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Numerical study on the variation of fracture parameters near crack tip

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Abstract - *The use of metals by mankind has led to an increase in the failure of metals. The study to predict the failure of components is very necessary. Different fracture parameters have been devised for such study. the measurement of these crack parameters is very important to predict the criticality of crack. CTOD is one such parameter which is meticulously studied. One way of predicting CTOD is through extrapolating CMOD value. Hence measurement of CMOD becomes very important. The current paper discusses the use of four hololens imaging system in fracture mechanics and numerical simulation has been conducted for the same loads to compare the results. The numerical results are in good agreement with the results available in literature with a variation of ±9%. The paper also discusses the stress around the crack tip based on the stress intensity factor values obtained from the numerical study.*

***Key Words*:** Numerical study, Fracture parameters.

1. INTRODUCTION

The problem of crack initiation and propagation has started ever since the start of metal in mankind. However, at the very early stage, it was not taken care of and during World War I. After the first World War, Griffith first gave the idea of failure of material [1]. After the pioneer work of Griffith, several researchers around the world started working on fracture mechanics, and slowly it became a separate branch to be studied to understand the behaviour of the material under loading condition [2-4]. Since then, several fracture parameters have been defined to study the criticality of the crack [5]. Crack tip opening displacement (CTOD) is one such important parameter, which is studied meticulously to find the criticality of the crack. Wells [6,7] first introduced the concept of CTOD to be applicable for both linear elastic plastic fracture mechanics and elastic plastic fracture mechanics.

When the displacement at the crack tip, i.e. the CTOD value, reaches a maximum permitted value, the crack will extend, according to the CTOD principle. As a result, CTOD has shown to be a highly effective crack metric for determining crack criticality [8]. Because CTOD has such a tiny value, precise CTOD measurement is difficult. As a result, numerous approaches for predicting and determining the value of CTOD have been developed. Paddle gauge [6], geometrical model estimate [9], double clip gauge methodology [10], and clip gauge extensometer [11] are some of the methods used. Along with the above conventional techniques, several optical techniques have also been used to estimate the value of displacement at the crack tip. Some of the optical methods include the method of caustics [12], method of photoelasticity [13], speckle photography [14] and holographic interferometry [15]. Amongst the aforesaid methods, speckle photography method turns out to be a handy method as it does not require special specimen preparation and vibration isolation as in the case of photoelasticity method and holographic interferometry respectively. Shakher and Yadav [14] discussed the use of two hololens system for the measurement of CTOD by extrapolating the displacement at crack mouth using the plastic hinge model. The use of two hololens imaging system in speckle metrology leads to the measure of vector displacement at the crack mouth which needs to be resolved in X and Y- direction to get the CMOD value.

A solution to the above problem was suggested by the group headed by (Prof.) B. N. Gupta in the year 2015, where a new ‘four hololens’ imaging system has been discussed [16]. The benefit of using the system results in the direct measurement of the CMOD, without the cumbersome process of resolving the displacement vector to calculate the CMOD value at that point. The article demonstrated the use of the imaging system to evaluate the CMOD for a side edge notched bend specimen (SENB) of aluminium alloy.

Along with the different experimental methods, several numerical methods have also been used to predict the value of the fracture parameters. There have been the use of finite element method [17], fractal finite element method [18], finite element discretised method [19], ANSYS [20] to predict the values of SIF and CMOD which has been further used to calculate the CTOD value.

The current study deals with the numerical simulation of the SENB crack in aluminium specimen using ANSYS 15, and the results are compared with the available literature. The simulation has been conducted further for different loads to get the values of crack mouth opening displacement and the stress intensity factor (SIF). Also the stress developed around the crack due to loading has been discussed.

2. NUMERICAL SIMULATION

Amongst the different simulation packages available, ANSYS has turned out to be a very useful tool to simulate the real time problems based on the boundary conditions. It has been used several times to evaluate the different fracture parameters like CMOD, SIF, J-integral etc. The simulated results were compared to those published in the literature [16] to verify the use of ANSYS in calculating fracture parameters. In the experimental investigation, the four hololens imaging system was employed to directly evaluate the value of CMOD for the specimen depicted in figure 1. For the simulation, the same dimension specimen was employed. The specimen's measurements were obtained in accordance with ASTM standards, with a width to length (W/S) ratio of 0.25 and a crack length to width (a/W) ratio of 0.4.

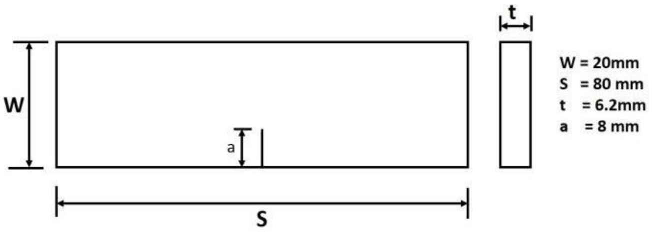

Figure 1. Schematic diagram of the specimen used in experiment [16] and numerical simulation.

The convergence test was used to verify the accuracy of the numerical approach used to acquire the CMOD values. By increasing the mesh density and finding the CMOD value at that density, the decision is determined. Figure 2 shows the relationship between the number of nodes and the CMOD value. As the mesh density increases, the CMOD value rises until it reaches a point where it is nearly asymptotic and constant. This convergence point marks the point at which the model becomes precise and reliable, allowing for accurate CMOD value computation. Figure 3 depicts the completed mesh, which contains 49256 nodes and 10158 components.

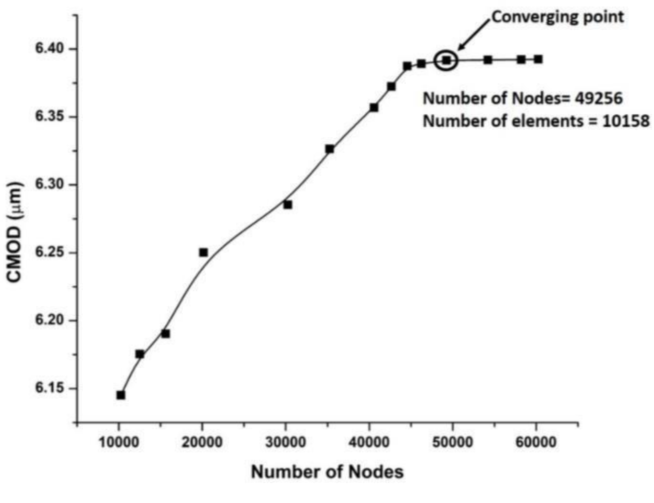

Figure 2. Convergence judgement of CMOD for a = 8mm at 16 kg

The material chosen for the simulation is aluminium alloy with the mechanical properties depicted in table 1.

Table 1. Mechanical properties of aluminium alloy (AA5082)

Young's modulus	70.3GPa
Density	$2.7 g/cm^3$
Poisons ratio	0.33
Tensile yield strength	193MPa
Compressive yield strength	193 MPa
Ultimate yield strength	228MPa

The numerical simulation has been conducted for different loads and the values obtained have been compared with the values available in the literature. Figure 4 shows the error plot drawn between the numerical value and the experimental value obtained from literature [16]. The plot shows that the CMOD value obtained from numerical analysis varies within a range of ±9% w.r.t. the experimental values.

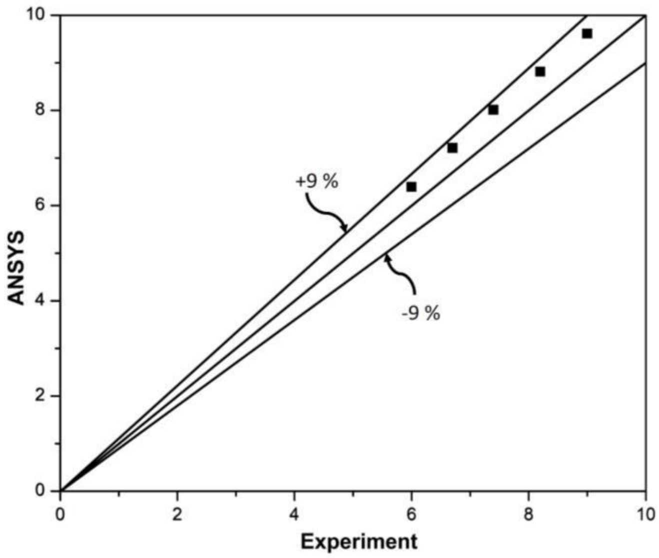

Figure 4. Comparison of experimental data with numerically simulated value

3. RESULT AND DISCUSSION

3.1 Variation of CMOD with load

The numerical simulation was carried out for the specimen depicted in Figure 1 for various weights ranging from 10 kg to 30 kg with a 1 kg increase. Figure 5 depicts the fluctuation of CMOD in relation to load. The graph's abscissa represents load (N), while the ordinate represents the CMOD value (m). The graph depicts CMOD's linear fluctuation with load. The graph shows that the crack has not yet reached a critical value that will aid in crack propagation.

3.2 Variation of SIF with load

The variation of stress intensity factor w.r.t. load is being depicted using figure 6. The load is plotted onto the X-axis and the respective value of SIF on the Y-axis. It can be seen that the stress intensity factor value increases linearly with the increase in load. This again shows that the crack is still in the extension phase where under the applied load the crack mouth and the crack tip opens and when the load is removed, the crack mouth and the tip returns to its original shape. It can be deducted that there is no plastic deformation obtained at the crack tip and hence the crack propagation does not occur at these loads.

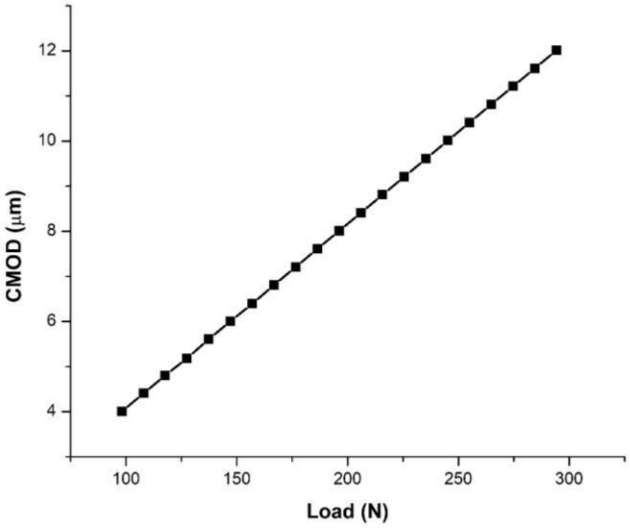

Figure 5. Variation of CMOD w.r.t. load

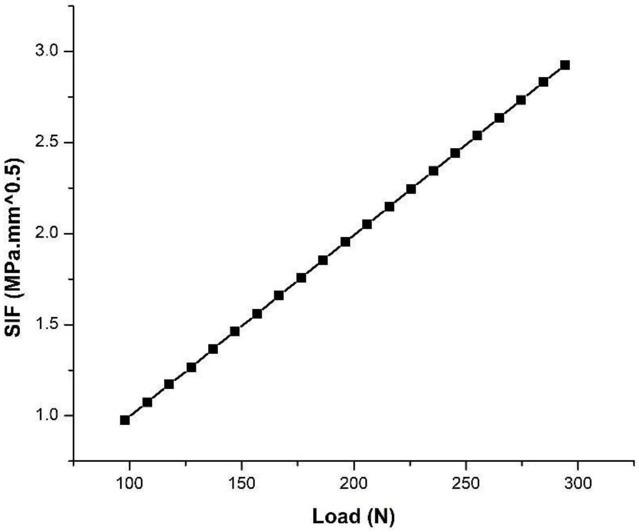

Figure 6. Variation of SIF with load

3.3 Stress around Crack tip

The SIF value is used to determine the stress near the fracture tip. Figure 7 depicts the stress fluctuation near the crack tip. It can be determined from the preceding figure that the stress fluctuates from a minimum to a maximum value and then back to a minimum value when it is measured around the crack just ahead of the crack tip, forming the shape of a butterfly around the crack tip as we travel from 00 to 3600. The plot clearly shows that the stress varies only for a very short distance ahead of the fracture tip, i.e. up to 0.02mm ahead of the crack tip, after which the amount of stress is nearly constant. Figure 8, which depicts the fluctuation of stress ahead of the fracture point, shows the same thing. It can be observed that the stress value is quite high near the crack tip (r 0), and that as we travel away from the crack tip, the stress value declines until it reaches a minimum value.

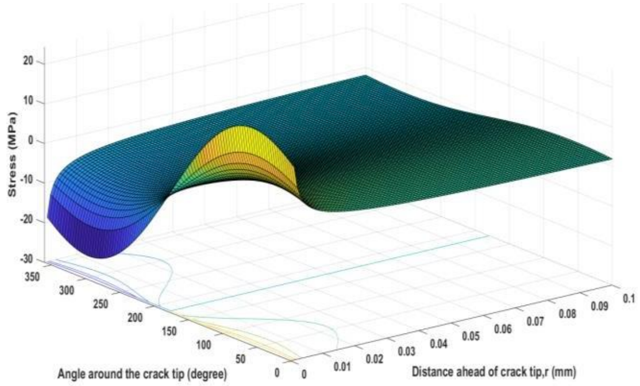

Figure 7. Stress around the crack tip at 10kg

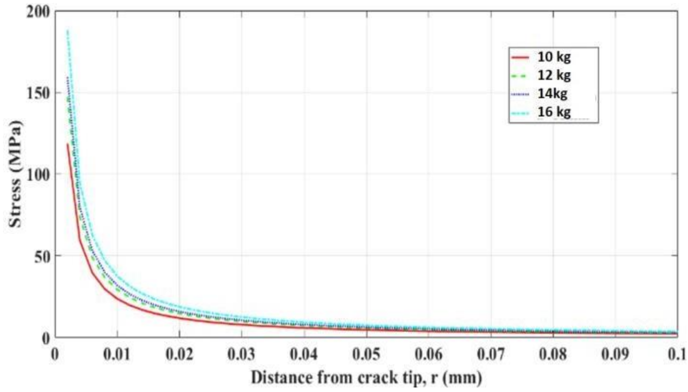

Figure 8. Variation of stress ahead of crack tip at different loads

4. CONCLUSION

The following conclusions can be drawn from the above numerical study:

I. The result from the numerical study and the experimental results has a close coordination. And hence, ANSYS can be used advantageously used for such calculations.
II. The CMOD and SIF value varies linearly with load up to certain limit. And up to this load, the crack is stable and is not liable to propagate.
III. The stress variation can be seen around the crack tip.
IV. The stress is very high at the crack tip and moving away from the crack tip causes the stress value to decrease and finally attains a constant value.

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