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Study on acoustic emission source localization of 16Mn structural steel of high temperature deformation

Yubo Zhang[1,2,a], Muhan Deng[1,b], Rui Yang[1,c,*], Feixiang Jin[2,d]

[1] China Waterborne Transport Research Institute, Beijing, 100088, China
[2] School of Materials Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing, 100191, China

[a]zyb@wti.ac.cn, [b]dengmh@wti.ac.cn,[c]orangez80@163.com,[d]59024400@qq.com,
*Corresponding author

Abstract. The location technique of acoustic emission (AE) source for deformation damage of 16Mn steel in high temperature environment is studied by using linear time-difference-of-arrival (TDOA) location method. The distribution characteristics of strain induced acoustic emission source signals at 20℃ and 400℃ of tensile specimens were investigated. It is found that the near fault has the location signal of the cluster, which can judge the stress concentration and cause the fracture.

1. Introduction

Because of its excellent characteristics 16Mn steel has been widely used in construction, transportation, petrochemical and other engineering fields. However, due to its shortcomings such as high thermal conductivity and poor fire resistance, the safety of the steel structure in the fire or high temperature environment has attracted much attention.

In the course of service, the steel structure will deform or even break under the action of the external load. The process of generation and change of internal defects will release energy in the form of elastic wave and propagate through the material. The defects in this process will become the source of acoustic emission (AE) .The acoustic emission can be used to locate the acoustic emission source, determine the location of the material defect, and localize the defect in the space. There are two methods for AE localization: area location method and time-difference-of-arrival (TDOA) location method. Compared with regional positioning method, TDOA location method is widely used because of its wide range of application and higher positioning accuracy. The research and application of AE technology in material science mainly focus on at normal atmospheric temperature, and there are few literatures about high temperature monitoring. C J Feng has studied the characteristics of acoustic emission signals during the high temperature tensile process of Q345R steel. It is found that the use of waveguide bars plays an important role in the acquisition of acoustic emission signals in high temperature environments. Sound emission is used to monitor the change of internal structure defects in special environment, so as to provide experimental and theoretical basis for safe operation and evaluation of steel structure.

2. Experimental procedure

2.1. Linear TDOA location method

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The time difference method measures a number of sensors into a certain geometry to determine the relative moveout of the stress wave from the acoustic emission source to each sensor. The location of the acoustic emission source is obtained by geometric relation calculation and the acoustic emission signal is directly related to it. When the ratio of the length to radius of the object to be detected is very large, a Linear TDOA location method should be used to locate the AE source, such as pipe, bar, steel beam, steel plate and so on. Figure 1 is the distribution model of TODA linear sensor array, two or more sensors are distributed in one dimension X axis coordinate system.

Figure 1. The distribution model of TODA linear sensor array

If there's an acoustic emission signal between the S1 and S2 to produce acoustic emission signals, the signal is reached at S1, the probe time is t_1, the signal reaches S2, and the probe time is t_2, therefore, the arrival of the two sensors is $\triangle t=t_2-t_1$. The distance of AE source from S1 is :

$$d=\frac{1}{2}(D-\Delta tV) \quad (1)$$

Where D is the distance between the two probes, and V is the propagation velocity of sound waves in the sample.

2.2. Specimens

The material used in this paper is low alloy structural steel 16Mn steel. The mechanical properties are shown in Table 1.

Table 1. The mechanical parameters of 16Mn steel

parameters	Yield strength σ_s(MPa)	Tensile strength σ_b(MPa)	Modulus of elasticity E(MPa)	Impact energy AK/J(20C°)	Elongation η (%)
value	345	560	206000	≥34	≥22

The standard plate tensile samples conforming to national standards GB/T228-2002 were prepared with the shape and dimensions as shown in Figure 2. The circular hole with Φ8mm at both ends is used to clamp the specimen together with the pins of the test machine. The acoustic emission guide bar is welded at a circular hole of Φ4mm as shown in Figure 3.

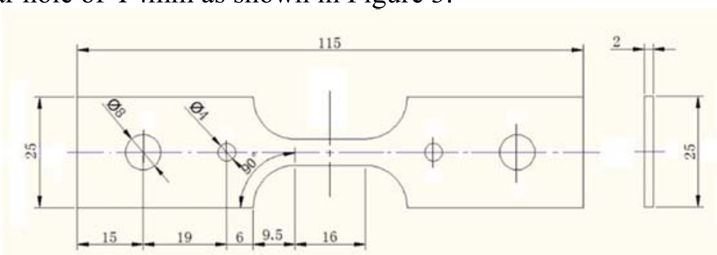

Figure 2. Details of the plate tensile specimens (mm)

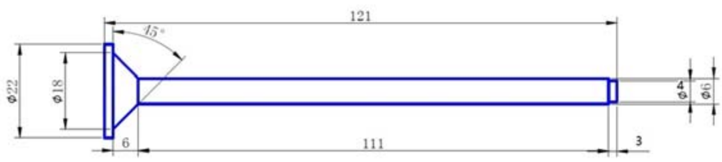

Figure 3. Details of the waveguide bars (mm)

2.3. Test procedure

High temperature tensile test using MTS880 material testing machine and equipped with high temperature control system. Acoustic emission instrument is used to monitor the acoustic emission source signal during deformation process. The acoustic emission instrument is a DISP with AEwin v2.19 acoustic emission instrument developed by PAC company. The sensor is fixed at the end of the wave guide bar by magnetic ring.

In this experiment, the loading of the sample is loaded by the method of displacement loading control and the tensile rate of 2mm/min. Meanwhile, the acoustic emission signal is monitored and the source location of the transmitter is carried out. When the sample and instrument are installed, the sample is heated to the set temperature (20℃,400℃) and the heat preservation is 15min. Loading process: preloading (below the yield strength) - unloading - reloading, the Kaiser experiment is used to determine whether the electromagnetic noise generated by the device is excluded.

3. Results and discussion

3.1. Characterization of deformation damage of steel 16Mn by acoustic emission

The amplitude of acoustic emission source localization signal varies with strain during the deformation damage of 16Mn steel at normal atmospheric temperature and high temperature can be seen in Figure 4. (a) , (b). At normal temperature (20℃) the tensile curve of the sample has an obvious yield plateau, at high temperature (400℃) the strength of the material decreases and the yielding platform disappears. The curve of the plastic deformation stress rise stage becomes smoother.

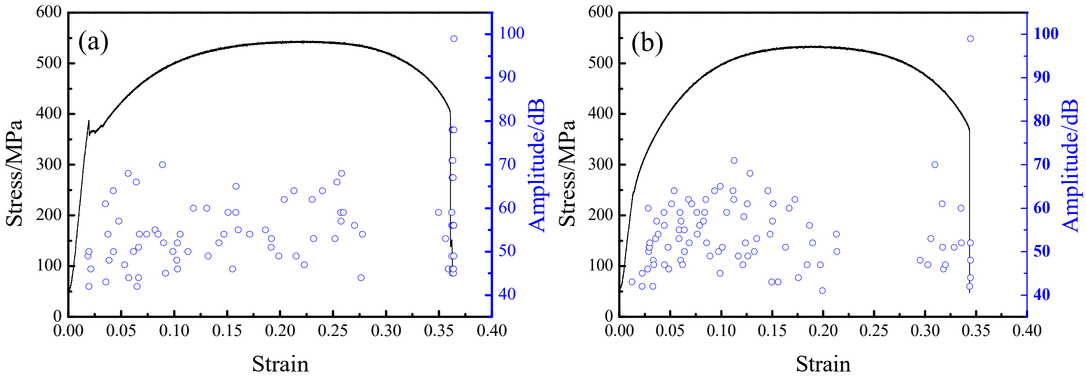

Figure 4. The amplitude of acoustic emission source localization signal varies with strain during the deformation damage of 16Mn steel (a)20℃，(b)400℃

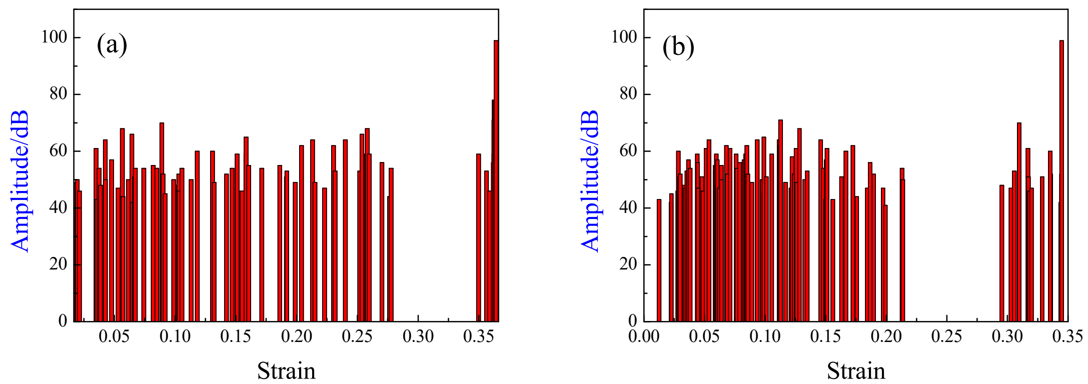

Figure 5. The amplitude of acoustic emission source localization signal of 16Mn steel (a)20℃，(b)400℃

Figure 5. (a) , (b) show the amplitude of acoustic emission source localization signal of 16Mn steel at different temperatures. Under the influence of high temperature, the bonding force between

crystal atoms decreases, which accelerates the manager deformation and grain boundary sliding. There are more acoustic emission locating signals near the fracture.

3.2. Analysis of test results of acoustic emission source localization

In order to further explore the law of AE localization signals in high temperature deformation damage, Figure 6. shows the spatial distribution of AE signals with strain at different temperatures.

At the yield stage, the positioning signal is the least and the signal amplitude is below 50dB. The main reason is that the signal produced in the yield stage is mainly continuous signal, corresponding to dislocation movement. There is no obvious structural damage and cannot form position signals. There are more signals in the strain hardening stage, and the whole signal amplitude is between 45-75dB. In the rapidly rising stage of stress, signals with higher amplitude (65-75dB) appear, which may be related to rapid deformation. A cluster signal appears near the fracture show that the local stress concentration caused the material shrinkage neck appeared, began to appear microporous, microporous aggregation leads to the final fracture, a close 98dB signal corresponding to the material fracture.

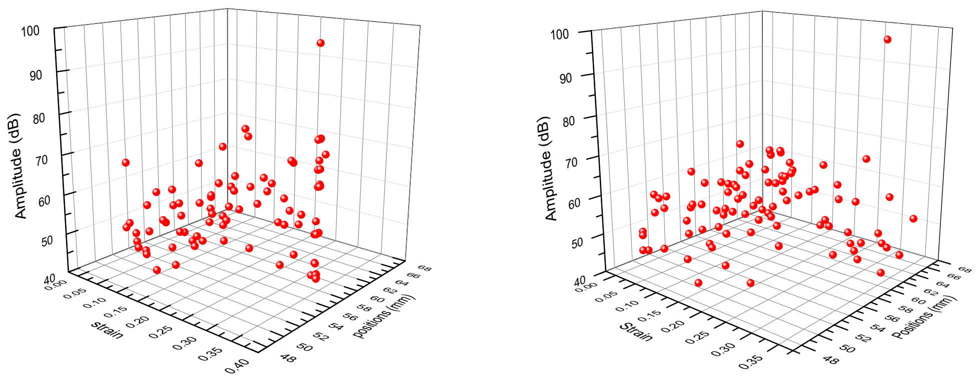

Figure 6. The spatial distribution of AE source localization signal amplitude with strain (a)20℃，(b)400℃

In order to verify the accuracy of AE location signals for the determination of necking and fracture, the actual measurements of the stretched sample were carried out, as shown in Table 2.

Table 2. Measured results of acoustic emission source location

Temperature(°C)	Sample breaking point(mm）	AE location breaking point(mm）
20	56	56.2
400	61	60.47

From the distribution law of acoustic emission signals at 2 temperatures, it can be seen that the location method of high temperature acoustic emission source using guided wave bar is feasible, and the AE location signals are all distributed in the range of the sample gauge. By comparing and analyzing the location signals, it is found that the AE localization signals have higher accuracy in judging the severely deformed region and the breaking point. From this we can deduce that the acoustic emission location signal given in the whole strain deformation damage stage is accurate.

4. Conclusions

The experimental results show that it is feasible to locate the high temperature acoustic emission source using the guided wave auxiliary method.

The tensile deformation damage process of 16Mn steel at high temperature can be reflected in the structural signals. The spatial distribution and time distribution of acoustic emission source agree with tensile deformation damage. The distribution of acoustic emission source before necking is uniform in the gauge interval. After entering the contraction stage, the acoustic emission signals are concentrated around the fracture point, and the appearance of the necking of the material corresponding to the local serious stress concentration appears. The location of microstructure damage resulting from the change of high temperature mechanical properties of 16Mn steel can be understood by acoustic emission source localization. The results will serve as a reference for real-time on-line monitoring and early warning of high temperature acoustic emission.

Acknowledgments
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