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Full Length Research Paper

Analysis of phase transformations in steel using online monitoring technique - Acoustic emission

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Steel is one of the most commonly used materials today, especially in industrial sectors such as ship building, automobile industry and in power plants. In order to meet the requirements for steel applications, new steels are being developed. In the present study, experiments are carried out to distinguish different phases using on-line monitoring technique - Acoustic Emission (AE). The main objective of this work is to a better understanding of the growth mechanism and solid-state phase transformations that can occur in carbon steel. In view of the fact that AE is an unexplored technique in this kind of steel research, this study also aims to give a good overview of the possibilities and limitations of AE, as a real time monitoring technique for the evolution of bainitic and martensite phase transformations. It was found from the experiments that the basic parameters by which the phase transformation can be found out are energy, counts, RMS and amplitude. By analyzing the obtained AE data, it is possible to study the phase transformation behavior.

Key words: Steel, online monitoring, acoustic emission, energy, counts, RMS, phase transformations and amplitude.

INTRODUCTION

Acoustic emissions are the waves produced by sudden release of stresses. The classic sources of acoustic emissions are defect-related deformation process such as crack growth and plastic deformation. The process of generation and detection (of stress waves) is illustrated in Figure 1. Sudden movement at the source produces a stress wave, which radiates out into the structure and excites a sensitive piezoelectric transducer. As the stress in the material is rising, many (number) of these emissions are generated. The signals from one or more sensors are amplitude and measured to produce data and interpretation (Lopez et al., 2000; Adrian, 1986; Baldev and Jha, 1994. The source of the acoustic emission energy is the elastic stress field in the material. Without stress, there is no emission (Graham and Alers, 1975). Therefore, an Acoustic Emission (AE) inspection is usually carried out during a controlled loading of the structure. This can be proof load before service, a controlled variation of load while the structure is in service, a fatigue test, a creep test, or a complex loading program.

Often, a structure is going to be loaded anyway, and AE inspection is used because it gives valuable additional information about the performance of the structure under load. Other times, AE inspection is selected for reasons of economy or safety, and a special loading procedure is arranged to meet the needs of the AE test. In production testing, AE inspection is used for checking and controlling welds, brazed joints, thermo compression bonding, and forming operation such as shaft straightening and punch press operations (Stan, 1990). In general, AE inspection can be considered whenever the process stresses the material and produces permanent deformation. Acoustic emission signals

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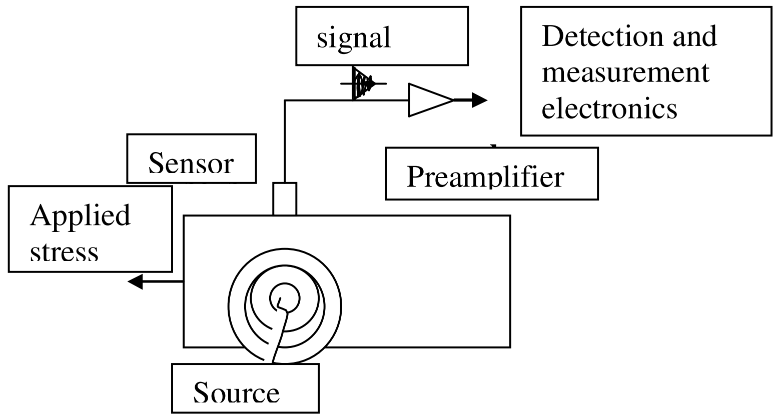

Figure 1. Basic principle of the acoustic emission method.

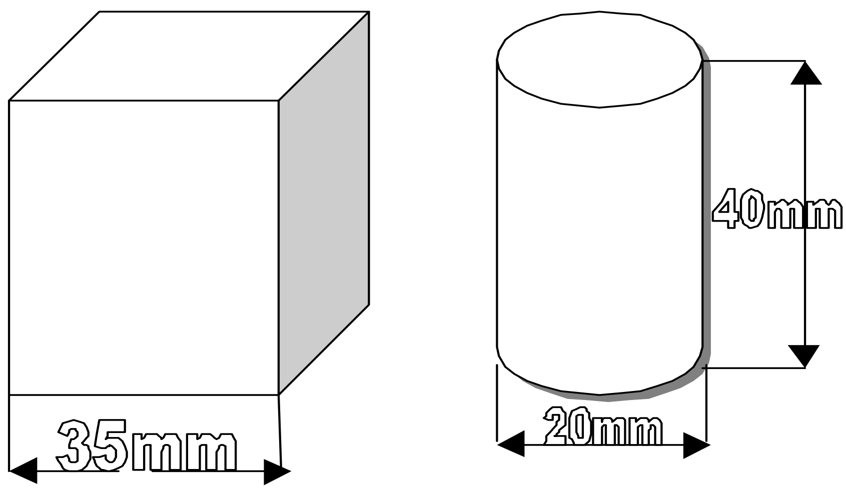

Figure 2. Specimens with different sizes.

can be observed at phase transition (PT) temperature during both increasing and decreasing temperature cycles. Acoustic emission signals were also observed below and above the phase transformation.

The signals at phase transformation are attributed to the micro deformations taking place in the grains due to increase in temperature; and the signals observed during decreasing temperature are attributed to structural change from cubic to tetragonal (Morais CF and Green AT (1975). Thermal anisotropic contraction of carbon and austenite axis seemed to be the reason for the signals observed below the phase transformation while a few signals observed above the phase transformation were attributed to micro-cracking due to local thermal inhomogeneties. AE signals were found to be strong while cooling the specimen due to sudden change in lattice parameters (Van Bohemen et al., 2002; Prabakar and Aparna 2004; Speich and Schwoeble, 1975; Cooper and Jones 2002; Stefanus and Van Bohemen, 2004; George, 2004).

EXPERIMENTAL

The specimens of sizes 35 × 35 × 35 mm, 20 mm diameter and 40 mm length were prepared with 4 mm hole at the center as shown in Figure 2. The rust or scaling on the specimen is removed to avoid detection of emissions due to breaking of scale during loading. A wave-guide of 20 mm diameter and 1 m length is prepared from the defect free austenitized stainless steel rod as shown in Figure 3. The purpose of the wave-guide is to place the sensor for testing. One end of the wave-guide is welded firmly to the metal piece to be tested as shown in Figure 3. The sensor is attached to the other end using grease as couplant and is bonded tightly with tape or screw head. The wave-guide is bent into the L-shape, to provide cooling such that the sensor could not be heated. Thermocouple is

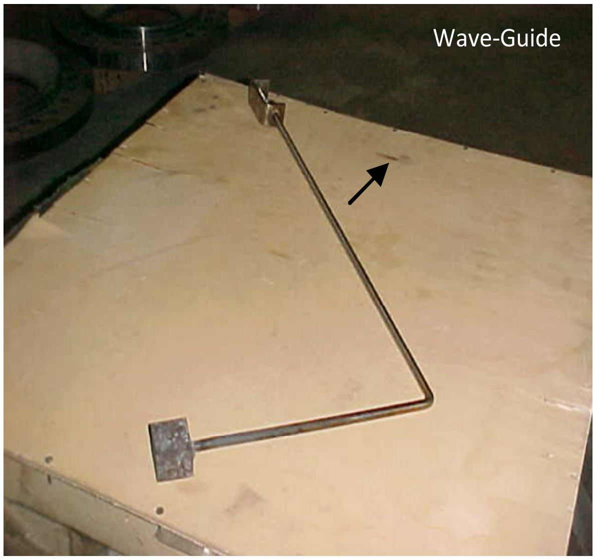

Figure 3. Wave guide.

Table 1. Materials used.

Materials used	Composition of the elements (%)				
	C	Si	Mn	Cr	Ni
C45	0.44	0.27	0.7	0.2	0.03

Figure 4. Furnace set-up.

attached to the specimen by placing a hole in the specimen for input in the pin connector position.

The INI file with threshold of 40 dB, Pre-Amp Gain of 40 dB and a sampling rate of 4 MHz was selected. The two sensors are to be placed in the linear location group by giving velocity 5000 m/s and distance between sensors. The INI file is loaded and the data acquisition is started without auto dump. Pencil break test is done to test the sensor sensitivity. If the indication of source position is correct, then the file is closed. After that one sensor is made as dummy, as per requirement of the experimental setup. Then, the data acquisition is started with auto dump on and the DTA file name is specified. After completion of the experiment the DTA file is closed.

Waveguide

The sensors can operate in the temperature range of – 40 to 180°C only. So the sensor cannot operate at higher temperatures. As a result of this acoustic emission, consulting uses wave-guides to remove the sensor from high temperature at the specimen surface and mechanically transmit the signal to the sensor. The wave-guide was shown in Figure 3. The wave-guides consist of a 1/4" austenitized stainless steel rod compression fitted and tack welded to a stainless steel base plate. Here, the stainless steel rod was austenitized so that it cannot effect the phase transformation. The base plate provides the mounting surface for the sensor (as shown in Table 1.), which is held firmly to the base plate face via a spring – loaded mechanism.

Thermocouple

The thermocouple used is a special chromel/alumel type. The temperature measurement range was around 1200 to 1500°C. These are based on the thermo-electric effect. If two dissimilar metals are joined together at both ends, and these junctions are maintained at different temperature by heating one junction and keeping the other cold, an electromotive force (emf) is induced in the circuit. The electromotive force induced will be proportional to the difference in temperature between the two junctions.

A thermo-couple assembly consists of three units namely; thermo-couple lead wires, and indicator. A thermo-couple is composed of two homogeneous but dissimilar metal wires. The ends of these wires are joined together by soldering, welding or fusing together. Thus, a closed circuit is formed. The free ends of the thermo-couple are connected to lead wires. Other ends of lead wires are connected to a suitable indicator. The indicator measures the electromotive force developed in the circuit. The extension lead wires are generally made of the same materials as the material of thermo-couple wire.

Furnace

Here a cylindrical type furnace with steel casing is used. This is a resistance type furnace. This is controlled by voltage varying from 0 to 270 V. The maximum temperature limit is 1200°C. The temperature can be maintained constant by setting the maximum limit in the controller and by just varying the voltage. The furnace setup is shown in Figure 4 and the experimental setup is shown in Figure 5.

RESULTS AND DISCUSSION

Material C45

The sample (C45 of 35 x 35 x 35 mm size- (as shown in Table 2) is austenitized at a temperature 83°C and

Figure 5. Experimental set-up.

Table 2. Sensors used.

Sensor used	Frequency range (KHz)
R 15s	50 - 200
R 50s	100 - 700

subsequently quenched in an oil bath. During cooling, AE waves of the sample were recorded. During austenitizing, the RMS voltage was at background noise level, and subsequently the onset of a peak in the AE data was observed at bainite transformation temperature; the bainite peak. The signal level increases to a maximum and then trials off to the background noise level. Upon further cooling, a second peak was observed at temperature of martensite formation; the martensite peak (Van Bohemen et al., 2002). The shapes of the bainite and martensite peaks reflect the evaluation of bainite and martensite formation.

The same observations are also observed in energy, counts and amplitude graph also (as shown in Figures 6, 7 and 8). Two distinct peaks were observed at different temperatures 500 to 600°C and again at 200 to 300°C which are attributed to bainite and martensite formation respectively (Van Bohemen et al., 2002). The micro-structure obtained from the C45 specimen found out to be bainitic and martensite (as shown in Figure 9.). The phases are then matched with corresponding hardness values HV 278, HV 400 respectively. The occurrence of AE during the phase transformation implies that the bainitic and reaction mechanism in steel C45 is diffusionless and is best described in terms of the displacive model.

Conclusions

The work has been carried out to determine the applicability of acoustic emission system for phase transformation studies during heat treatment process. The results found are cross-examined by other techniques like metallography and hardness test. Acoustic emission signals are observed at phase transition temperature during both increasing and decreasing temperature cycles. Acoustic emission signals are also observed below and above the phase transformation. The signals at phase transformation are attributed to the micro deformations taking place in the grains due to the increase in temperature. The signals observed during decreasing temperature are attributed to structural change from cubic to tetragonal. Thermal anisotropic contraction of carbon and austenite axis are found to be strong while cooling the specimen due to sudden change in lattice parameters.

These experiment results were analyzed using Noesis

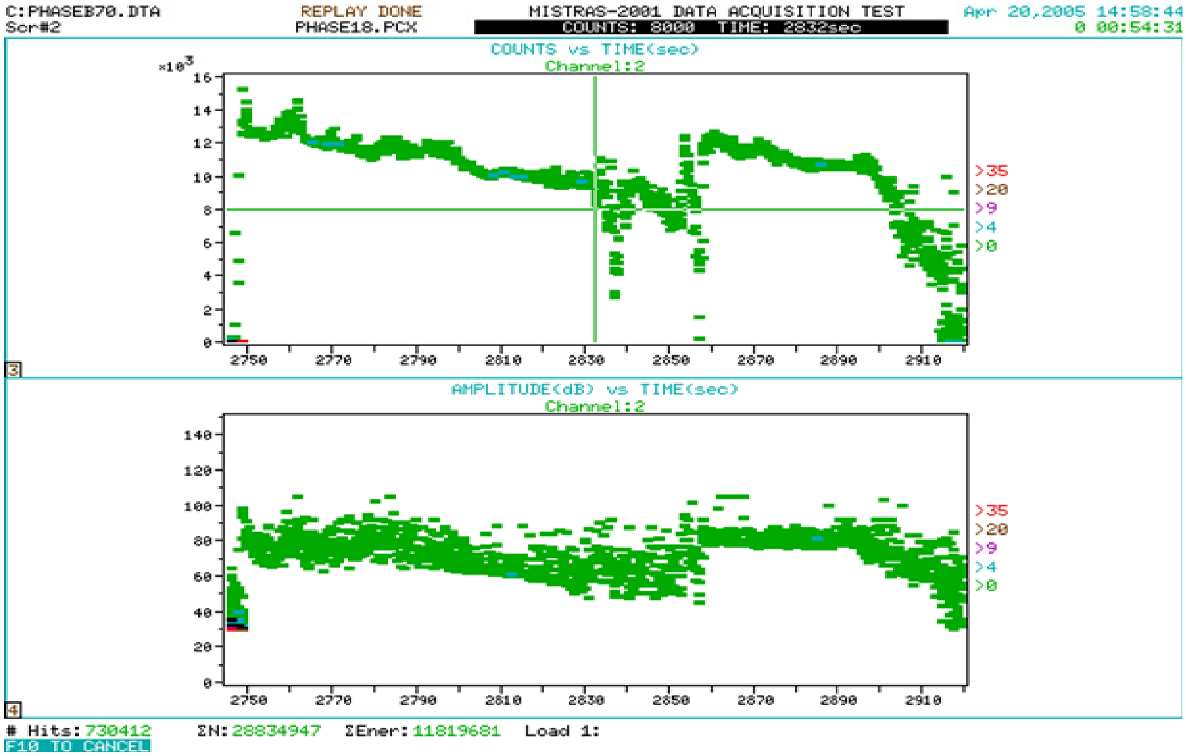

Figure 6. AE signals showing two distinct phase transformations during oil quenching.

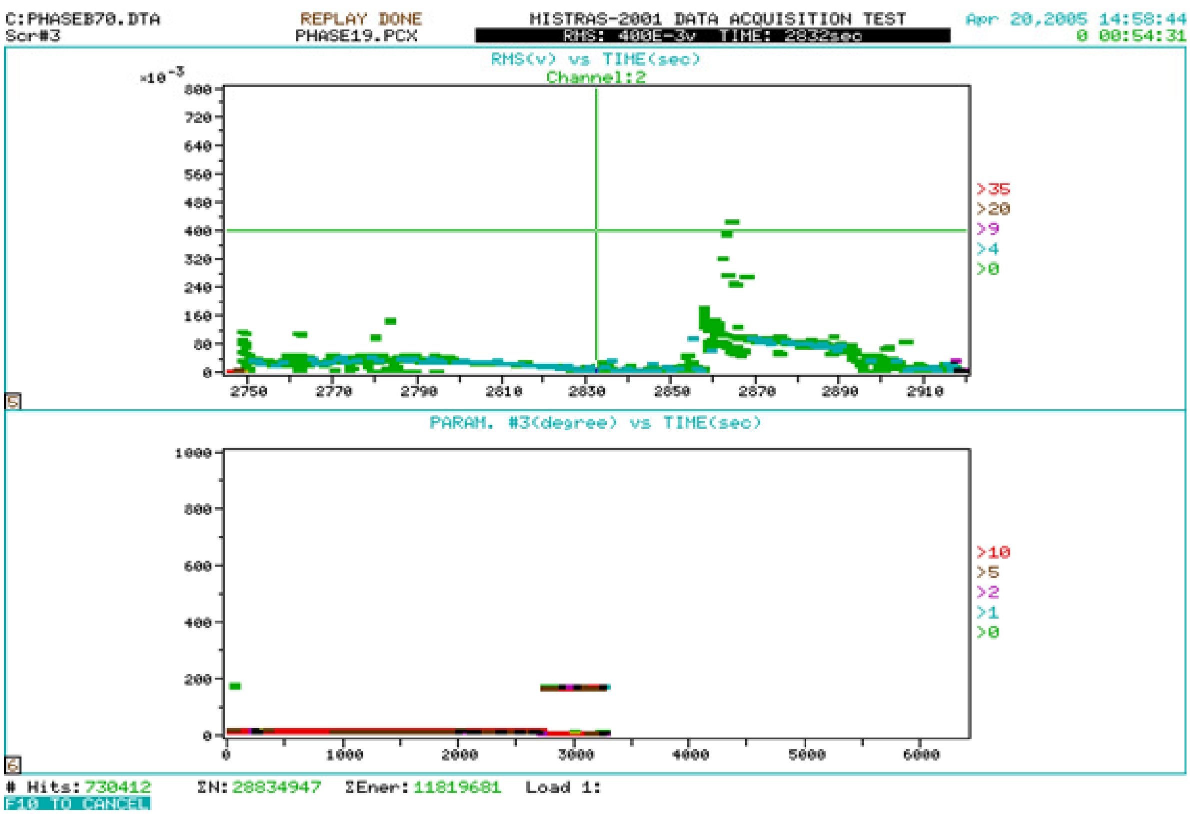

Figure 7. AE signals showing two distinct phase transformations during oil quenching.

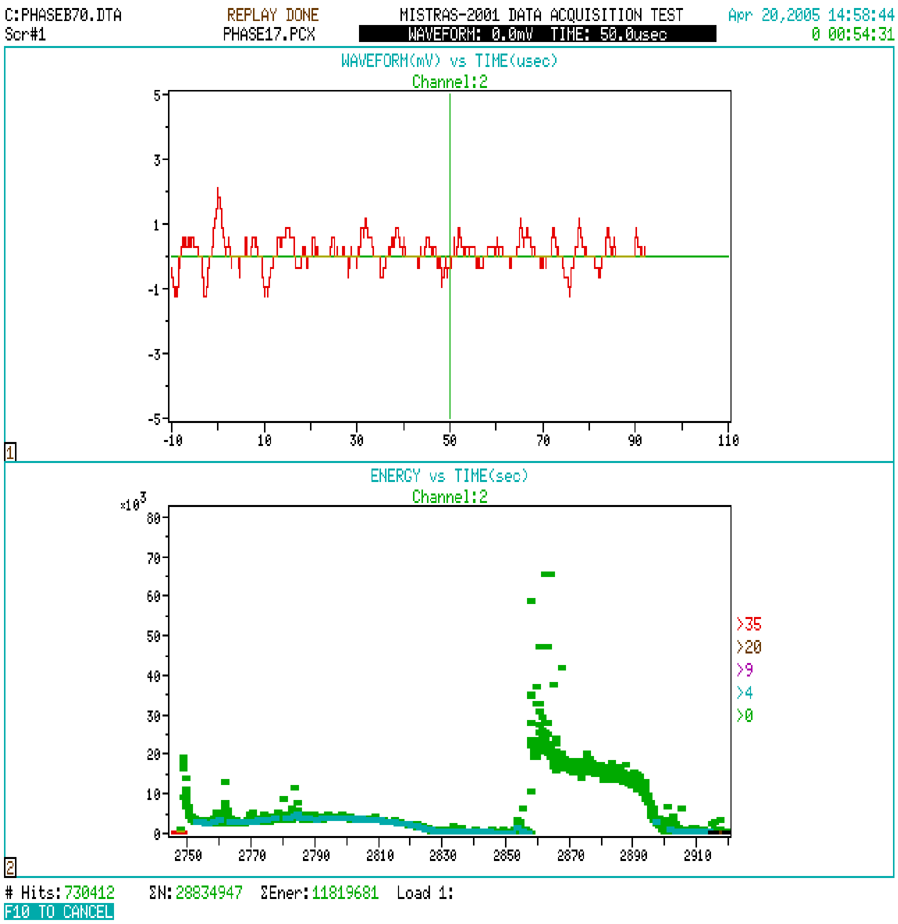

Figure 8. AE signals showing two distinct phase transformations during oil quenching.

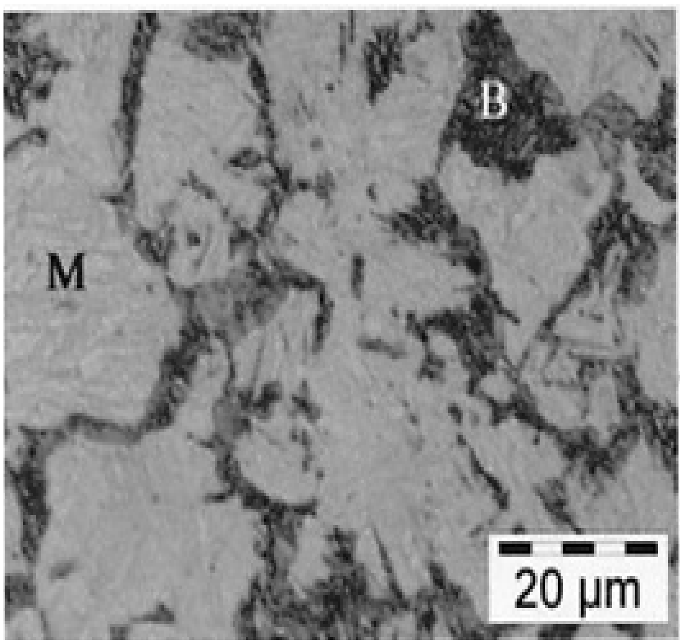

Figure 9. Optical microscopy image of the microstructure of steel.

seemed to be the reason for the signals observed below the phase transformation, while a few signals observed above the phase transformation are attributed to micro-cracking due to local thermal inhomogeneties. AE signals software. In Noesis, the signals, which are similar in nature, are grouped using clustering technique. The signals are discriminated with ease by using this software. From this experiment it is found that COUNTS, ENERGY and RMS are the basic parameters by which it is possible to find the starting and end of the phase transformation. This experiment deals with acoustic emission measurements during continuous cooling of different steels. The test results are summarized as follows:

1. During quenching of steel from AC1 temperature, two distinct peaks are observed at temperatures of 500 to 600°C and 200 to 300°C.
2. The peaks observed are confirmed to bainitic and martensitic phases by metallography and hardness test.
3. The occurrence of AE during the bainitic transformation implies that bainitic transformation is by diffusionless mechanism as martensitic transformation.
4. The amount of the two phases formed can be correlated with the ratio of the bainitic and martensitic peaks.

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