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EXPERIMENTAL STUDY ON ELASTO-PLASTIC STRESS BEHAVIOR AT NOTCH ROOTS UNDER CYCLIC LOADING

Ganga Reddy C, Department of mechanical engineering, University Visvesvaraya College of Engineering; .
Dr. Shantharaja M, Department of mechanical engineering, University Visvesvaraya College of Engineering

Abstract

The objective of this work was to measure the Elasto-plastic stress and strain behavior of the notch root of the Al6061 alloy plate undergoing tensile and compression cyclic loading. The Elasto-plastic cyclic tests were conducted by using tensile machine with a pair of strain gauges. The results shows that the stress-strain curve at the notch is similar to the curve obtained in all in all conditions with prescribed strain. Experimental results the strain at each reversal i.e. tensile to compression and compression to tensile depend on the history of loading not on geometry of specimen. The plasticity leads to hardening effect of the specimen during cyclic loading was observed.

Keywords: Al6061, cyclic load, Elasto-plastic, stress-strain curves

Introduction

Many engineering components contain geometrical discontinuities, such as shoulders, keyways, oil holes and grooves, generally termed notches. The local stress and strain are accumulated in the notched area during loading. If stress exceeds the yield stress the plastic stresses developed small region of notch of structure [1]. In static loading the local plastic strains around the notches do not alter the material properties but in dynamic and cyclic loading condition varies severely reduces their life[2]. During cyclic loading elastic and inelastic strain may influence the crack nucleation at highly stressed regions and it propagate continuously which leads to component failure / fracture[3]. Local stress-strain method is widely used to investigate the notched cyclic behaviour to predict the life of the components. Although this experiment more suitable only laboratory tests but it gives crack initiation, fatigue life notch root progression and even crack initiation life. The local stress damages can be estimated using various parameters like stress, strain energy and plasticity index at the root notch. Other method to estimate nucleation of crack life based on uniaxial smooth specimen tests. Peterson[4] developed model for predicting stress concentration factor for various geometrical structures. Hardrath and Ohman [5] developed theoretical formula for predicting stress concentration factor under elasto-plastic conditions. Gemma [6] states that the predicated elasto-plastic stress concentration methodology for bi-axial stress conditions. Hoffmann et al [7] developed Elasto-plastic notch stress evaluation based on stress-strain equivalent method. Equivalent strain energy method associated with deformation theory, which fetches more accurate results compare to Neuber's rule [3]. In the case of cyclic loading, the stress strain curves at the root of notches are almost same as un-notched behavior. It implies that the stress strain curves depend on only external loading constitutions but not specimen geometry. Although many researchers [8-12] showed that the notch correction model could be combined with Elasto-plastic model to predict the local stress-strain behavior but no or little work focused to measure the notch sensitivity in cyclic loading conditions. Present investigation was undertaken cyclic stresses and strains at notch roots were determined experimentally by a companion-specimen technique.

Experimental Study

The calculation of local stresses directly from measured local strains is complicated by the history dependence of local Elasto-plastic stress-strain behavior and by cyclic variations in stress-strain properties. This method, other experimental details, and results are presented and discussed in the next sections.

The cyclic tests were conducted for different without notched specimens; the dimensions of the specimen and material used are given the Table 1 and Fig. 1. For cyclic loading three different stress-concentration factors were considered they are 2, 4 and 6.

Table 1: Dimension of notched specimens

Kt	Material	a	r	h	t
2	Al6061	5.1	8.1	24.5	4
4	Al6061	4.9	4.1	12.25	4
6	Al6061	5.08	3.1	12.25	4

Attention was restricted to the point of maxi mum stress concentration, and for each specimen configuration, this point was located at the notch root. Due the thickness of the specimen the plane stress was existed at the notch root because of uni-axial tensile load. Al plate was used for this research work and their chemical compositions are given in the Table 2. The local stress and strain at notch roots were measure by using strain gauges placed at the notches. The reading of the strain gauge was noted at prescribed intervals to draw stress-strain curves. To determine the stress concentration of notched specimen at each strain level based on strain gage reading of un-notched specimen readings. In all tests of Kt =2, =4 and =6 specimens, strain gauges with gauge length of 1.6 mm were used. A pair of strain gauges used at each notch root or one strain gauge used on each face of the notched specimen and they are connected in series to show the mean strains.

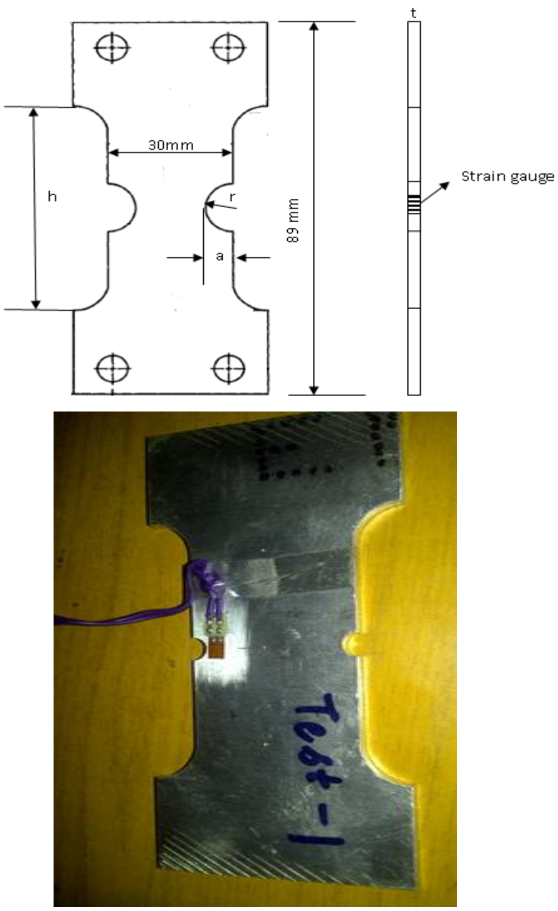

Fig. 1 Cyclic test specimen a) dimensions and b) tests specimen

To minimize the zero-shift error in the strain gauge two strain gauges used in opposite direction. Notched specimen was loaded to one complete cycle that is one half tensile and one half compressive cycles on the same specimen.

Specimen Setup

In order to have effective gripping of the specimen and to slipping while loading, the specimen (Aluminium 6061) a smooth surface had been roughened at the ends. A strain gauge was mounted on the specimen at the vicinity of the notch root, as the mounting of the strain gauge exactly at the notch root was difficult, owing to very small width of the plate and curvature of the notch. The strain gauge was mounted on the specimen at the point shown in the Figure 2 and 3.

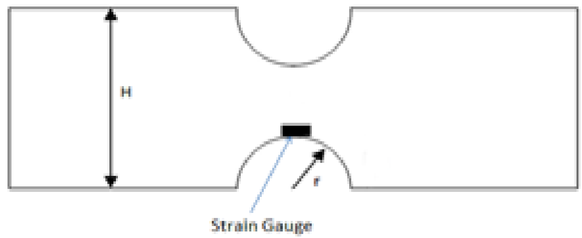

Figure 2 Positioning of strain gauge

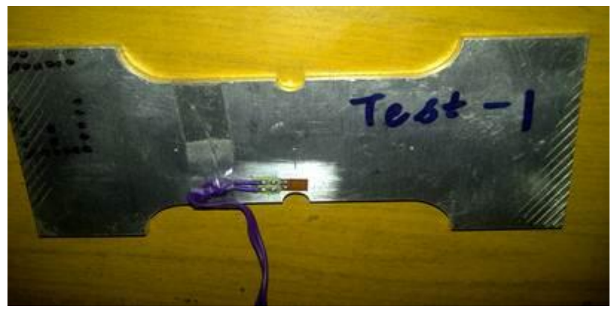

Figure 3 Positioning of strain gauge

The strain gauge was then wired to the microstrain indicator which gave the direct reading of the strain. The Figure 4 shows the strain indicator and the load indicator setup.

Figure 4 Strain gauge synced with UTM

The specifications of the Strain Gauge used to measure the strain are given in the Table 1

Table 1 Specification of strain gauge

Gage Type	Foil type.
Nominal Resistance	350 Ohms +/-0.1%
Gage Factor	2.10 +/-1%
Grid Size L & W	3.0 X 3.1mm
Overall Size L & W	7.2 X 4.9mm
Voltage	5 V to 15 VDC
Hysteresis	+/- 0.1% of R.O
Zero balance compensated	+/- 2%
Temperature Range	-5 Deg C to 65 Deg C
Termination	With Leads
Maximum Strain	20,000 Micro strains

Specimen Loading

The specimen was then fixed on the UTM. The UTM loading was done gradually via the computer software. As the load was being applied, the microstrain readings were noted down corresponding to the respective loads, from the strain indicator. The maximum load applied was 26.4kN. The Figure 5 below shows the specimen fixed on the UTM machine.

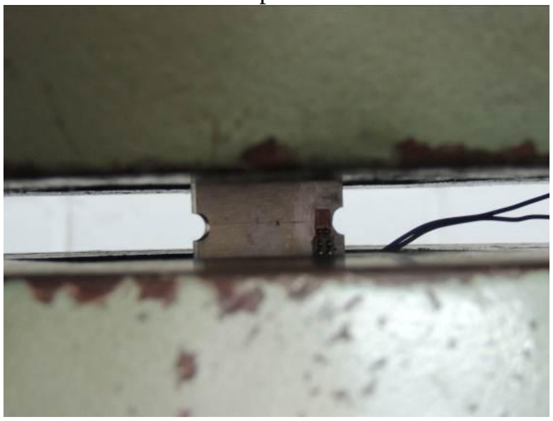

Figure 5 Specimen fixed on UTM

Results and discussion

The objective of the work was to compare the measured local elastic-plastic residual stresses with experimental studies. Evaluate the residual stress and plasticity after loading was carried out. The simplified experimental procedure is proposed to measure the residual stresses at the root of the notch after a simple loading and unloading tests.

The effect of tensile / compression stress range on one-cycle stress-strain behavior as shown in Fig. 6, Fig. 7 and Fig. 8 for different Kt =2, 4 and 6 respectively. The arrow shows the direction of loading both tensile (continuous line) and compression (dotted line) loading. Residual stress induced during tensile loading which relaxed when unloading but it returns other path which is below the previous curve which is due to strain energy influenced on plastic deformation within the materials, which leads to permanent deformation in the specimen. During compression loading the permanent deformation is relaxed further loading the compressive stress induced in the specimen until reach the maximum. After peak load the load relaxing in the compression, residual stresses are accumulated in the specimen. But the magnitude is much more than that of tensile residual stress induced in the specimen during tensile loading due to more plastic deformation. The right upper side half cycle and lower left half cycle nearly anti-symmetrical in nature but the different magnitude. The area between the curves shows that observed energy during the cyclic loading by the materials.

The area between the curves is increasing with increasing stress concentration factor (Kt) but the maximum stress decrease with increasing Kt due to higher stress concentration at notched location.

Since after unloading of tensile or loading of compression the compressive residual stress developed at the notch which helps to close micro-cracks. The compression residual stress retarded the cracks and lifetime increased. In this case larger plasticity is induced during the crack initiation. But other hand unloading of compression and loading of tensile the tensile residual stresses are developed at the notch which initiate and helps to propagate the micro or macro-crack. Plasticity and not only depend on loading history after the first unloading but also depends on shakedown phenomena may occur.

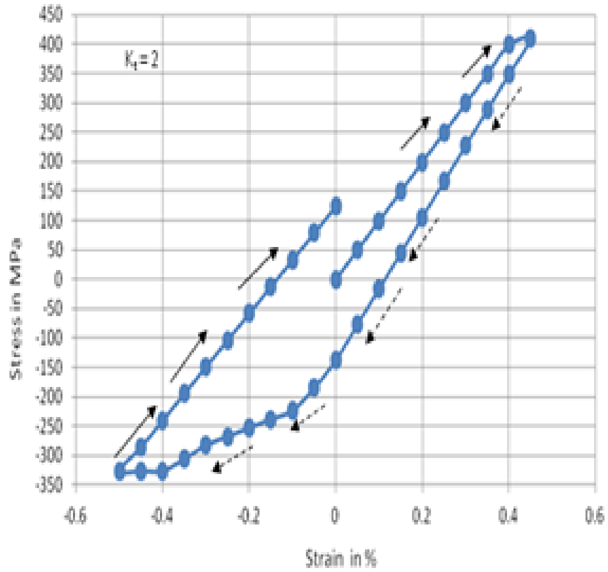

Fig. 6 Stress-strain curves for first cycle. KT = 2 for Al 6061 alloy

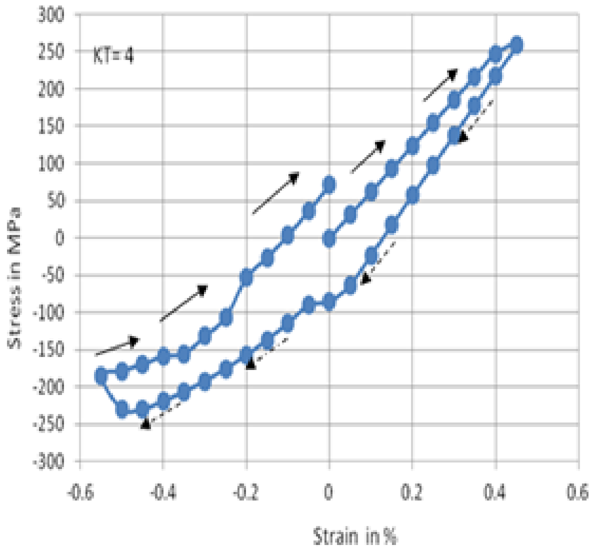

Fig. 7 Stress-strain curves for first cycle. KT = 4 for Al 6061 alloy

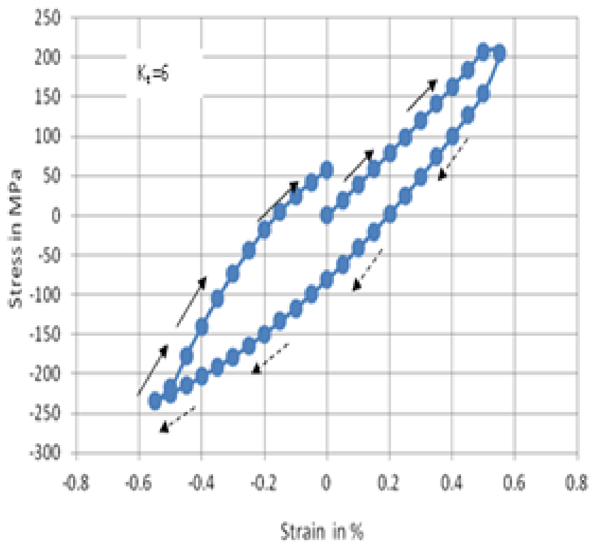

Fig. 8 Stress-strain curves for first cycle. KT = 6 for Al 6061 alloy

Conclusion

For specimens had elastic stress-concentration factors of approximately 2, 4, and 6, the local stress-strain behaviour was essentially the same for constant values of the product of maximum nominal stress σ_{max} and elastic stress-concentration factor K_T. Stabilization of local stresses appeared to occur in approximately one cycles of reversed loading for Al6061. The experimental studies of elasto-plastic stress-strain values in the article give more efficient information about notch elasto-plastic and stress-strain behaviour for the notch region under uni-axial loading. The local elasto-plastic stress-strain range increased with increasing stress concentration and decreases the strain range as well as maximum stress during the stabilization. Both half and full cycle residual stresses decreased in magnitude as the tensile (maximum) and compression (minimum) stresses increased.

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Biographies

GANGA REDDY C received the B.E. degree in Mechanical Engineering from the University of Bangalore, Karnataka, in 1997, the M.E. degree in Mechanical Engineering from the University of Bangalore, Bangalore, Karnataka, in 2002. Currently, He is a research scholar with the Department of Mechanical engineering at University of Bangalore. He works for HCL technologies as Group Project Manager with Mechanical Center of Excellence in the area of CAE. His work and research areas include Finite Element analysis, Non Linear simulation, Material modelling, Computational fluid dynamics, Aero Engines, Aero-Structures and Automotive crash simulation. Mr.Ganga Reddy can be reached on mail ID: gangareddyc74@gmail.com

DR. SHANTHARAJA received the B.E. degree in Mechanical Engineering from the University of Bangalore, Karnataka, in 1993, the M.E. degree in Mechanical Engineering from the University of Bangalore, Bangalore, Karnataka, in 1996 and received Ph.D from Bangalore University from Department of Mechanical Engineering, Bangalore University in 2009. Currently, He is an Assistant Professor with the Department of Mechanical engineering at University of Bangalore. His subjects and research areas include Composites, Machine Design, Finite Element analysis, Mechanical Vibrations, Kinematics and Dynamics of machinery.