Effect of sample edge-plastic zone proximity on Crack Tip Opening Angle

D. T. Asquith[1a], and V. P. Pasialis[2]

[1,2]Sheffield Hallam University, Howard Street, S11WB, Sheffield, United Kingdom

[a]d.asquith@shu.ac.uk

Abstract. The effect of sample edge-plastic zone proximity on Crack Tip Opening Angle (CTOA) has been investigated. Four CT specimens made from high-strength nuclear steel were statically tested until crack reached the geometric edge limits of the specimens. Digital Image Correlation (DIC) measurements were obtained. Results indicated that there was a significant increase in the CTOA as a result of the interaction between the plastic areas in the edge and around the crack tip.

Introduction

The purpose of this study was to quantify the impact of geometrical limits on the Crack Tip Opening Angle (CTOA). A total of four compact tension (CT) tests were prepared according to ASTM E399 standard [1]. All specimens were fatigue-precracked and statically tested until crack reached the edge of the sample. Two similar versions of steel grade SA-508-4N were used, denoted as '5400869' and '5400928', respectively, with the former being slightly tougher and harder.
The determination of CTOA values was performed according to ASTM E2472 standard [2]. According to the standard, the CTOA is calculated at r_i=1mm distance from the crack tip (Figure 1) using the following mathematical expression (Eq.1).

$$CTOA=2\tan^{-1}[(u_i-l_i)/2r_i] \qquad (1)$$

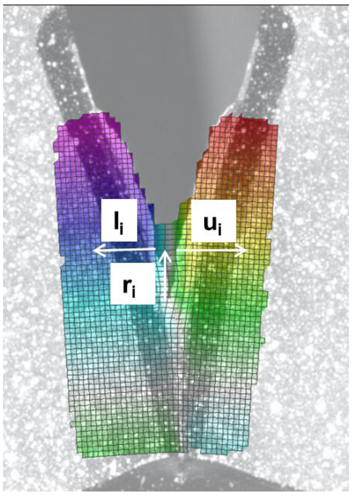

Figure 1: Calculation of CTOA using DIC.

Results depicted in Figure 2 indicate that there is a significant increase in the CTOA when crack reaches the edge of the sample. The reason for the increase in the CTOA is the interaction of two plastic areas located around the crack and near the edge of the sample, as observed by DIC measurements Figure 3(left). The in-plane full displacement field is deemed appropriate to interpret the edge effect on CTOA. Displacements in both plastic zones have opposite directions and there is a very narrow area where x-displacements are almost or equal to zero, as depicted in Figure 3(right). As the specimen opens wide, the plastic area near the edge expands while compressive stresses along the x-axis become greater. Therefore the crack cannot easily propagate and fracture energy is spent on the crack opening, hence the increased CTOA. Suppose d is the distance between the zero displacement zone and the edge of the sample. It should be noted that the tip of the crack does not lie in that zone. Distance d decreases with crack propagation and when it reaches a critical value, the CTOA increases greatly. Critical distance d_c was calculated to be approximately 5mm for grade 928 specimens and 7mm for grade 869 specimens.

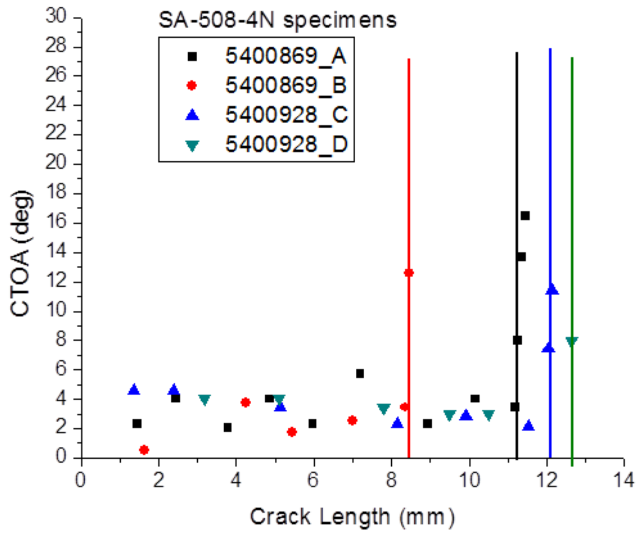

Figure 2: CTOA vs Crack Length plot for two different grades of the same steel.

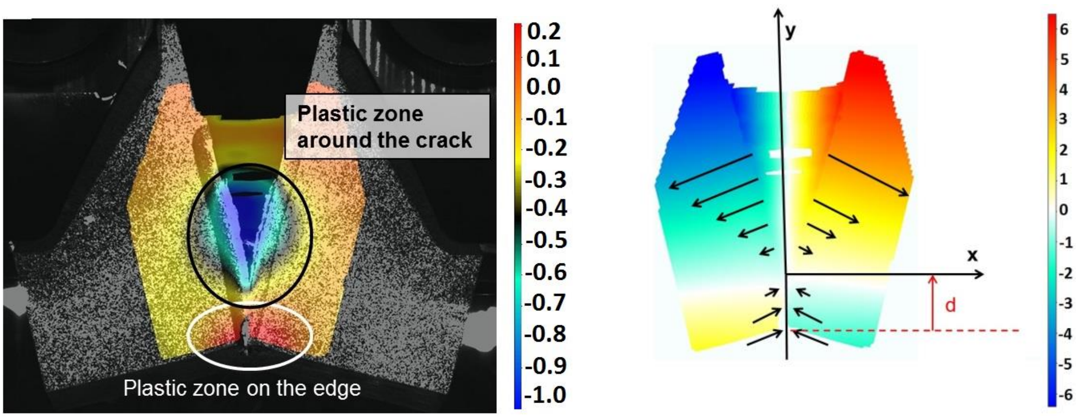

Figure 3: Plots obtained by DIC measurments.
Left) Out-of-plane displacement plot in mm, Right) X-displacement plot in mm.

Conclusion

The effect of the sample edge-plastic zone proximity on CTOA was investigated by employing DIC measurements. There was a significant increase in the CTOA when zero-displacement zone reached a critical value which may imply a dependency on the material used. However, a more extensive experimentation is to follow in order to solidify this argument.

References

[1] ASTM E399-12, Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials, 2013, USA.
[2] ASTM E2472−12 Standard Test Method for Determination of Resistance to Stable Crack Extension under Low-Constraint Conditions, 2013, USA.