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EFFECT OF NOTCH DIMENSION AND LOCATION ON FATIGUE LIFE AND THERMAL BEHAVIOR OF LOW CARBON STEEL (ST37-2)

Laith H. Al Najar[1], Luay S. Al-Ansari[2] and Mohammed W. Al-Jibory[3]

[1] **MSc student, Kerbala University, Email: laithhalnajar@yahoo.com**

[2] **Ph. D., Asst. Prof., Mechanical Engineering Department, University of Kufa. Email: luays.alansari@uokufa.edu.iq**

[3] **Ph. D., Lecturer, Mechanical Engineering Department, Kerbala University. Email: maljibory71@yahoo.com**

ABSTRACT

The effect of depth and location of the notch on the v-notched specimen on fatigue life of cantilever rotating beam of low carbon steel (ST37-2) is studied, by applying fully reversed cycle load of 150 N, and mean stress of Zero. The temperature variations during fatigue life were measured by infrared camera at three points in specimens. These points are the edge point, notch point and other specified points. Numerically, the finite element model of fatigue test was obtained using the ANSYS Workbench. The ANSYS model was based on the S/N curve measured experimentally.

From the results, there is a notch position that changed the fracture position from the notch position to the edge position. Also, fatigue life can be increased by putting the notch in appropriate position on the specimen. The temperature variation at different points in the specimen gave a good prediction to the fracture position before the fracture occurs. Also, from the comparison between experimental and numerical results, the two curves were similar but the ANSYS model based on the experimental S/N curve gave a good prediction for fatigue life.

KEYWORDS: Fatigue, Finite Element Method, ANSYS Software, Carbon Steel (St37-2), Notch, S/N Curve, Heat Generation**.**

تاثير بعد و موقع الشق على عمر الكلل و السلوك الحراري لفولاذ واطئ الكاربون (St37-2)

ليث حسين النجار أ.م.د. لؤي صادق الانصاري م.د. محمد وهاب الجبوري

الخلاصة

تم دراسة تاثير عمق و موقع الشق لعينات الذراع الناتئ الدوار بشق ذو شكل الحرف (V) على عمر الكلل لفولاذ واطئ الكاربون بتسليط حمل انعكاسي كامل مقداره (150) نيوتن و متوسط الاجهاد مقدارة صفر. تم قياس التغيرات في درجة الحرارة خلال عمر الكلل بواسطة كامرا الاشعة تحت الحمراء في نقطتين محددتين وهما نقطة الحافة و نقطة الشق. عدديا, تم الحصول على النموذج الخاص بطريقة (FINITE ELEMENT) باستخدام برنامج ال (ANSYSWORKBENCH) والذي يستند في حساباته على مخطط الاجهاد وعدد الدورات المحسوب عمليا.

من النتائج, موقع الشق يؤثر على موقع الكسر حيث ينقله من الشق الى الحافة. ايضا, هناك زيادة في عمر الكلل عن طريق وضع الشق في مكان مناسب من العينة. التغير في درجة الحرارة في نقاط مختلفة من العينة اعطى تنبؤا جيد لموقع الكسر قبل حدوثه. ايضا, من المقارنة بين النتائج التجريبية و العددية يوجد تشابة بين المخططات حيث نماذج برنامج ال(ANSYS) المبنية على النتائج العملية لمخطط الاجهاد و عدد الدورات اعطى تنبؤا جيد لعمر الكلل.

1. INTRODUCTION

Fatigue defined as "a form of failure caused by fluctuating or cyclic loads over a short or prolong period of time". On the other hand it was done at an ultimate stress less than the static yield strength of certain metal (Nestor, 2004). Fatigue behavior divided into two types, the first one is when high loads are applied that produced elastic and plastic strain, for every one cycle, likewise fatigue life in this region is relatively little less than 103 , and it is called low – cycle fatigue (LCF). The other type is called High –cycle fatigue (HCF), it is for lower stress – less than (LCF) –, the deformations are totally elastic, and longer fatigue life more than 103cycles (Richard and Keith, 2015). Although Fatigue knowledge has been developed step by step utile this time. In the 1840s in railway industry, they noted that railroad axles failed at its shoulders. That was the first major impact of failures due to repeated load. So the expression "fatigue" has been used in the 1840s and 1850s to explain failures occurring from repeated stress.

In 1850-1860 August WÖhler execute many fatigue testing experiments, and he presnts the concept of the S-N curve. After that a lot of researchers worked in this field to produce their theories for expanding knowledge on fatigue that we got to what it is now (Ralph et al., 2011). Fatimi et al. (2004) examined fatigue behavior on two types of material for notched specimens, also they calculated the stress concentration factor using finite element method and they considered Neuber's rule, and applicability of expected S/N curve. Also, Michele and Giovanni (2004) created in their paper new strategy for calculating fatigue strength reduction factor of notched specimens Kf of steel. Furthermore, Kharyia (2005) established experiments on rotating bending testing machine for v-notched specimens of low carbon steel alloy, the results show that the fatigue resistance decreases due to increase of the notch depth. Moreover, Borivoj et al., (2007) show the effect of notches and other defects on fatigue strength of the steel. By the way Verreman and Guo (2009) compare in their paper between experimental and finite element method results of medium carbon steel v-notched specimens. Alang et al., (2011), studied the effect of the surface roughness on fatigue life of notched rotating cantilever beam specimens of carbon steel, and Masao et al., (2011) studied the effect of notch in low cycle fatigue by utilizing multiaxial loads where the experimental work was done on notched specimens produced from SUS 304 stainless steel in tension and torsion load condition at 600° C. Nasim and Gholam (2011) concentrated in their study the effects of notch dimensions for different shapes on fatigue life, by using rotating bending machine specimens of low carbon steel alloy under constant load and room temperature. Also, Qasim and Emad (2014) studied the effect of v-notch with different dimensions on fatigue life by using cantilever beam specimens of Low Carbone Steel and compared the experimental results with numerical results of ANSYS program. On the other hands there are a number of researchers work on heat generation during plastic deformation as Rabiei et al., (2000) studied the heat generation during the compression- compression fatigue failure on perforated, and Caroline et al., (2012) studied the heat generation due to plastic deformation to fracture.

In this work, the effects of notch dimensions (depth and location) on fatigue life are studied experimentally and theoretically using the finite element method (by ANSYS Workbench 15.0). Experimentally, the S-N curve was plotted at the beginning, and then the effects of notch dimensions on fatigue life were studied. Also, the temperature increasing due to plastic deformation at the fracture point was measured using infrared camera (IR).

2. EXPERIMENTAL WORK

In this paper, the experimental work based on investigation of the effect of the notch depth and location on fatigue life, and monitoring the temperature change with the time during the tests. This test divided into two parts: first one is done to draw S/N curve, and the second is done to investigate the effect of the notch depth and location on fatigue life as shown in Fig. 1. Low carbon steel alloy (ST37-2) is used in this work, and provided from The State Company for Mechanical Industry. The chemical composition of the specimens used in this work was shown in Table 1 and its mechanical properties was shown in Table 2.

Table 1. Chemical Composition.

C%	Fe%	P%	S%	Si%	Al%	Cr%	Mn%	Ni%	Cu%	Mo%
0.187	Bal.	0.0041	0.021	0.281	0.02	0.122	0.636	0.091	0.136	0.011

Table 2. Mechanical Properties.

Yield strength (Mpa)	Tensile strength (Mpa)	Elongation percentage %	Modulus of elasticity (Gpa)
655	704.74	14.17	200

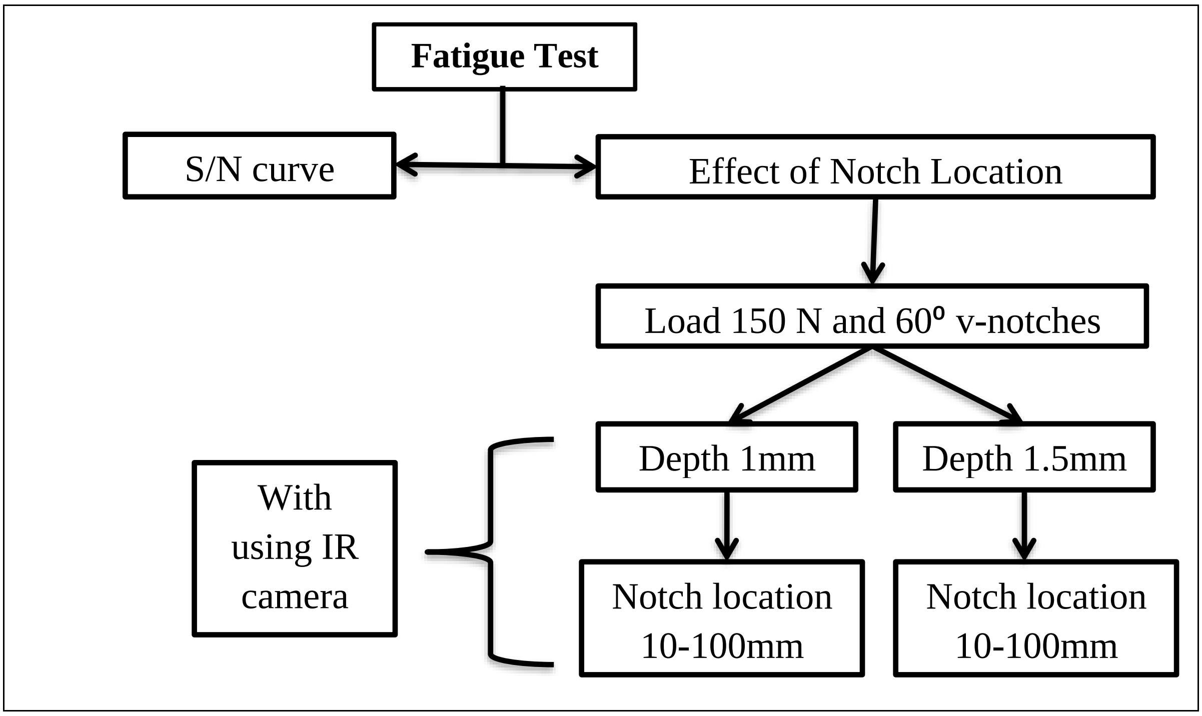

Fig. 1. Experimental Work Procedure.

3. FATIGUE TEST

3.1. Fatigue Testing Machine

Rotating bending machine type (WP 140 Apparatus of Gunt) was used in the test. This type with single cantilever beam specimen with constant amplitude and fully reversed load, as show in Fig. 2.

Fig. 2. Fatigue testing machine.

3.2. Fatigue test samples

The fatigue samples are machined in convenient dimension (ø = 12mm and L = 40 mm) and (ø = 8 mm and L = 106 mm) as shown in the Fig. 3. Two types of specimens are done; the first type is smooth samples without notch used in the experiments to plot the S/N curve. While the second type is notched specimens used in the experiments to study the effects of notch location and notch depth on the fatigue life. This was done by doing v-notch with angle 60^o and two different depths 1mm and 1.5mm. Every notch depth localized in different locations on different samples. The v-notch are done at distance (10, 20, 30… 100) mm from the edge as show in Fig. 4.

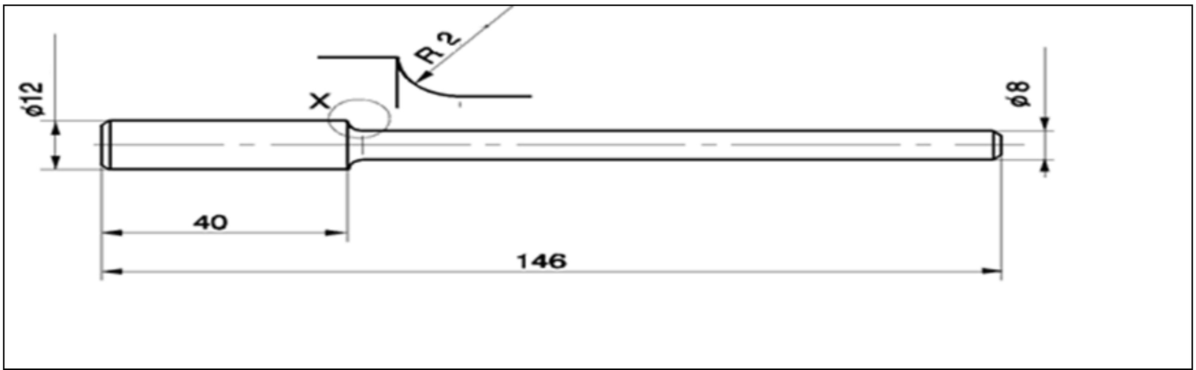

Fig. 3. Fatigue test sample.

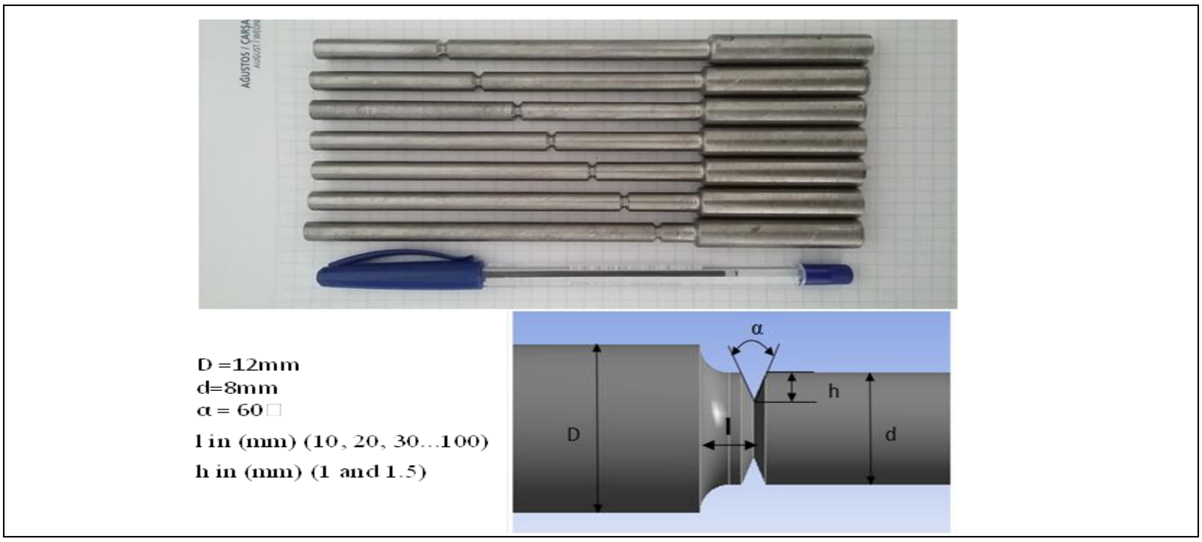

Fig. 4. Notched Specimens Test.

4. MONITORING TEMPERATURE CHANGE

During the fatigue behavior test, infrared camera (IR) (Flir E50) is used to monitoring the temperature change during the fatigue life of the specimens, as shown in Fig. 5.

(a)

(b)

Fig. 5. Infrared Camera and Fatigue Testing Machine Position in Fatigue Teste (a) Infrared Camera, (b) Infrared Camera with Fatigue Testing Machine.

5. NUMERICAL INVESTIGATION

Finite element method is applied by using ANSYS Workbench 15.0 to do simulation with experimental work that based on experimental S/N curve, the models divided into more than (33,000) elements type triangle surface masher as shown in Fig. 6.

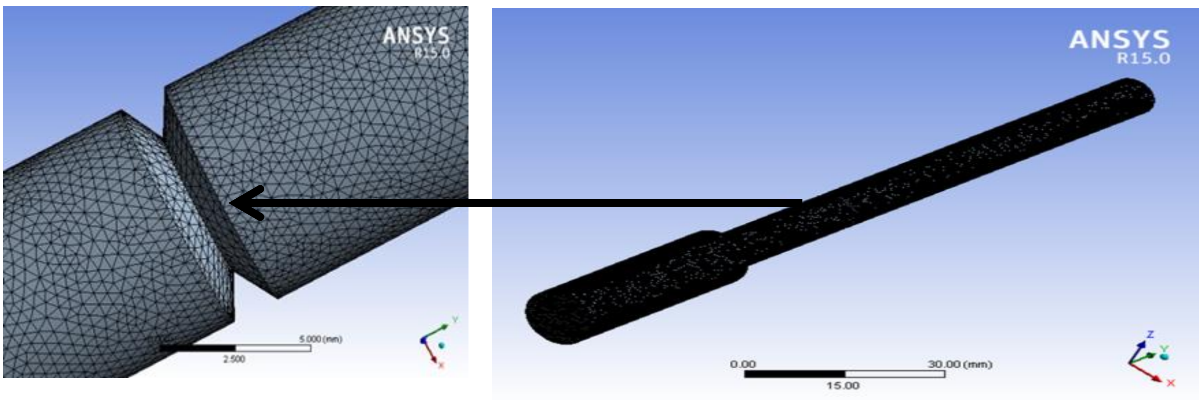

Fig. 6. Mashed ANSYS Model.

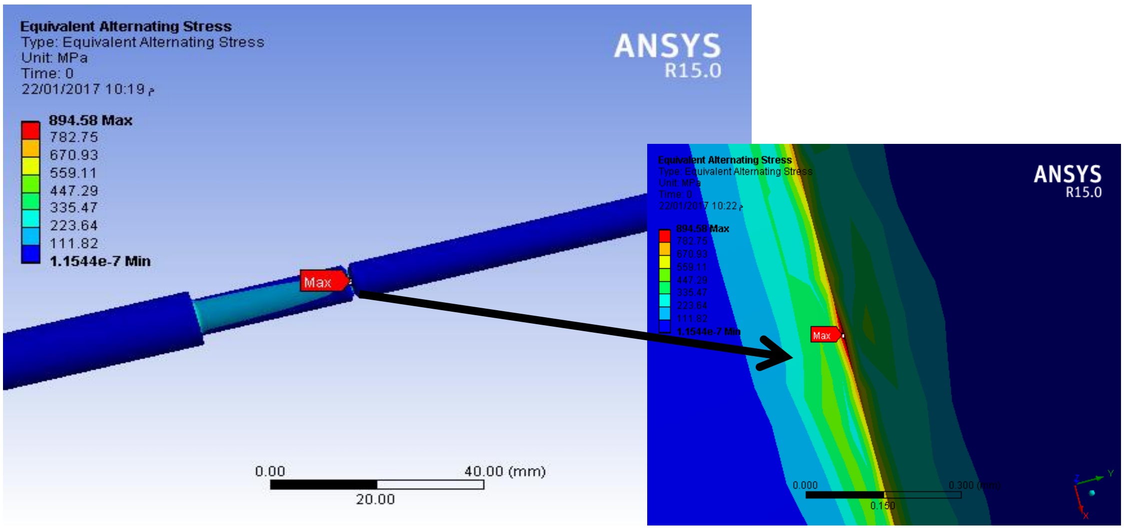

Fig. 7. Maximum Stress at Notch Area.

6. RESULTS

From experimental and numerical results it is found the following:

- Fig. 8 shows the S/N curve of the tested material that is obtained from experimental fatigue test of smooth specimens with different applied loads, this curve used then in ANSYS program.
- Fig. 9 and Fig. 10 show the experimental and numerical effects of notch position on fatigue life. From these figures the following points are found:
- There are similarities in behavior of the experimental and numerical results. This means that, the S/N curve of smooth specimen is sufficient in fatigue model in ANSYS program (i.e. no need for S/N curve for each notched specimens).
- Fatigue life depends on the depth and location of the notch, and it is inversely proportional to the depth of the notch.
- Numerically, Fig. 11 and Fig. 12 show the effect of notch position on the stress at notch and edge regions. The notch position closer to the edge, that leads to transform the maximum stress from the edge and concentrate it the in notch region. The moving of the notch away from the edge leads to increase the stress in edge and decrease it in notch as illustrated, that due to reforming the stress flow at those points. On the other hand the intersection point as shown the figures is referring to transforming the position as shown in Table 3.

- Fig. 13 shows the pictures of thermal camera for temperature distribution along the specimen and temperature change during the fatigue test.
- Figs. 14, 15, 16 and 17 show the temperature change on significant points (edge, notch) during the fatigue life. The following points were found:

1. Maximum amount of heat generation occurred in fracture position because of the concentrating of stress and strain in that position.
2. Increasing in heat generation with increasing of strain rate, can be seen during the fracture occurring, where the temperature variation curve slope is increased.

- Fig. 18 shows the macrostructure of specimens at fracture position when the notch depth is (1, 1.5 mm) and for different notch positions. The cross sectional area of the specimen divided into two regions. The first one is smooth region which refers to the slowly crack propagation, while the second one is the rough region which refers to the sadden fracture. The sadden fracture area was inversely proportion with fatigue life.

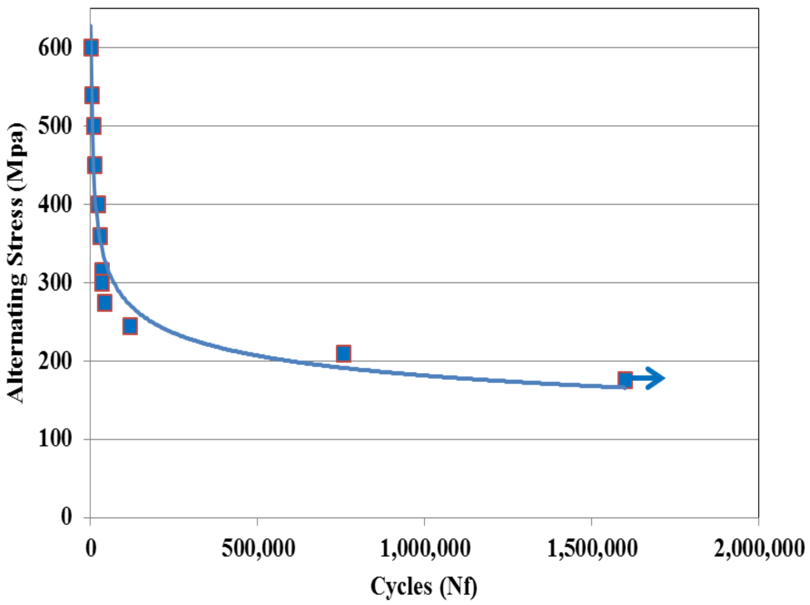

Fig. 8. S/N Curve of Testing Material.

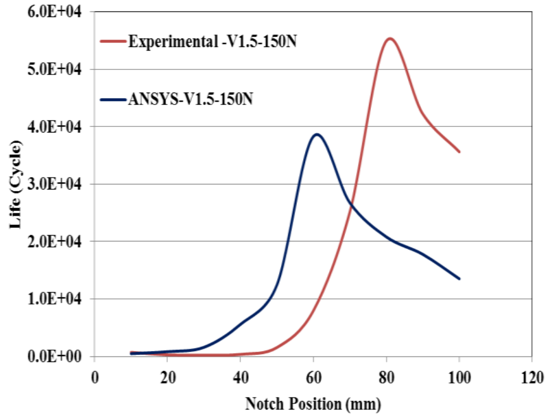

Fig. 9. Experimental and ANSYS Fatigue Life and Notch Position of (1.5) mm Depth.

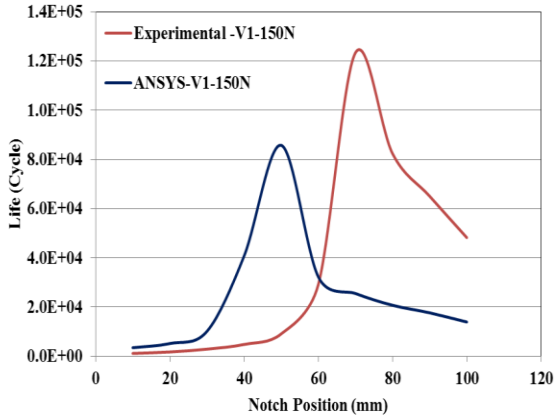

Fig. 10. Experimental and ANSYS Fatigue Life and Notch Position of (1) mm Depth.

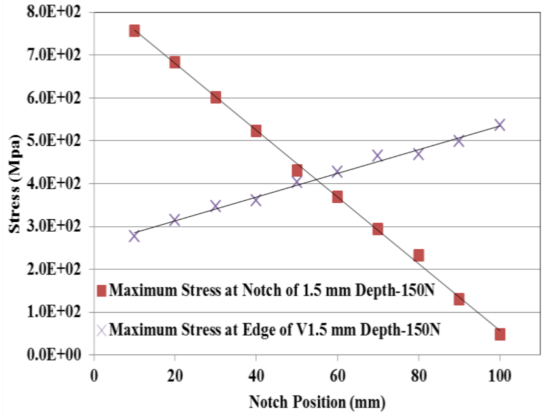

Fig. 11. ANSYS Maximum Stress in Edge and Notch with Notch Position of (1.5) mm Depth.

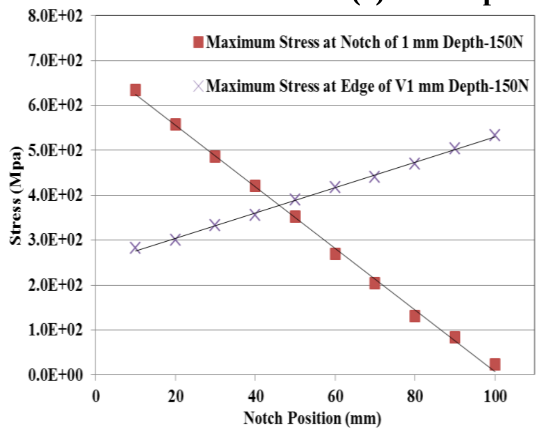

Fig. 12. ANSYS Maximum Stress in Edge and Notch with Notch Position of (1) mm Depth.

Table 3. Cases of Experimental Fatigue Test.

No.	Depth (mm)	Notch Position (mm)	Load (N)	Fracture position
1	1mm	10	150	10
2	1mm	20	150	20
3	1mm	30	150	30
4	1mm	40	150	40
5	1mm	50	150	50
6	1mm	60	150	60
7	1mm	70	150	Edge
8	1mm	80	150	Edge
9	1mm	90	150	Edge
10	1mm	100	150	Edge
11	1.5mm	10	150	10
12	1.5mm	20	150	20
13	1.5mm	30	150	30
14	1.5mm	40	150	40
15	1.5mm	50	150	50
16	1.5mm	60	150	60
17	1.5mm	70	150	70
18	1.5mm	80	150	Edge
19	1.5mm	90	150	Edge
20	1.5mm	100	150	Edge

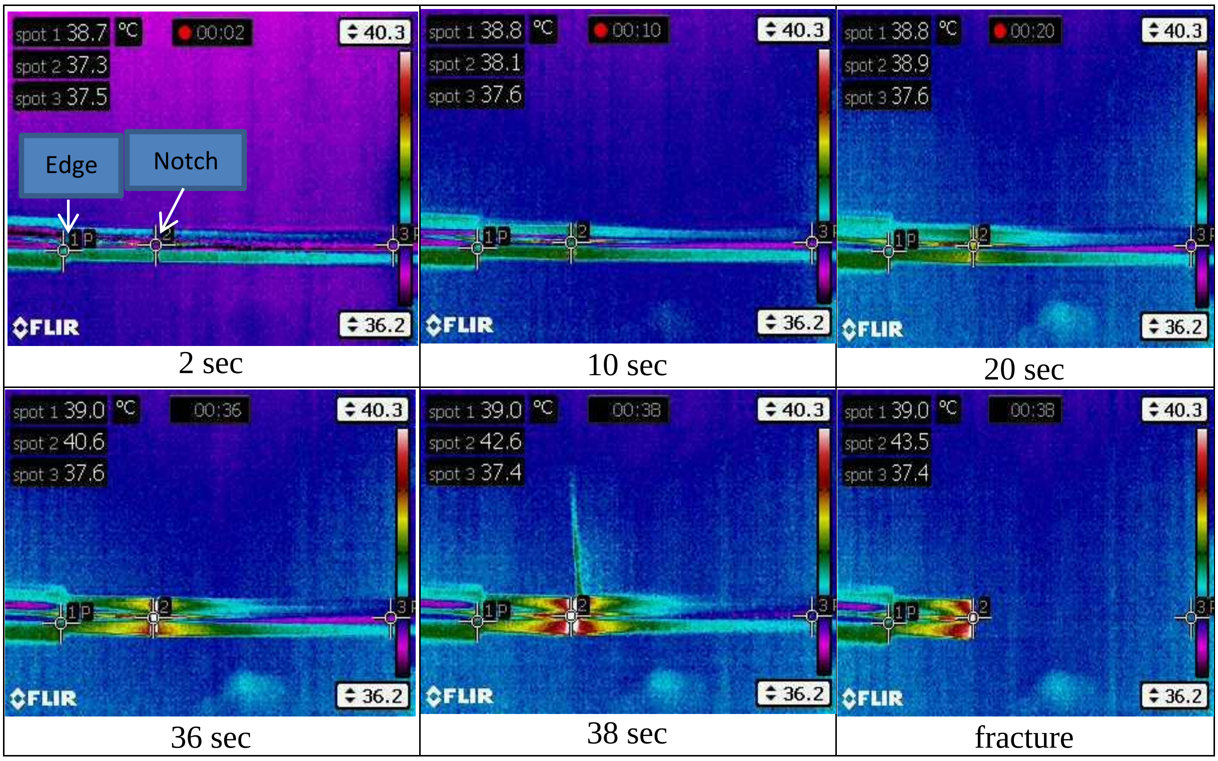

Fig. 13. Temperature variation during fatigue life.

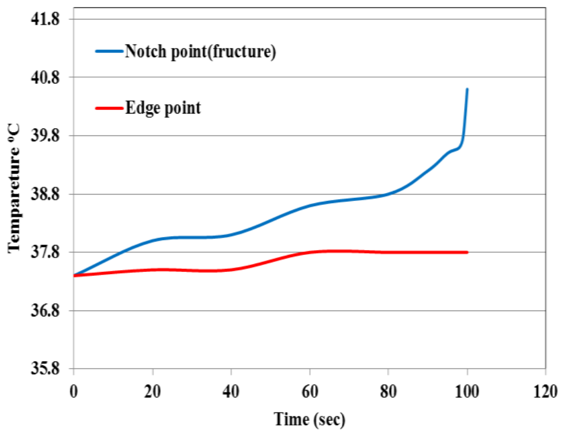

Fig. 14. Temp. Variation with Time at Specific Points of Notch Location 40mm and (1) mm Depth

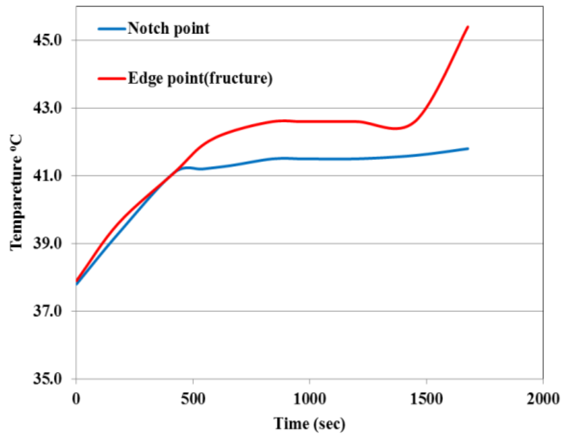

Fig. 15. Temp. Variation with Time at Specific Points of Notch Location 70mm and (1) mm Depth

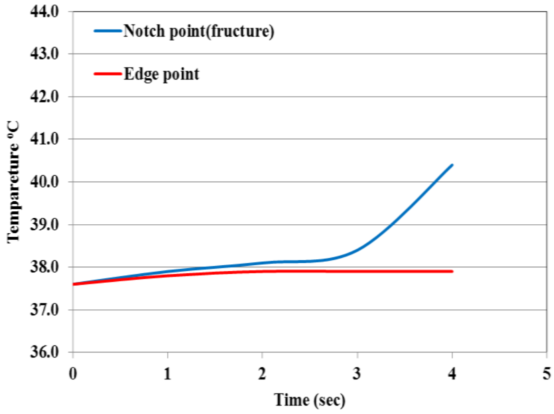

Fig. 16. Temp. Variation with Time at Specific Points of Notch Location 40mm and (1.5) mm Depth

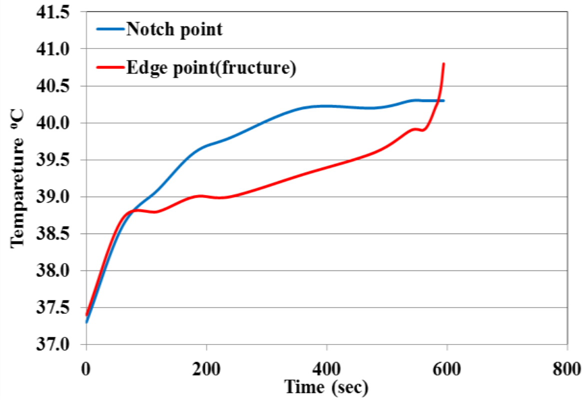

Fig. 17. Temp. Variation with Time at Specific Points of Notch Location 80mm and (1.5) mm Depth

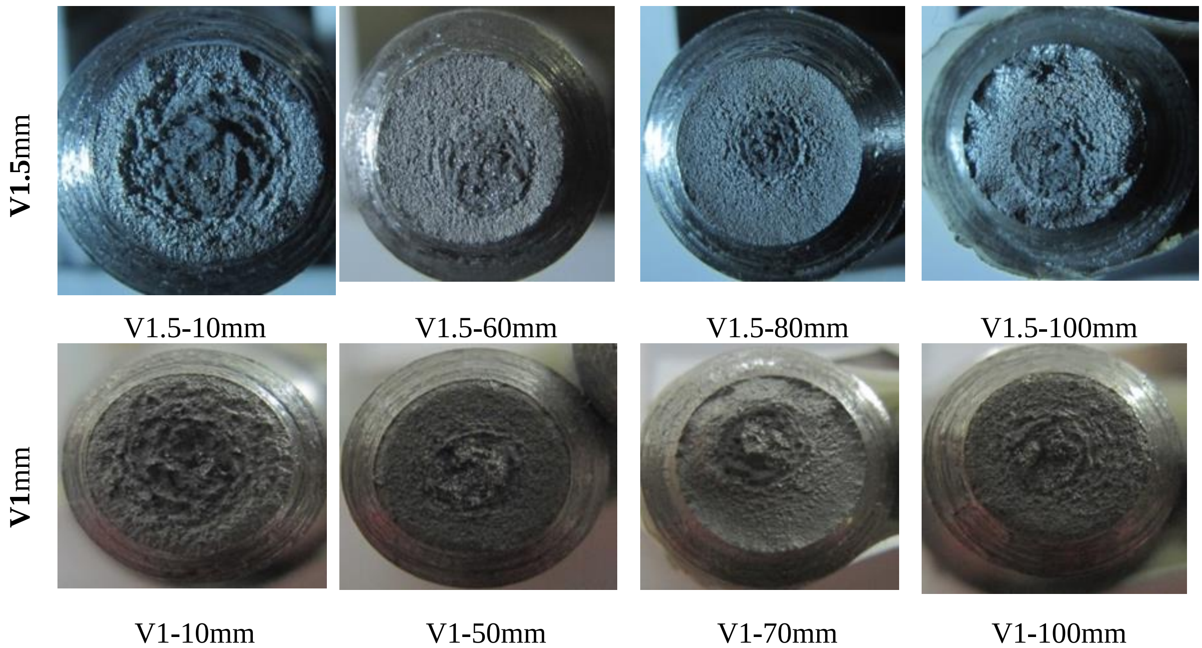

Fig. 18. Macrostructure test of fracture surface.

7. CONCLUSIONS

From the results, the following points can be concluded:

1. The ANSYS model based on the experimental S/N curve gives a good prediction for the notch effect without need to the S/N curve for each specimen having a notch.
2. The depth and position of the notch effect on the fatigue life. The fatigue life can be increased by putting the notch with certain depth in appropriate position on the specimen.
3. The temperature variation at the fracture position gives a good prediction to find the position of the fracture before it occurs.

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