Journal of University of Babylon, Engineering Sciences, Vol.(26), No.(1): 2018.

The Effect of Load Magnitude on Fatigue Life and Thermal Behavior of Notched Fatigue Specimen

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Abstract

Fatigue failure is an important phenomenon that occurred in the mechanical and structural systems. Furthermore, the failure due to fatigue load causes losing in that system. So many researches studying the fatigue behavior and improving the design of mechanical and structural systems in order to increase the fatigue resistance of these systems.

In this work, the effects of notch position and load magnitude on fatigue behavior were studied. In order to study the fatigue life of the test specimens due to make V- notched, the rotating cantilever beam samples were used. Also, the temperature distribution along testing specimens was monitoring of IR camera during the fatigue tests. Numerical model has been done by using ANSYS Workbench 15.0. The comparison between experimental and numerical results was made, also the hardness of the fractured surfaces was measured.

The results show that, the fatigue life of the test specimens can be increased by making a notch in the appropriate position. Also, there is a similarity between experimental and numerical results. IR camera gave a good expectance to the fracture position from changing in temperature distribution along the test specimens. Finally, the area of sudden fracture of the fractured surfaces reduced directly with load magnitude and inversely with notch shifting away from edge region.

Keywords: Fatigue, Finite Element Method, IR Camera, ANSYS, V-Notched, S/N Curve, Heat Generation.

الخلاصه

ظاهرة الكلل هي مهمة تحدث في النظم الميكانيكية والهيكلية. وعلاوة على ذلك، الفشل بسبب الحمل الكلل يسبب فشل النظام الميكانيكي. وقد أجريت العديد من الأبحاث لدراسة سلوك الكلل وتحسين تصميم النظم الميكانيكية والهيكلية من أجل زيادة مقاومة الكلل لهذه الانظمة.

في هذا العمل، تم دراسة آثار موضع الحز ومقدار الحمل على سلوك الكلل. من أجل دراسة عمر الكلل لعينات الاختبار بجعل حز بشكل (V) استخدمت عينات الذراع الناتئ الدوار(ROTATING CANTILEVER BEAM). أيضا، توزيع درجة الحرارة على طول عينات الاختبار كانت مراقبة بواسطة كاميرا الأشعة تحت الحمراء خلال اختبارات الكلل. تم تنفيذ النموذج العددي باستخدام (ANSYS WORKBENCH 15.0). أجريت المقارنة بين النتائج العملية والعددية، كما تم قياس صلادة الأسطح التي تعرضت للكسر.

يمكن زيادة عمر الكلل لعينات الاختبار من خلال جعل الحز في الموقع المناسب. أيضا، هناك تشابه في السلوك بين النتائج العملية والعددية. أعطت كاميرا الأشعة تحت الحمراء توقعا جيدا لموقع كسر من تغيير في توزيع درجة الحرارة على طول عينات الاختبار. وأخيرا، مساحة منطقة الكسر المفاجئ في الأسطح المكسورة قلت طرديا مع مقدار الحمل وعكسيا مع تغيير موقع الشق بعيدا الى نهايه.

كلمات مفتاحية: الكلل، طريقة العنصر المحدد، كامرا الاشعه فوق الحمراء، انسز، حز بشكل حرف V، مخطط الاجهاد وعدد الدورات، الحرارة المتولدة.

1. Introduction

Fatigue is a phenomenon caused a fracture in the mechanical structures that were under cyclic load and it was done at stress level below the yield strength of the material that the components built from (**Nestor, 2004**). Fatigue behavior divided into two areas according to cycles of fatigue life, when fatigue cycles below 10^3 cycles, it was in the low fatigue cycles area, and for cycles more than 10^3 called high fatigue cycles (**Richard, 2015**). The knowledge on fatigue behavior built gradually a long past time until now. In the 1840s found that the railroad axles have been fractured at their shoulders, which was a starting ignition on the knowledge of fatigue so this ward "fatigue" used since that time, and then come August WÖhler to put the S/N curve concepts. After that new researchers worked in this field (**Ralph, 2011**), as (**Kadi, 2001**), investigated the notch influence on fatigue behavior at high cyclic fatigue. Also, (**Fatimi, 2004**), studying the fatigue behavior on notched samples, and used finite element method to calculate stress concentration factor, and (**Borivoj, 2007**), studied the effect of notches on fatigue behavior of spring steel material by using Charpy standard samples. Furthermore, (**Dargi, 2010**), tried to predict numerically and analytically the duration of crack growth and its effects on notched structural components. Moreover, (**Goanta, 2011**), investigated the relation between the plastic deformation level and the hardness number of the fractured surfaces. By the way, (**Qasim, 2014**), studied the effects of different V-notch dimensions on fatigue life and used ANSYS program for numerical investigation and comparison between the results. On the other hand, there are a number of researchers work on the heat that was generated from plastic deformation as (**Rabiei, 2000**), worked on heat generation due to plastic strain under compression fatigue load, also (**Caroline, 2012**), studied the heat generation during plastic deformation until the fracture accrued.

In this paper, studied experimentally and numerically the effect of notch location and load magnitude on fatigue life. Experimentally, the S/N curve was drawn and then the effect of the parameters on fatigue life was studied, also the temperature increasing because of plastic deformation at fractured point was recorded by using IR camera. Numerically, using (F.E.A) by ANSYS Workbench15.0 program to build a simulation model.

2. Experimental Work

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

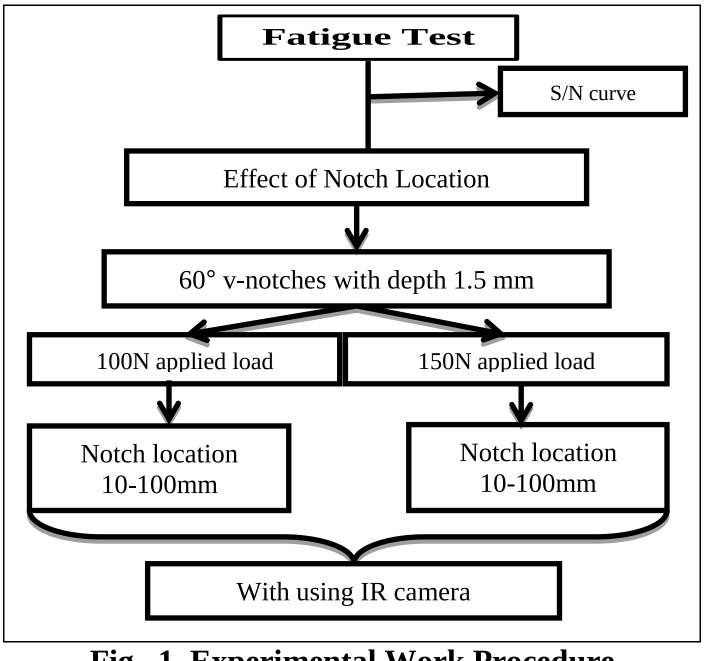


Fig. 1. Experimental Work Procedure

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

2.1 Fatigue Test

2.1.1 Fatigue Testing Machine

Its fatigue rotating bending testing machine type (WP 140 Apparatus of Gunt) is shows in Fig. 2 use single cantilever beam specimen with constant amplitude and fully reversed load.

TABLE 2
Mechanical Properties

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

Fig. 2. Testing Machine

2.1.2Fatigue test samples

The fatigue samples were 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 were preperd; the first one was smooth samples without notch for drawing S/N curve. While the second type was notched specimens for studying the effects of notch location and applied load (100,150) N by doing v-notch with angle 60^{o} and notch depth 1.5mm. This notch depth localized in different locations on samples. The v-notch were made at a distance (10, 20, 30,...100) mm from the edge as show in Fig. 4.

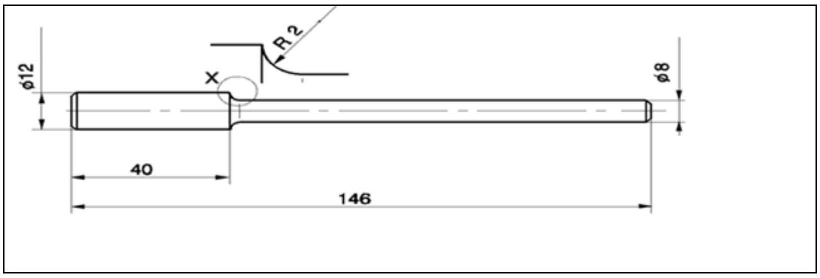


Fig. 3. Fatigue test sample

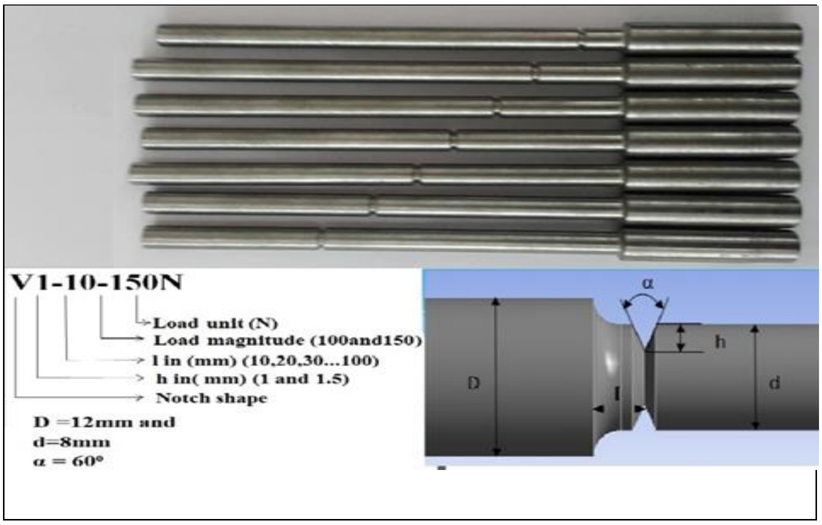


Fig. 4. Notched Specimens

2.1.3 Monitoring Temperature change

During the fatigue test, infrared camera (IR) (Flir E50) was used to monitor the temperature change during the fatigue test of the specimens, as shown Fig. 5.

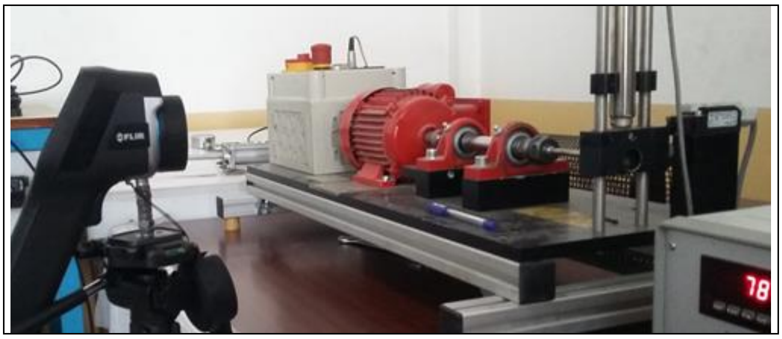


Fig. 5. Infrared Camera and Fatigue Testing Machine Position in Fatigue Teste

3. Numerical Investigation

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

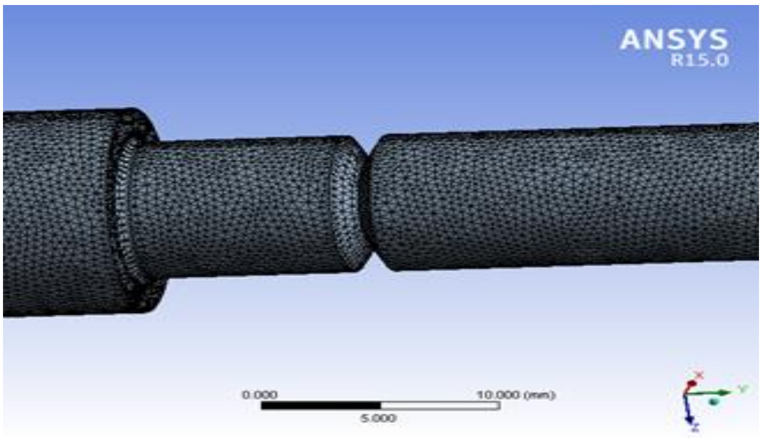


Fig. 6. Mashed ANSYS Model

4. Results And Discussions

From experimental and numerical results found the following :

I- Fig. 7 shows the S/N curve of the tested material that was getting from experimental fatigue test of smooth specimens with different applied loads, this curve used them in ANSYS program.

II- Figures (8 and 9) show the experimentally and numerically the effects of notch position and load magnitude on fatigue life and from these figures the following points are found:

1- There are similarities in behavior between the experimental and numerical and that means, the S/N curve of smooth specimen is sufficient in fatigue model in the ANSYS program (i.e. no need for a S/N curve for each notched specimen as done in (**Qasim, 2014)**).

2- Fatigue life is depending on load magnitude (inversely proportional) and notch's location.

III- Numerically, figures (10 and11) show the effect of notch position on stress at the notch and edge regions. The notch position closes to the edge that leads to transform the maximum stress from the edge and concentrate it in notch region. With moving the notch away from edge that leads to increasing stress in edge and decreasing it in notch as illustrated, that due to reforming the stress flow at those points, on the other hand the intersection point on the figures referring to transforming position as shown in Table 3.

IV- Fig. 12 shows the temperature distribution along the specimen and temperature change during the fatigue test.

V- Figures (13, 14, 15 and 16) show the temperature change on significant points (edge and notch) during the fatigue test and found the following points؛

1- Maximum amount of heat generation occurred in fracture position because of concentrating in stress and strain in that position.

2- Increasing in heat generation with increasing of strain rate. Can see it during fracture occurring, where the temperature variation curve slope increased.

VI- Fig. 17 shows the macrostructure of specimens at fracture position when the notch depth is (1.5 mm) under (150) N load, and for different notch positions. The cross section 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 sudden fracture. The sudden fracture area was inversely proportion with applied load and fatigue life as shown in Fig. 18.

5. Conclusion

From the results, the following points can be concluded:

1- The ANSYS model based on the experimental S/N curve give a good prediction for the notch effect without need the S/N curve for each specimen having any notch .

2- The applied load magnitude and position of notch effect on the fatigue life, and the fatigue life can be increased by putting the notch with certain depth in appropriate position on the fatigue testing specimen.

3- The temperature variation on the fracture position gives a good prediction to find the position of fracture before it occurs.

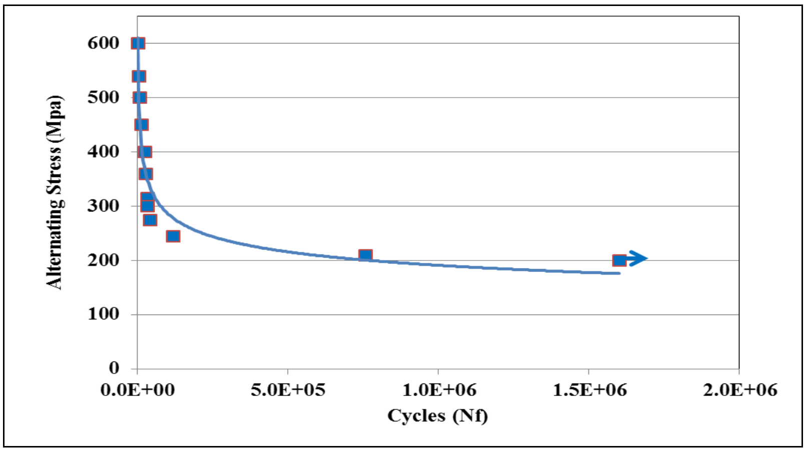


Fig. 7. S/N Curve of Testing Material

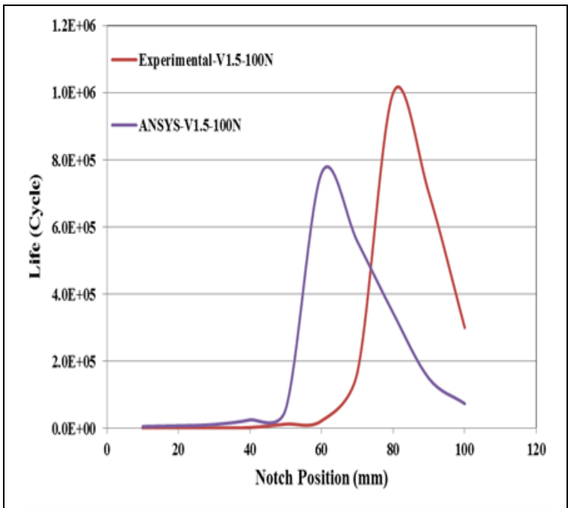


Fig. 8. Experimental and Numerical Fatigue Life and Notch Position of (1.5) mm Depth and 100N applied load

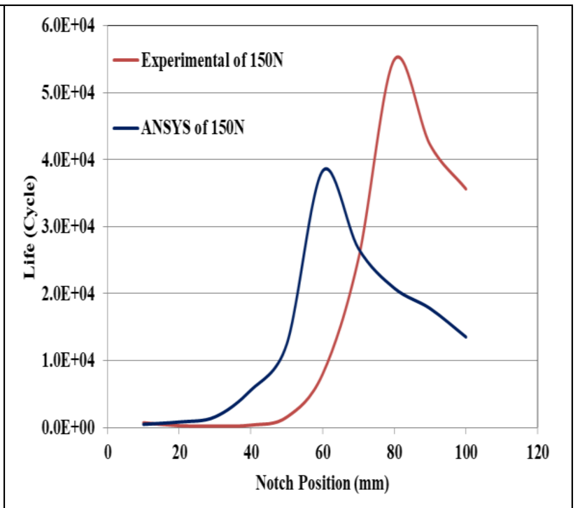


Fig. 9. Experimental and Numerical Fatigue Life and Notch Position of (1.5) mm Depth and 150N applied load

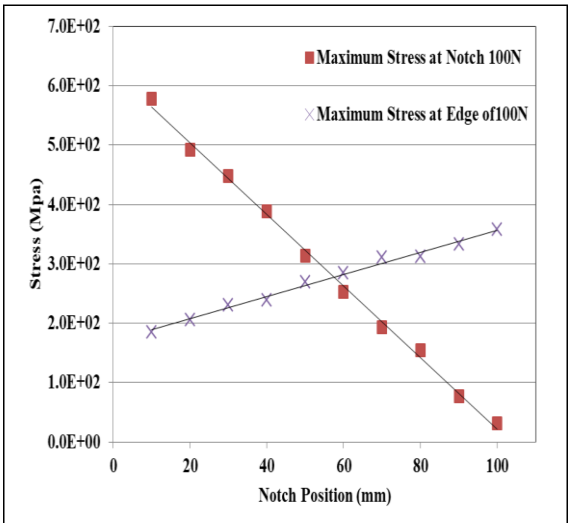


Fig. 10. ANSYS Maximum Stress in Edge and Notch with Notch Position of (1.5) mm Depth 100N applied load

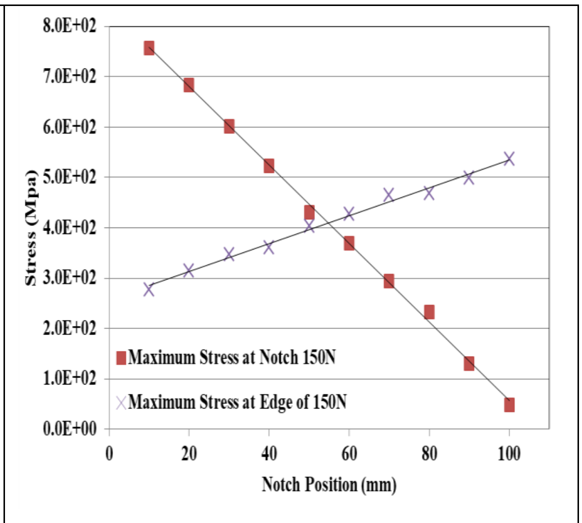


Fig. 11. ANSYS Maximum Stress in Edge and Notch with Notch Position of (1.5) mm depth 150N applied load

TABLE 3
Cases of Fatigue Test and Fracture Positions

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

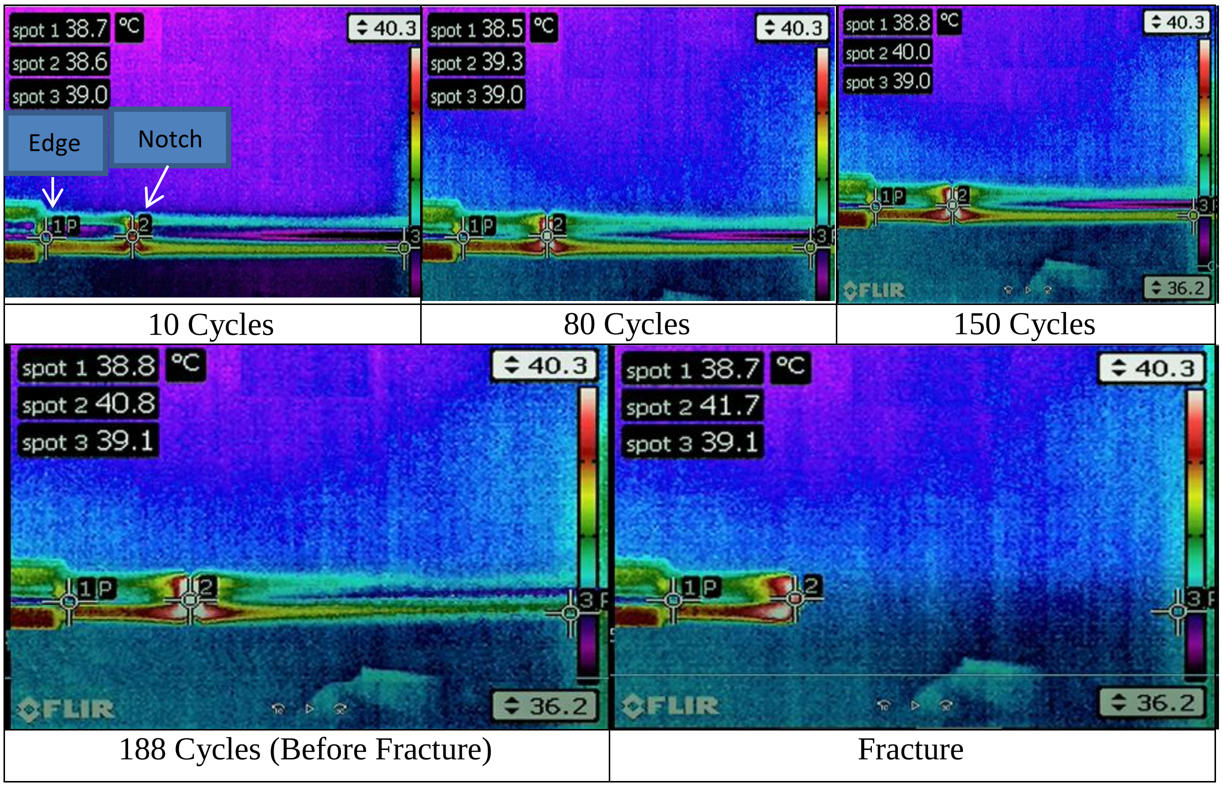


Fig. 12. Temperature variation during fatigue life of V1.5-20-150N

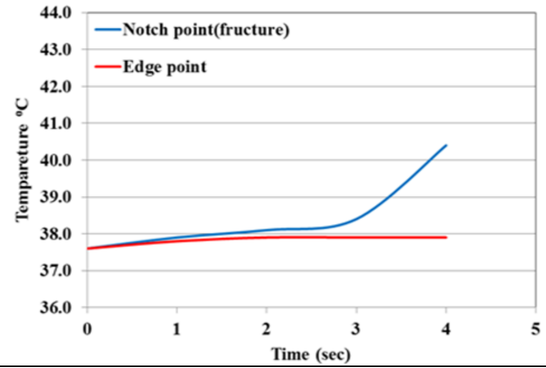


Fig. 13. Temp. Variation with Time at Specific Points of Notch Location 40mm and (1.5) mm Depth 150N applied load

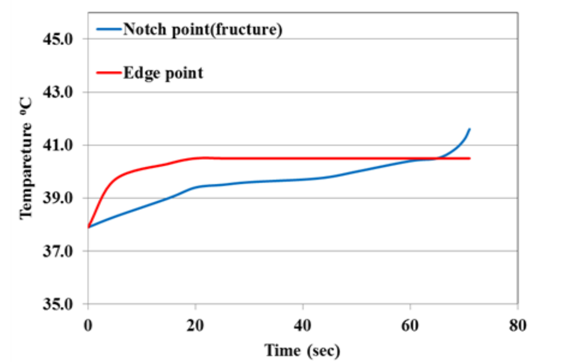


Fig. 14. Temp. Variation with Time at Specific Points of Notch Location 50mm and (1.5) mm Depth150N applied load

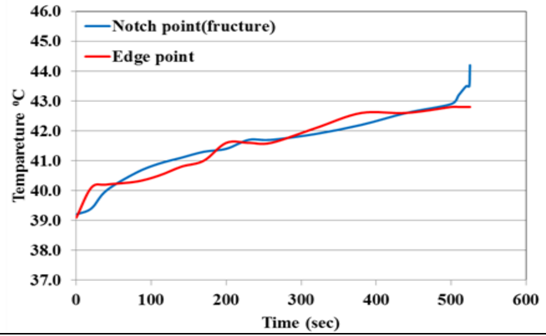


Fig. 15. Temp. Variation with Time at Specific Points of Notch Location 70mm and (1.5) mm Depth150N applied load

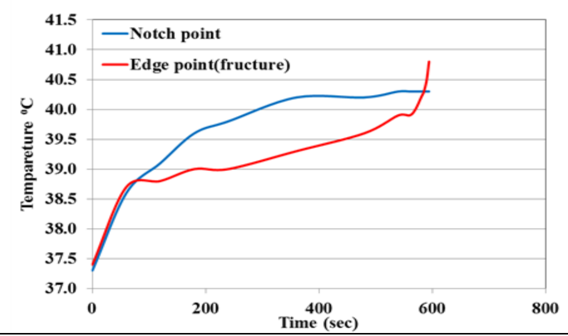
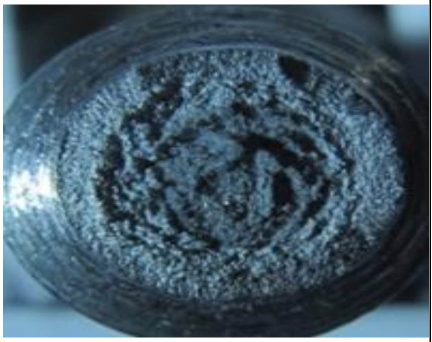
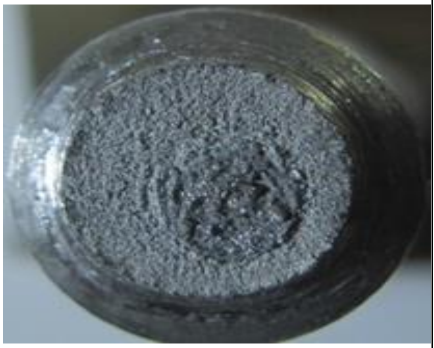


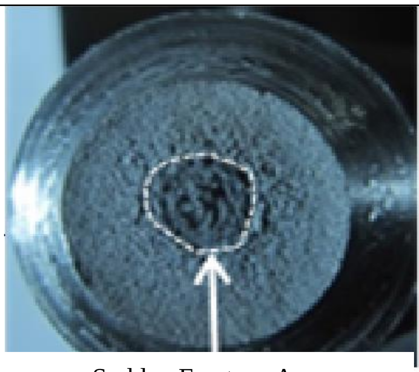
Fig. 16. Temp. Variation with Time at Specific Points of Notch Location 80mm and (1.5) mm Depth150N applied load



V1.5-10mm



V1.5-60mm



Sudden Fracture Area

V1.5-80mm

V1.5-100mm

Fig. 17. Macroscopic test of fracture surface

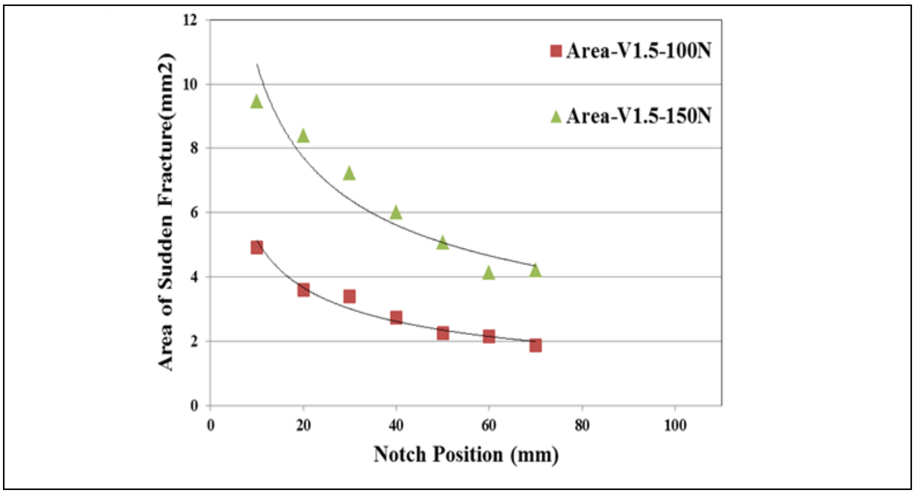


Fig. 18. Reduction in Sudden Fracture Area Due to Notch Position

Refrences

Borivoj Sustarsic, Bojan Sencic, and Boris Arzensek, Philippe Jodin , 2007, "The Notch Effect on the Fatigue Strength of 51CrV4Mo Spring Steel", Original scientific article, Materials and Technology, Volume 41.

Caroline Hyll, Hannes Vomhoff, and Och Mikeal Nygards , 2012, "Analysis of the Plastic and Elastic Energy during the Deformation and rupture of Paper Sample Using Thermography", Nodic Pulp and Paper Research Journal, Volume 27.

Dragi Stamenkovic and Katarina Maksimovic , 2010,"Fatigue Life Estimation of Notched Structural Components", Journal of Mechanical Engineering, Volume 56.

Fatemi A., Zeng Z., and Plaseied A., 2004, "Fatigue Behavior and Life Predictions of Notched Specimens Made of QT and Forged Micro Alloyed Steels", International Journal of Fatigue, Elsevier, Volume 26.

Goanta Viorel, Axinte toader, and Iftimie, Dumitru George , 2011, "The Variation of the Vickers Micro – Hardness in the Vicinity of the Fracture Surface at Static Loading", Journal of Engineering Studies and Research, Volume 17.

Kadi N., 2001,"Notch effect in High Cycle Fatigue", NATO Science Series Volume 11.

Nestor Perez , 2004, "Fracture Mechanics", Kluwer Academic Publishers.

Qasim Bader and Emad K. Njim , 2014, "Effect of V Notch Shape on Fatigue Life in Steel Beam Made of Mild Steel AISI 1020", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 4.

Rabiei A., Evans A. G., and Hutchinson J.W., 2000 , "Heat Generation during the Fatigue of a Cellar Al Alloy", Metallurgical and Materials Transaction, Volume 31A.

Ralph I. Stephens *et.al.*, 2011, "Metal Fatigue in Engineering", Second Edition, Aweiley- Interscience Publication, John Wiley and sons, INC..

Raymond Browell and Al Hancq , 2006, "Calculating and Displaying Fatigue Results", ANSYS,Inc,.

Richard G. Budyhas and Keith Nisbett J. , 2015, "Shigley's Mechanical Engineering Design", Tenth Edition, Mc Graw-Hill Education, New York.