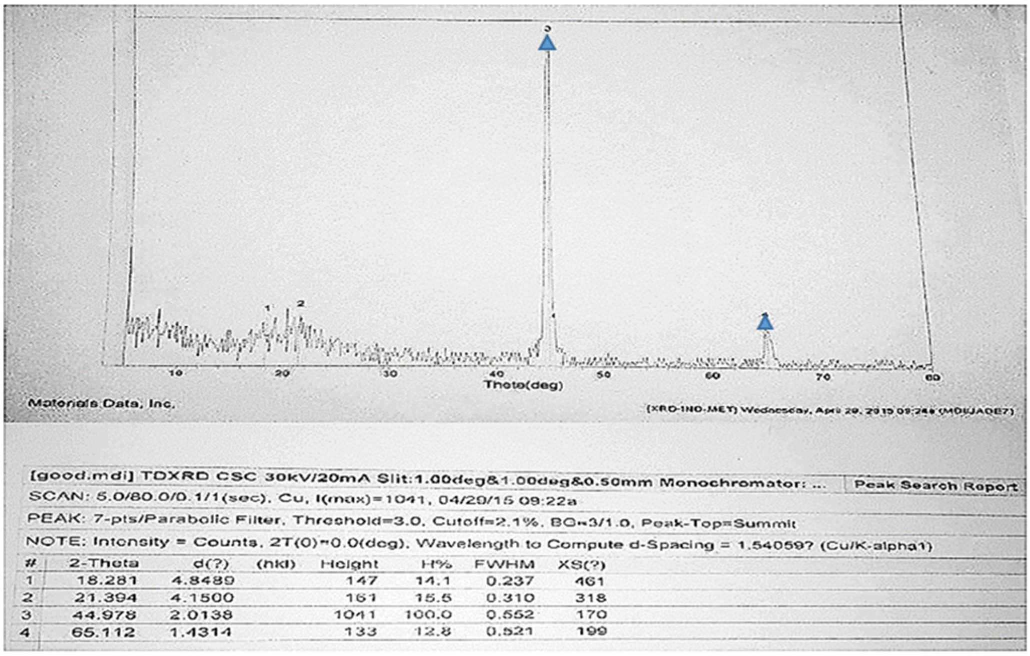


Fig. 2. Pictures show the microstructure of steel sample.



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[good.mdi] TDXRD CSC 30kV/20mA Slit:1.00deg&1.00deg&0.50mm Monochromator: ...
SCAN: 5.0/80.0/0.1/1(sec), Cu, I(max)=1041, 04/29/15 09:22a
PEAK: 7-pts/Parabolic Filter, Threshold=3.0, Cutoff=2.1%, BG=3/1.0, Peak-Top=Summit
NOTE: Intensity = Counts, 2T(0)=0.0(deg), Wavelength to Compute d-Spacing = 1.54059? (Cu/K-alpha1)
#   2-Theta    d(?)    (hkl)   Height    H%     FWHM    XS(?)
1    18.281   4.8489             147    14.1   0.237    461
2    21.394   4.1500             161    15.5   0.310    318
3    44.978   2.0138            1041   100.0   0.552    170
4    65.112   1.4314             133    12.8   0.521    199
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Fig. 3. XRD analysis of Sample.

B. Tensile and Hardness Results

Table (2) and Fig (4) present the hardness and tensile properties of used steel. A high ductility level can be observed due to the high content of ferrite which is very suitable for most automotive applications. These results have good agreement with previous literatures [7].

Table 2,
Hardness and Tensile tests results

State	Hardness (HV), (Kg/mm)	ΔL (%)	Yield strength (σ_y),(MPa)	Tensile strength (σ_u),(MPa)
As received	182	29	325 (approx.)	413

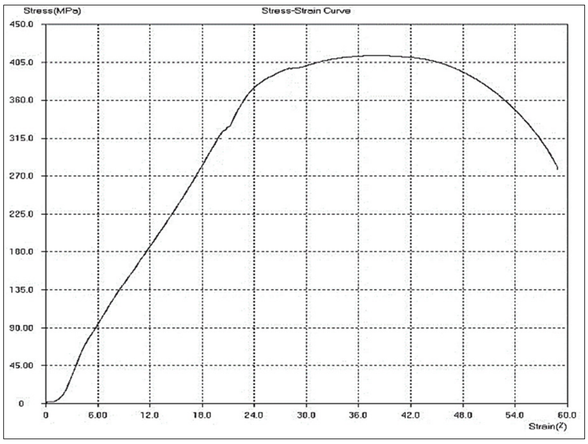

Fig. 4. Stress-strain of As-received steel material (St 37).

C. Fatigue Behavior

Before fatigue test was carried out a roughness measurement have been made to ensure the proper surface roughness for fatigue samples.

Rotating bending fatigue testing machine was used to determine Fatigue limit of used steel as a stress- number of cycle to failure (S-N) curve. Fig (5) and Table (3) shows the results of this test, which was 160 MPa, and this is deal with previous literatures [8].

Table 3,
Stress-Number of cycles data for as received samples

Sample no.	Stress (MPa)	Number of cycle
1	400	11600
2	380	19480
3	350	27260
4	300	46720
5	260	60080
6	210	91200
7	200	210300
8	180	480500
9	160	1e^6 (not fail)

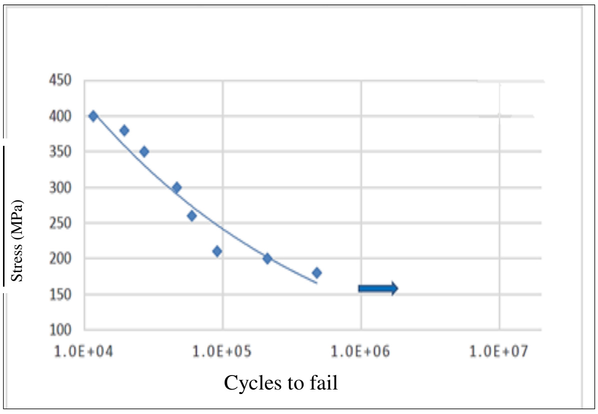

Fig. 5. S-N curve for steel (St 37) in as received condition.

Particular attention is paid to the fractography study, which was done using Scanning Electron Microscope, for samples at high and low stress levels. Fig (6) presents section of fracture surface for specimen at high stress level (380 MPa). For more clarify the failure zones marked with number from 1 to 4. It can be shown from Fig (7) that the crack initiate from the surface and propagate quickly with small extension. At the same time, the final catastrophic failure zone was wider comparing to that of crack progress zone. This is attributed to high levels of load in this region.

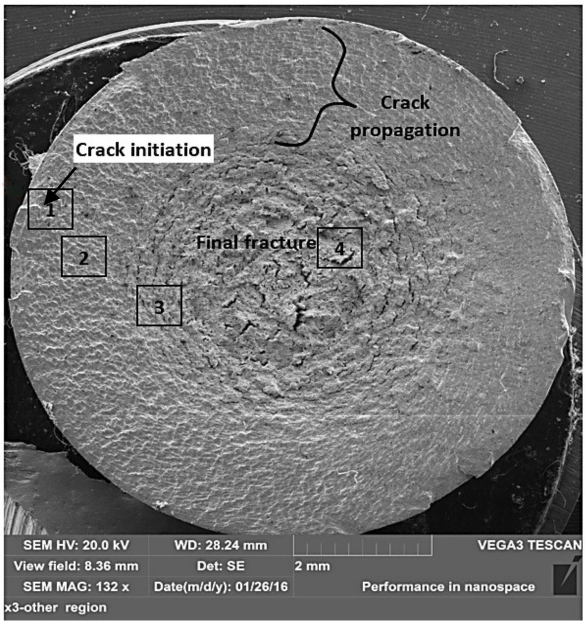

Fig. 6. Fatigue fractography for (St 37) in as received condition at high stress.

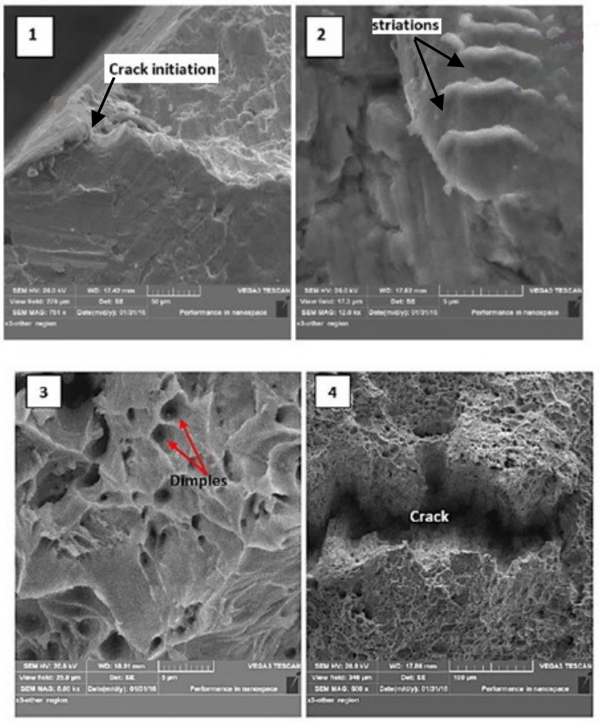

Fig .7. Fatigue fractography for sample in as received condition at high stress (cont.).

Fig (8) represents fracture surface for specimen at low stress levels. Fig reveal different features than previous one (high stress levels) due to difference in loading levels. It’s clear that there is wider crack propagation zone because the crack has more time to advance before failure. More than initiation spot was noticed and the final catastrophic failure zone was smaller. Also river marks were noticed in the propagation zone which refer to crack advancing direction toward final fracture.

In addition to, by viewing the fractography in more details and reviewing the previous literature [9], it can be concluding that this configuration of fracture topography indicates the low stress with high stress concentration conditions. The failure zones marked with number from 1 to 3 as shown in Fig (8).

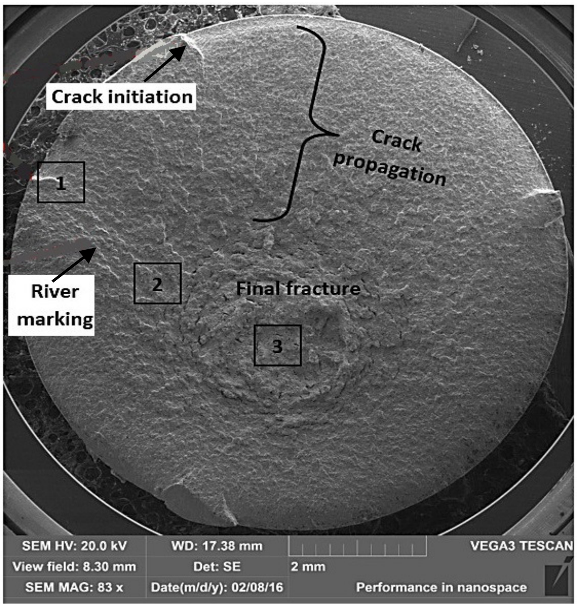

Fig .8. Fatigue fractography for sample in as received condition at low stress.

For more analysis, failure zones divided in Fig (9) into three areas and marked with number from 1 to 3. first zone (1) shows the crack initiation zone with many river marks, while zone (2) shows the evolution of micro cracks with circumferential direction around the final rupture. Zone (3a) indicates the final fracture with formation of voids as a part of ductile fracture phenomena. Zone (3b) represents a magnifying zone of the same zone (3a) which reveal crack facet which is the main feature of Transgranular cleavage fracture. This type of failure (Cleavage fracture) is familiar for BCC structures especially steels [10]. Also it was noticed that the final fracture is off-center, i.e. shifted toward the opposite side of final overload, this result is in a good agreement with Shipley et al [11].

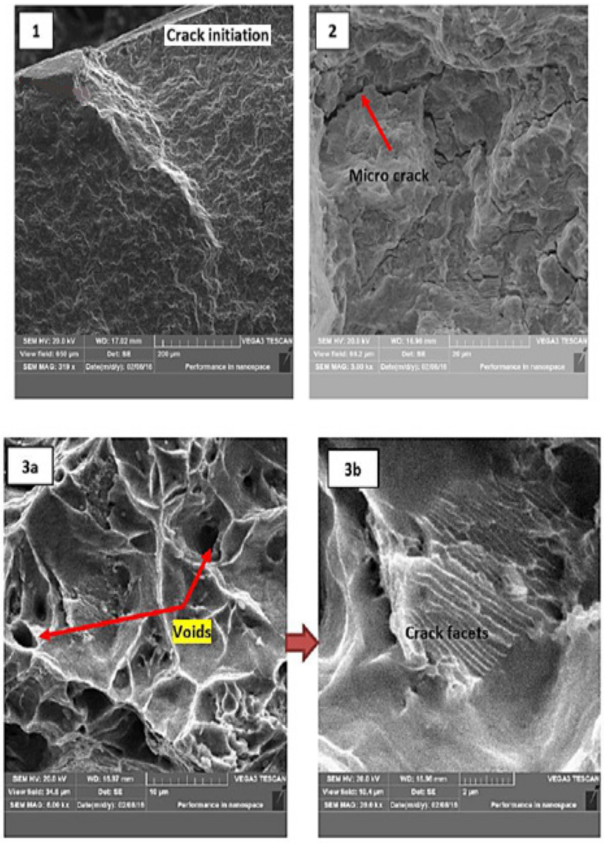

Fig. 9. Fatigue fractography for sample in as received condition at low stress.

4. Conclusions

From the obtained results, it is possible to conclude the following:

1. The Void coalescence ductile fracture is the main failure mode in high stress level.
2. The dominant failure mode is the general fatigue failure mode, which started by crack initiation and propagation, also ductile fracture (void coalescence) with Transgranular Cleavage fracture was noticed in low stress fatigue mode for this alloy.
3. This alloy is seeming to be encouraged to use in automobile applications subjected to moderate fatigue loading due to good fatigue limit and elongation.

5. References

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دراسة مقطع كسر الكلال للفولاذ المطاوع المستخدم في صناعة السيارات

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الخلاصة

يعد فشل الكلال من أخطر المشاكلات الشائعة المؤثرة على أجزاء السيارات المعرضة لأحمال دورانية. لهذا فان فهم سلوك الشقوق اثناء حدوث الكلال يساعد على تجنب حدوث الفشل النهائي للجزء اثناء الخدمة واطالة عمره. ان الهدف الأساس للبحث هو دراسة سلوك الكسر للفولاذ الواطئ الكربون والمستخدم في صناعة السيارات. لهذا السبب، تم دراسة مقطع الكسر للكلال عند احمال كلال واطئة وعالية لتقويم الأجزاء وتحليلها. كما تم اجراء اختبارات الصلادة والشد لتحديد خواص الفولاذ المستخدم. كذلك، تم توصيف المادة عن طريق دراسة البنية المجهرية ودراسة حيود الاشعة السينية لتفحص الاطوار والمكونات للسبيكة. ان اختبار الكلال (الاجهاد-عدد الدورات) تم اجراءه عند نسبة اجهاد (R=-1)، وتم دراسة مقطع الكسر باستخدام المجهر الالكتروني الماسح (SEM). اشارت نتائج الفحص المجهرية والاشعة السينية بان الطور السائد لهذا النوع من الفولاذ هو الفرايت مع نسبة قليلة من البيرلايت، بينما اظهر مقطع الكسر تكون كسر مطيلي بالتحام الفجوات حيث ان هذا هو الأسلوب عند اجهادات عالية، بينما أظهرت النتائج عند اجهادات كلال واطئة تكون الكسر الانقسامي تكون الكسر المطيلي الناتج عن التحام الفجوات لهذه السبيكة.
