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Determination of Crack Growth in St52 Structural Steel via Acoustic Emission Technique and Its Application in Steel Structures

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ABSTRACT: Acoustic emission is one of the most important techniques in none-destructive test, that is able to evaluate crack growth in steel element of structure and is efficient in order to condition monitoring for deployment on in-service bridge component and these data can be used for schedule planning for maintenance of bridge structure. In the line of experiments and empirical research, samples of structural steel (St52) were used as a compact tension specimen in axial tensile fatigue test in order to study the crack growth. In this study, application of acoustic emission technique for health monitoring and determination of crack length in components of steel structure which are under axial fatigue load are investigated by using experimental test result, for this purpose correlation between acoustic emission parameters such an energy rate, count rate, and crack length and fatigue life has been studied. Finally, by using the extracted data from acoustic emission and fatigue test result, and least mean square regression analysis, the value of the constant for the relation between crack length and acoustic emission parameters have been determined.

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1- Introduction

Acoustic emission method is one of the non-destructive methods widely used to detect and determine the position of damage in the structures and their components under load. This method can provide comprehensive information on the location of cracks in tensile structures and also provide information on the progress of cracks in structures that are under continuous or cyclic stress.

In this paper, the relationship between the energy release rate and the crack growth rate is presented and a theoretical model is presented to evaluate the fatigue life of the components. For this purpose, standard Compact Tension (CT) specimens were used with St52 structural steel, these samples were subjected to cyclic loading using axial fatigue apparatus, and simultaneously with the installation acoustic emission sensors, the behavior of acoustic emission parameter and crack growth rates were analyzed.

2- Theory

Crack growth occurs when the bonding between the molecules breaks down, that leads to the release of energy, this energy made plastic deformation in the crack area that leads to failure. This energy is expressed as follows:

$$J = g.t.a \qquad (1)$$

Finally, the relationship between the crack growth rate and the release rate of the acoustic emission is expressed in terms of Eq. (2).

$$\frac{da}{dN} = D\left(\frac{dU}{dN}\right)^q \;, \quad D = \frac{C}{B_e^q} \;, \quad q = \frac{m}{p} \qquad (2)$$

The constants in these relations (D and q) can be determined using empirical results.

Another important parameter that can be used as an indicator of cyclic loading is cumulative counting (the number of times the output signal energy is in a higher threshold than the threshold). The rate of counts for cyclic loads is presented by a power relationship similar to that of the crack growth of the Paris-Ertegan. This power relationship provides a natural relationship between condition monitoring by acoustic emission technique and qualitative fracture mechanics to predict crack growth. By Eq. (3) and numerical integral, we can calculate the length of the cracks, in this equation; the counting rate is modeled directly with the crack growth rate and is not dependent on the intensity of the stress.

$$\frac{da}{dN} = D\left(\frac{dn}{dN}\right)^q \qquad (3)$$

In order to determine the crack growth relationship with the energy released in the laboratory sample, in addition to measuring the energy by the acoustic emission sensors, it is necessary to determine the length of the crack. One of the common methods for determining the length of the cracks is the measurement of the opening of the crack, which has been used in this study. For this purpose, the opening rate of the crack opening was measured first with the help of an extensometer, then the length of the crack was calculated using Eq. (4).

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$$a = w\begin{pmatrix} 1.001 - 4.6695u_x + 18.4u_x^2 - 236.82u_x^3 \\ +1214.9u_x^4 - 2143.6u_x^5 \end{pmatrix} \quad (4)$$

$$u_x = [\sqrt{E.t.d/P_{max}}]^{-1} \quad (5)$$

3- Methodology

In this study, CT specimens were used in accordance with ASTM E647 standard and they were considered as plates with a length of 100.96 in width and two in thicknesses of 15 and 12 millimeters. Some advantages of these samples are small and no need for a large amount of material, high tensile stresses for low loads, and the similarity of their behavior with the edges cracks of the bridges. Their disadvantages also include their relatively hard production and the opening of the crack by a bending moment in a piece that is not present in the bridge parts.

After specimens were prepared, for fatigue test a santam set by cyclic load ability was used that was equipped by clip gage for determining the crack opening. In order to simultaneously measure the acoustic, emission AMSY-5 system was used which is manufactured by Vallen System Gmbh from Germany.

4- Results

After performing the fatigue tests on the samples prepared in different ratio of loads and thicknesses and measuring the amount of released acoustic energy, two important parameters, cumulative energy and cumulative count, were obtained to determine the relationship between the cracks length and the energy of acoustic emission. The results are presented in following. One of the important parameters that can be used in analyzing the crack length in a piece is the cumulative energy. This parameter is equal to all the released energies up to the moment. The value of this parameter for one sample is shown in Fig. 1.

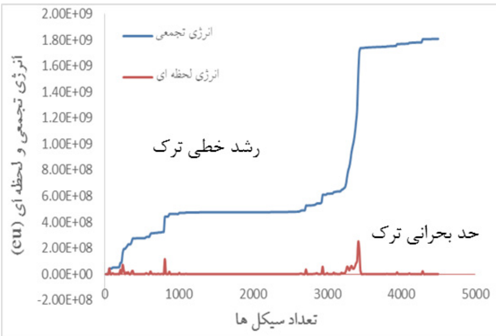

Fig 1. Cumulative energy

As seen in the Fig. 1, the cumulative energy pattern is compatible with the crack growth pattern, this diagram has three regions similar to the crack growth in terms of cycles, most of it is in the second region, where the energy increase is very small, this area is related to the formation of the plastic region and the expansion of the crack in the flexible failure mechanism, which takes a relatively long time. In the third region, a sudden increase can be seen which indicates the release of a large amount of energy and it is related to the sudden failure. As can be seen, the behavior pattern for all load states and different thicknesses is similar so this parameter could be well used for prediction of the condition before a critical threshold.

As mentioned in the second section, another indicator that can be used to determine the condition of a piece is the cumulative counting; the rate of this indicator for a sample is shown in Fig. 2. These diagrams can be used to predict the length of the cracks.

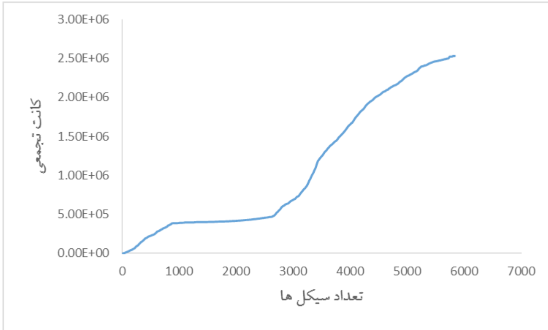

Fig 2. Cumulative counting

As shown in Fig. 2, the cumulative count index is continuously increased with the number of cycles. Therefore, in the case of continuous data calculating from the beginning of the life of a piece, crack length can be determined by this indicator. Considering the similarity between the behavior of acoustic parameters and the crack growth rate by determining the parameters of the acoustic emission and laboratory data, can determine the relationship between these parameters with the parameters of the failure mechanic.

After obtaining the required constants, the prediction of the length of the samples based on the acoustic emission data was calculated and compared with the actual length. By comparing the obtained results, it was observed that the energy parameter gives a more accurate estimation than the count. In Fig. 3, the length diagram is plotted based on the number of cycles and the results indicate a relatively small difference between the calculated values and the actual results.

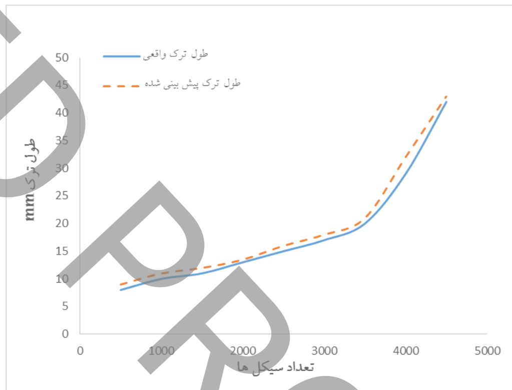

Fig 3. Crack length

5- Conclusion

In this research, the relationship between the crack growth with the energy of the acoustic signal has been investigated, as described in the research theory section, crack length and remain life could be evaluated with the help of cumulative count and cumulative energy parameters without the need to know the intensity of the stress. To use these data on structures and other components, it is necessary to determine the parameters of the relationship between the crack growth rate and the acoustic emission parameters by laboratory data, which is a certain amount for any material. Therefore, according to the purpose of this paper, which was to condition monitoring of metal bridges, these constants were determined for St52, and by linear regression, the required values were calculated.

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