AE 手法を用いた初期段階の故障損傷の評価
Pre-Failure Damage Evaluation and Characterization by AE Technique

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Pre-failure damage behaviors of different materials (ductile cast iron, steel) have been investigated by acoustic emission (AE) technique. As spheroidal graphite cast iron has high strength as well as excellent workability and damping capacity, it has been widely used as automobile and many other machine parts. In this study, the failure of the materials cased by cracks, micro-cracks have been investigated. AE data with different thresholds have been taken for analyzing the damages. CCD images with high resolutions have been taken for analyzing the deformation of the materials under different tensile loadings. The crack, micro-crack data has been investigated by using microscopic images with high resolutions and magnifications rate in a real time data processing system. The combination of above results has revealed the pre-failure damage characteristics of tested materials significantly.

Key Words: Pre-damage evaluation, AE sensing technique, Ductile cast iron, Crack initiation.

1. Introduction

The acoustic emission testing (AET), a present interesting technique used for the non-destructive evaluation (NDE) of materials, can monitor changes in materials behavior over a long time and without changing any of its components. This property makes the AET quite unique in various applications along with the ability to detect crack propagations occurring to the surface as well as to the deep inside of a material. Consequently, AET is an important addition to NDT methods surveying actively a structure by scanning for geometric defects as well as to visual inspection methods observing a material surface [1].

Unlike to other NDT methods, the AET is often used during loading to a structure, not before or after the loading like most of other techniques. Therefore, AET can be successfully applied to characterize the failure of a structure from a very beginning to its complete failure. In AET, acoustic emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stressing a material. When a structure is subjected to an external stimulus (changes in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. In AE system, two types of data acquisition system are generally found. They comprise to the hit-driven data, where an AE sensor detects an emission (called a hit) that has been crossed a previously-specified threshold, and time-driven data, which quantify values that are averaged at regular intervals over the duration of the test [2]. In hit driven data, AE wave in terms of physical parameters which describe the energy, frequency, and duration of each hit as well as many other related parameters that are used for correlating the damages or cracks in a structure or material.

Mechanical properties particularly the material damage due to cracks etc. of spheroidal graphite cast iron (ductile cast iron or ductile iron) are mainly affected by the size, shape as well as the structure of graphite nodule in the base material [3]. Ductile iron is not a single material but is part of a group of materials which can be produced to have a wide range of properties through control of the microstructure. The common defining characteristic of this group of materials is the morphological structure of the graphite. In ductile irons, the graphite is in the form of spherical ‘nodules’ rather than flakes (as in grey iron), thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name. Besides the requirement that the graphite be manipulated into the spheroidal shape, the ferrite and pearlite ratios can be controlled through alloying, shakeout temperature control or post-casting heat treatment to vary the relative amounts pearlite and ferrite from 0% pearlite and 100% ferrite, to 100% pearlite and 0% ferrite. The control of the pearlite and ferrite ratio manipulates the tensile, yield and elongation characteristics of the ductile iron to produce numerous standard grades of material.

In the present research the failure of the ductile cast iron material caused by crack, micro-crack has been investigated to identify the crack initiation and propagation characteristics via AET method. The AE data as well as the magnified structural CCD images have showed the properties of the material-damage initiation by cracks and its propagation phenomena as well.
2. Experimental Methodology

2.1 Specimen preparation

For preparing the specimen to conduct the desired experiment, test materials of ferrite ductile cast iron (FCD (FCD380)) have been cast into a block size with dimension of 100 x 80 x 260mm. Chemical compositions of the test materials are listed in Table 1. The numerical values in this table are represented by the corresponding values in percent content of carbon (C), silicon (Si), manganese (Mn), phosphorus (P) and sulfur (S) respectively. Photograph of the microstructure of prepared test material is shown in Fig.1. For changing the grain size of the ferrite, the ferreting heat treatment condition has been set up for two controls after austenitizing temperature and time. At first the cast material of FCD has been heated up to a temperature just below the eutectoid transformation (720°C) and maintained that temperature constant for 15 hours. After that, it has been cooled inside the furnace (F.C.) in order to keep the ferrite grain size in the test material as the ferrite gain size of cast materials. The ferreting heat treatment condition and the measured microstructural characteristics of treated test material are shown in Table 2. The determination of the ferrite grain size has been carried out according to the method of ferrite grain determination test for steel of Japanese Industrial Standards (JIS G 0552) and the determination of the rate of spherical graphite has been carried out in compliance with the speroidal graphite iron castings of Japanese Industrial Standards (JIS Z 5502). The average ferrite grain size (Df), average particle size (Dm), area fraction of graphite (ft) and other related values are seen in this table. The specimen has been prepared by cutting the test material from the bottom part of the cast block. Then the central part of the specimen has been mirror polished to examine the crack propagation by conducting the microstructural analysis. The dimension of the prepared specimen with AE sensor is shown in Fig. 2. In

Table 1: Chemical composition of basic test material (FCD)

<table>
<thead>
<tr>
<th>Composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>3.71</td>
<td>2.33</td>
<td>0.14</td>
<td>0.013</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Fig. 1 Microstructure of FCD specimen.

Table 2: Characteristics of heat-treated FCD

<table>
<thead>
<tr>
<th>Feritic gain</th>
<th>Spherical graphite</th>
</tr>
</thead>
<tbody>
<tr>
<td>size</td>
<td>FERD</td>
</tr>
<tr>
<td>720°C, 15h, F.C.</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Fig. 2 Dimension of specimen with 4 AE sensors (S1-S4).

Fig. 3 A panoramic view of the experimental system for crack detection by AE technique.

Table 2 the four AE sensors are mentioned as S1, S2, S3 and S4 where their respective positions are mentioned in brackets with x- and y-directional values. All dimensions are indicated in millimeters.

2.2 Experimental procedures

According to the objective the test specimen is attached to a universal testing machine for pressing testing loading which creates the adequate cracks to the specimen until occurring final crack-damage. All the AE sensors are attached to the specimen by inserting special silica gel between the sensor and specimen for avoiding the mismatch of acoustic impedance. Each sensor is connected to the pre-amp and then to the main 4-channel AE amplifiers. After applying adequate filtration, the AE signals are stored in a digital storage oscilloscope (DSO) from where the data are transferred to the personal computer for the analysis. The microstructure and the initiation of crack-damage are visualized by the real time imaging of a high-speed digital microscope (VW-9000, KEYENCE Ltd., Japan). The total set-up is shown in Fig. 3.

3. Experimental Results and Discussion

Experiments have been conducted focusing on the
Fig. 4 AE signal for crack damage with threshold, showing the AE parameters.

Fig. 5 Microscopic figure with crack damage.

Fig. 6 AE signals for four sensors with respective AE parameters.

Fig. 7 Detection of Crack initiation and propagation.

detection of initiation and propagation of crack-damage of ductile cast iron by applying the AET technique. AE signal (AE event) due to the crack damage is shown in Fig. 4, where the corresponding AE parameters are mentioned. The corresponding microscopic image of the damage is shown in Fig. 5. AE events for other three sensors (S2-S4) are also shown in Fig. 6 with their AE parameters. The vertical axis of AE event indicates values in volt, where the horizontal axis is in micro-seconds. Crack initiation and propagation are shown in Fig. 7 ((a), (c), (e) for microscopic view, (b), (d), (f) for AE event). It is found that the amplitude value of each signal increases as the crack-damage increases, although, in 7(c) it decreases due to noise and some harmonic effects.

4. Conclusions

The AET technique has been successfully installed for damage evaluation and characterization of material as a NDE technique. The method has been applied successfully in characterizing the cracked damage of ductile cast iron.

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References

