Study on the Characteristics of Acoustic Emission for Grey Cast Iron

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Abstract
Although serious advantages of the acoustic emission (AE) diagnostics of steels and structural elements are well-known, few researchers have concentrated on cast iron material study with AE. In this paper, the AE generated during tensile tests performed on grey cast iron specimens of different grades was investigated. Some similarities of AE parameters in such materials are remarkable. The amplitude range of AE signals is mainly from 45 dB to 90 dB throughout the test. Their frequencies are all around the band of 50kHz~500kHz. In particular, the AE activity of grey cast iron is different dramatically from mild steel. Based on the load-time history curves and signal analysis, the relationship between characteristic parameters of AE waveform and AE source from the specimens was investigated. The data show that the informative AE parameters including amplitude, energy and counts versus time can be used to represent the dynamic evolution of grey cast iron specimens. AE signals occurred occasionally at the initial stage of tensile and then the amount of signals increased dramatically. The identifiable features associated with the AE signals as related to the crack extension are higher amplitude, very short rise time and energy in direct proportion to duration time. These results can provide useful information for AE inspection on structures made of cast iron.

Keywords: Acoustic emission, grey cast iron, parametric analysis, tensile

1 Introduction

Cracking in the shell material of dryers has been a safety concern for the paper industry for many years. Numerous case studies about dryer failures have been discussed and summarized [1-3]. The non-destructive testing methods in common use for in-service inspection of dryers are visual testing (VT) and ultrasonic testing (UT). However, it is difficult to find cracks with VT, and UT is time-consuming and is not perfect because of coarse grains. Acoustic emission (AE) method, which can utilize the elastic energy released from any crack propagation incident, has been widely used for real time monitoring of the condition of materials and structures [4]. However, there are only a few researchers having been in the effort to use AE method to assess of the damage mechanisms of such material and resultant correlations to material parameters. Morgner and Heyse [5] found the mechanical and AE behavior of cast iron differs from those of steel. By incorporating electron microscopy, it showed that the failure starts with plastic deformation at the tips of graphite flakes, and graphite body appears to have no influence on the measurable AE. Sjögren and Svensson [6] researched pearlitic cast iron during four-point bending test together with AE measurement. Although the saturation of their AE system limited the data analysis, the plastic deformation and other strain events were quantified by AE hits rate. Some investigated the feasibility of using AE as an inspection tool for evaluation the actual condition of Yankee Dryer. Allevato, and Williams [7-8] used AE method to monitor tensile and compact tension experiments for dryer material in lab, and made AE field test for inspecting two old dryers with discontinuities and one new dryer. It concluded that AE is a suitable and feasible inspection technique for Yankee dryers, and recommended more effort should be given to AE attributes to help understand its occurrence.

In order to draft an acoustic emission testing standard for cast iron dryers in China, the priori-
ty is to evaluate acoustic emission AE parameters as a clue/judgment of crack inspection of grey cast iron. In this paper, tensile tests with AE monitoring were studied. It was focused specifically on gathering basic AE data from tensile specimens fabricated from the supplied dryer materials, and characterizing some AE signatures and/or trends, which can be special features of that material.

2 Experiments

2.1 AE system
The AE measurements were realized with the AE system AMSY-6 (Vallen-System, Icking, Germany) including a broadband AE sensor VS900M and two AE resonant sensors VS150. The bandwidths of the VS900M and VS150 are 100–900 kHz and 100–450 kHz, respectively. The preamplifiers had 40 dB gain with a 20-1000 kHz bandpass filter. The AE acquisition settings used for all specimens were the same: threshold = 36.6 dB, and sampling point=8192. The AE sensors were mounted on the test objects with screw clamps via contact layer of a lubricant.

2.2 Tensile test
The AE signals generated during tensile test could be used to provide information concerning crack. Thus, to obtain basic AE data of dryer material, three grades of grey cast iron, most commonly used for dryer in China, were chosen for tensile test. Their composition and mechanical properties are listed in Tables 1 and 2. The configuration of flat tensile specimen and the placement of AE sensors are shown in Figure 1. Three specimens were tested for each material grade at ambient temperature (300 K). In order to decrease the machinery noises, such as the grinding of the clamps, the hinge pins contacted with specimens and the backlashes in the clamps, the specimens were all subject to a preliminary loading in a universal testing machine (Shimadzu AG-25TA) under 4 kN prior to the testing. Then, the tensile test with simultaneous recording of the AEs was accomplished in the testing machine at a cross-head speed of 0.3 mm/min.

Table 1  Chemical composition (wt.%) of tensile specimen

<table>
<thead>
<tr>
<th>Grade</th>
<th>Chemical composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>HT200</td>
<td>3.16</td>
</tr>
<tr>
<td>HT250</td>
<td>3.04</td>
</tr>
<tr>
<td>HT300</td>
<td>3.01</td>
</tr>
</tbody>
</table>

Table 2 Typical mechanical properties of testing material

<table>
<thead>
<tr>
<th>Grade</th>
<th>Rm /MPa</th>
<th>Rp0.1 /MPa</th>
<th>A /%</th>
<th>E /kMPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT200</td>
<td>200-300</td>
<td>130-195</td>
<td>0.3-0.8</td>
<td>108-197</td>
</tr>
<tr>
<td>HT250</td>
<td>250-350</td>
<td>165-228</td>
<td>0.3-0.8</td>
<td>103-118</td>
</tr>
<tr>
<td>HT300</td>
<td>300-400</td>
<td>195-260</td>
<td>0.3-0.8</td>
<td>88-113</td>
</tr>
</tbody>
</table>
3 Experimental results and discussion

3.1 General results for all tensile specimens

Despite the differences among the three grades of grey cast iron, and two types of AE sensors (VS150 and VS900M) were used, but the information of AE features they recorded have much in common. First, although the sensitivities are different, the waveform variations for sensor 2# and 3# are similar, and 90% energy of AE signals for the three cast iron while stretched are all within the frequency range of 50~500 kHz. It is shown in Figure 2 that the AE waveform and its frequency spectrum for HT200 during tensile test. Therefore, the sensor type of VS150 can be used for AE field test on grey cast iron pressure vessel. For the results recorded by broadband sensor have not been reported previously, the detailed AE information followed are all described using sensor 3#. Second, the historical changes of the AE activities and the relation graphs between different AE parameters for three grades of grey cast iron are similar.

The diagrams for AE amplitude and the load over time are shown in Figure 3(a) ~ 5(a). From these history plots, the significant change of the AE events occurred at which time/load can be seen clearly. For the three kinds of grey cast iron, the changes of amplitude together with time are analogous. At the beginning, they presented a quiet AE activity. Then, a few AE signals with low amplitudes occurred, followed by an appearance of large quantity AE for a period of time. At last, a small amount of AE with high amplitudes emerged, which is more than 80 dB in Fig 3 and 5, and higher than 75 dB in Fig 4.
The relationship diagram between AE parameters is usually used to show the features of AE sources. In Figure 3(b) ~ 5(b), the counts versus rise time are plotted, respectively. They all contain a small part of AE events with very short rise time, an abundant of AEs aggregated like a parallelogram, and a few AEs featured by larger counts and rise time longer than $10^3$ μs. Because the parameter distributions of three grades of grey cast iron are analo- 
gical, an uniform standard can be used for AE evaluation of such kind of material.

3.2 AE analyses for HT200 tensile test
For field AE test, the diagrams of AE parameters, which can represent the material characteristics should be used to evaluate the condition of AE sources. Thus, in this part, the AE parameters combined in different ways are analyzed in order to pick out the typical AE diagrams for judgment. In Figure 6~8, the main results of one specimen using sensor VS900 (sensor 3#) for HT200 are presented.
The AE amplitude, energy and counts can be used for evaluation of AE source intensity. Figure 6(a) correlates energy of the AE signals and the load over time, and Figure 6(b) shows counts correlated to the time. A period (bin size) of 3 s in the x-axis, which correlates to 120 sections at a test duration of approximation 360 s, was used. This setting is helpful to data observation. Therefore, the y-axis is actually stands for the energy/counts rate of AE signals. Base on the envelop of energy/counts, from the test time of 111s, the AE activity of the tensile test can be generally divided into three segments. At the initial stage of test, it is characterized by quiet AE activity. At the time of 111 s, the transition occurs in form of a sudden increase in AE energy/counts (Seg. I). Thereafter, the energy/counts increased intermittently until 186 s (Seg. II), where the energy/counts kept growing up to 294 s and then followed by a slight drop. In the last segment, an increase in AE activity is recognizable after 329 s, and the energy/counts kept rising until fracture. Compared with Figure 3(a), it is a good correspondence among amplitude, energy and counts versus time. The maximum energy/counts in Figure 6 during Seg. II is caused by large AE pulses concurrency, whose amplitude is relative low. The energy/counts increasing in Seg. III is the result of higher amplitude, although the amount of AE signals is less than that of Seg.II.

The stages of accommodation of strain of a cast iron component have been established as [6], (a) Decohesion and fracture of the graphite particles, (b) Plastic deformation of the matrix, (c) Micro cracking, (d) Macro cracking, and (e) Fracture. And from an acoustic emission point of view, decohesion and fracture of the graphite is believed not to give rise to any AE signals [5]. Therefore, the starting point of Seg. I (111s) is the beginning of brittle deformation. During Seg. II, the AE sources in the bulk of the specimen should include brittle deformation, micro cracks initiation and micro cracks gathering. Of course, the different stages to failure are concurrent rather than subsequent. This can be demonstrated from the AE amount variation between Seg.I and Seg. II in Figure 3(a). It[5] pointed out that the different measured amplitudes of the acoustic emissions observed in loaded grey cast iron are strongly related to the type of event from which they are generated. Due to the damage accumulation from Seg.II to Seg. III, the crack propagation became unstable and the AE amplitude got larger up to rupture. For a short time before fracture, the Seg. III of AE activity must corresponds to macro cracks initiating and run-through stage, during which micro cracks neighboring connect to each other to form macro cracks and the macro cracks extend, connect and in the end get run-through[10-11].

Due to the threshold level shows no effect on amplitude, but has influence on the value of energy and counts. Hence, the amplitude is more suitable to estimate the intensity of AE source for different field tests. Compared with counts parameter, energy contains both signal fluctua-
tion and level. Therefore, energy parameter is more applicable to the AE source mode discrimination. For further observation, rise time and duration time versus energy corresponding to different segments are shown in Figure 7 and 8. It can be clearly seen that the relation plots of energy-rise time in Figure 8 shows the same morphology with that of counts-rise time in Figure 3(a). During Seg. I, the plots in Figure 7(a) are discrete. The plots representing Seg. II and Seg. III in Figure 7(b) can differentiate from each other. Seg. II is obvious a transition stage. Its energy is between $16 \text{ eV}$ and $10^5 \text{ eV}$, and the rise time is in the range of $1 \sim 10^3 \mu$s. The AEs in Seg. III can be divided into two parts, one is featured by very short rise time (0.2µs) and wide range of energy, and the other is a positive correlation. In Seg. III, some part of AE signals with lower energy indicate that no new cracks opened, and the signals continued probably result from brittle deformation and micro cracks gathering. The other AE signals with higher energy may from macro cracks initiation. For the very small size of the macro cracks, the AE rise time is relative short.

![Figure 7. Energy versus rise time for HT200](image)

(a) AE plots during Seg.I  
(b) AE plots during Seg.II and III

![Figure 8. Energy versus duration time for HT200](image)

(a) AE plots during Seg.I  
(b) AE plots during Seg.II and III

The plots in Figure 8 of Seg. I and II both show exponentially relationship. But while Seg. III, the energy is almost in direct proportion to duration time. It shows that along with the macro cracks development, the AE signal featured by longer duration time correlating to larger energy.

From above all, the AE source with more than 80 dB amplitude, very short rise time and energy in direct proportion to duration time, is the typical character for crack propagation in this material.

### 4 Conclusions

(1) For the three grades tensile specimens were all kinds of flake graphite grey cast iron material, their AE characteristics have much in common. The frequency ranges for these three while stretched are all within the band of 50~500 kHz. Their AE activities along test time have similar variation. Therefore, an uniform standard can be used for AE evaluation of such
kind of material.

(2) The AE activity can be divided into three segments. The Seg. I with AE increase dramatically should come from brittle deformation. During the Seg. II, the large amount of AE are mostly from brittle deformation, micro cracks initiation and micro cracks gathering. And the Seg. III is the stage of crack propagation.

(3) The AE source of brittle deformation in these grey cast iron are featured by exponentially relationship between energy and duration time. And the micro cracks initiation and micro cracks gathering corresponds to higher energy, counts and amplitude (less than 70~80 dB). And the identifiable features associated with the AE signals as related to the crack defect events is higher amplitude, very short rise time and energy in direct proportion to duration time.

(4) The history diagrams using amplitude and energy rate versus time can be available for AE activity observation in material. And the related plots using energy over rise time and energy over duration time are can be used in acoustic emission source recognition.

Acknowledgements

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References