Crack Initiation Detection in JAC780Y during Tensile Loading by Using Direct Current Potential Drop and Acoustic Emission Techniques

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***Abstract*— In this work, the non-destructive and fracture test techniques were studied for micro-crack detection in the advanced high strength steel (AHSS) notched sheets. Crack initiation of JAC780Y during tensile loading was investigated by Direct Current Potential Drop (DCPD) and Acoustic Emission (AE) techniques. The results confirm for the first time that both techniques can be induced to indicate micro-crack from fracture behavior of AHSS sheet in forming and AE technique can detect the crack initiation faster and more effective than DCPD.**

***Index Terms*—crack detection, acoustic emission, direct current potential drop**

I. Introduction

Direct Current Potential Drop (DCPD) method was established in the 1950s and the approach is based on the Ohm's law, which exhibits the relationship between electric voltage and material resistance. Example apparatus is shown in figure 1a, where a DC power supply (current source) with controller is used to provide a constant electrical current to the tested samples. A pair of conductors (wires) are welded onto each of the two sides of the gauge section near the notch area and connected to a voltage meter to record the potential drop during the tensile test. Typically, the output potential slightly increases at the beginning and then quickly increases as depicted in figure 1b. This is assumed to be as a result of the crack initiation in the critical location and could be used to indicate the state of damage onset of a concerned material [1, 2].

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A major application of the approach is crack growth monitoring in pipes and pressure vessels [3]. In the automotive industry, DCPD is utilized to determine crack initiation in metal forming parts after pressing and during their lifetime, particularly in fatigue crack detection of Advanced High Strength Steel (AHSS) sheets. Some metal stamping parts in automotive vehicles are often applied with cyclic loading which induces fatigue cracks in their final state. Therefore, almost all failures of AHSS sheets have occurred due to fatigue and shear crack behaviors, which have initially originated from crack initiation or micro-crack in microscopic scale [1, 4]. Many studies have attempted to use the DCPD method to identify onset of stable crack initiation in such fracture mechanics tests, such as Panich *et al.* [1], Charoensuk *et al.* [2], and Lian *et al.* [4]. DCPD method is also a method for the detection of crack growth in fatigue, creep, and stress corrosion problems.

Acoustic Emission (AE) is a favourable non-destructive technique to use for crack detection in many applications. The principle of AE is based on receiving sound energy that generated from the material crack point to AE sensor. High sensitivity AE sensor can pick up signals at an early stage of crack initiation, such as dislocation movement and slip-band formation [5]. AE methods have been found to be an effective way of detecting fatigue and fracture behaviours of materials and detect micro-scale internal cracking detection [6].

Several attempts using AE for crack monitoring in forming process have been made to investigate AE activities during deformation, such as [5, 6, 7, 8]. These authors reported that this technique can perform very well in detection of the crack during deformation process. AE features (RMS and peak-to-peak) were used to evaluate bendability of sheet metals in three-point bending test [8].

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The typical AE monitoring component in many studies consists of AE sensor, signal conditioners (amplifier and filter), data acquisition, and data processing as shown in Fig. 2a.

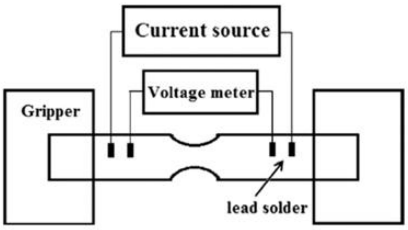


Figure 1. DCPD technique for crack evaluation and an example result during tensile test [3]

In this work, the crack initiations were determined during performed notched tensile tests of JAC780Y advanced high strength steel (AHSS) sheet. The AE and DCPD techniques have been used to detect the crack initiation during the tensile test (on-line monitoring). The crack initiation state has been precisely investigated and this has enabled the prediction of the instance of a fatigue crack.

II. Experimenttal Setup and Procedure

A. Nortched Tensile Testting

JAC780Y, an advanced high strength steel (AHSS), sheet, with a nominal thickness of 1.0mm was selected in this study and the chemical composition is illustrated in Table I. Three differently notched tensile sample geometries were used, namely, Radius (R), Semi-circle (S), and U-notch samples. The sample dimension is depicted in figure 3b. All notched tensile samples were prepared in rolling direction (RD) and the wire EDM cutting process was used to prepare the three notch samples.

TABLE I. Chemical Composition of JAC780Y AHSS Sheet (%wt, %Fe bal.)

C	Si	Mn	P	S	Ni
0.123	0.016	2.706	0.010	0.004	0.009
Cr	Mo	Cu	Pb	Sn	Zn
0.192	0.064	0.013	0.006	0.000	0.088
Bi	Co	Ca	Zr	B	N
0.007	0.000	0.000	0.003	0.003	0.002

B. Sensors and Data Acquistion

The DCPD measurement method generally uses four wires welded to the notched samples as shown in figure 3a. The two outer wires were connected to a constant current source for applying a constant current to the examined samples, while the two inner wires were used to read the voltage across the crack area. This voltage was averaged and logged by a true-RMS multimeter (Fluke 289/FVF). The sampling frequency was 1 kS/s. Two acoustic emission sensors were used to sense the cracking signal during the tensile test as shown in the experimental setup (Fig. 3). The narrow band sensors (R15S, PAC) have a frequency response of 50-400 kHz which is suitable for cracking sound detection in metals. The acquired signals were gained and improved by pre-amplifiers (60 dB) and band pass filters (figure 2). The AE signals were connected to a National Instruments NI-9223 and cDAQ9171 for data collection. The AE signal was sampled at 500 kS/s and processed using National Instruments Labview software.

C. Experimental Procedure

To obtain the crack initiation state, the examined steel samples were analysed with both the DCPD and AE techniques. In DCPD, the constant current of 0.5A was selected to supply to the notched samples via the two outer wires (figure 3a) due to the material properties and dimensions of the samples in order to obtain the constant electric current flow on the samples and to avoid critical heating of the samples [2]. The voltage was monitored by a digital multimeter.The AE sensors were mounted by C-clamps on top and bottom of the testpiece. Industrial grease used as couplant substance was applied between testpiece and the sensors to remove any air from the workpiece-sensor interface and to obtain a good quality acoustic emission signal. A root mean squared value (RMS) was used to recognize the AE activity during tensile test. The notched tensile testing was conducted initially by using a 250kN universal tensile testing machine. To achieve a quasi–static condition, the crosshead speed of the machine was adjusted to ensure a strain rate of 0.01 s^{-1} for all tests. During the incremental loading tests, the sensing signals of cracks acquired from two techniques were collected and then processed. The sensitivity of these techniques were finally compared in terms of crack detection time.

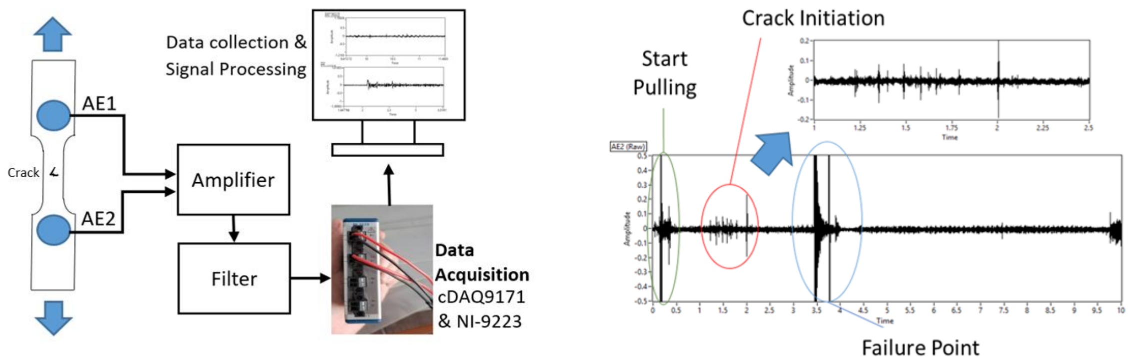
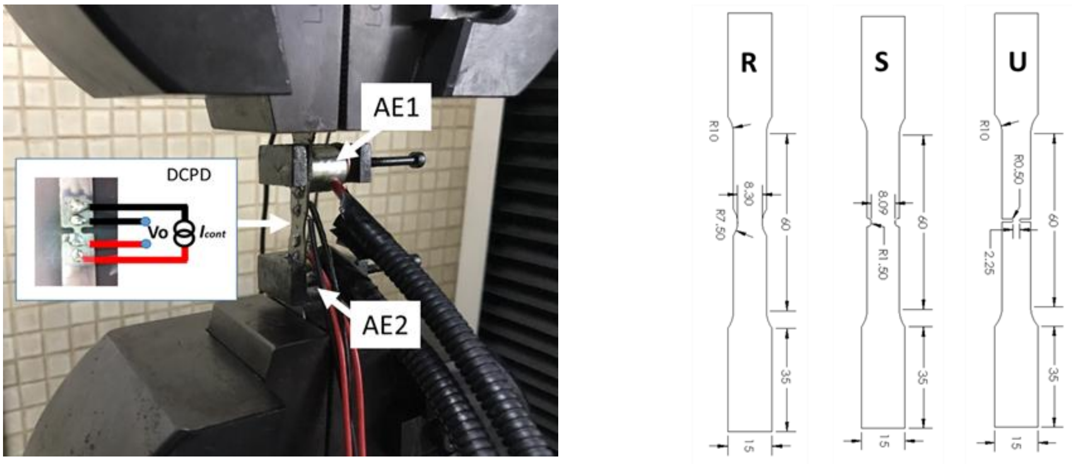


Figure 2. AE system for data collection and typical AE signal during tensile test.



(a) (b)

Figure 3. Experimental Setup and test sample dimension

III. Result and Discussion

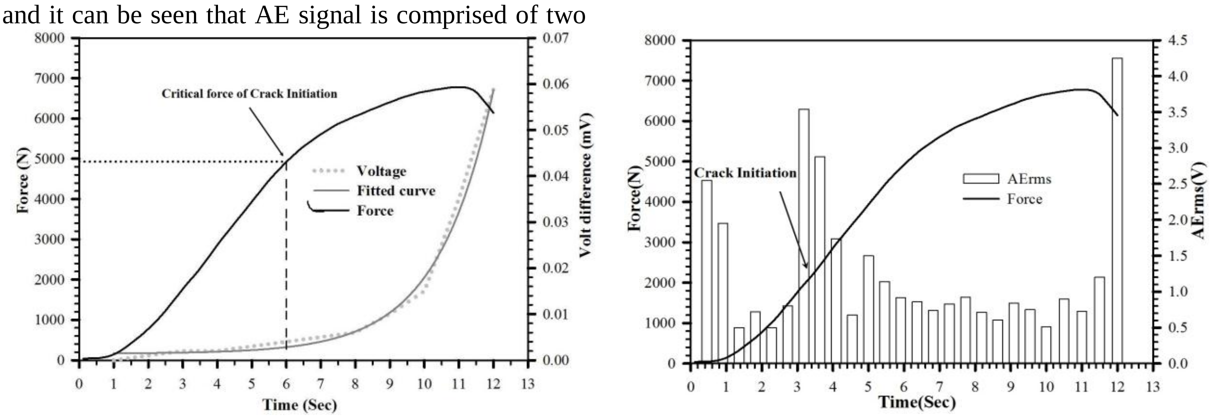
Fig. 4 to Fig. 6 shows DCPD voltage and AE_{rms} of three-notch samples compared with the tensile force recorded by tensile machine.

From the DCPD results, the determined potential slightly increased at the beginning because of the reduction in cross section area of specimens. After a certain plastic deformation of tested sheet samples, void coalescence or microcrack formation occurred. This crack formation causes severe defects and a sudden increase of electrical resistance and potential voltage in consequent. The crack initiation by DCPD method was indicated by observing the first abrupt change in slope of the potential curve. Clearly, the biggest cross section area is R-notch sample, which establishes exactly time occurred early crack initiation than S-notch sample since the S-notch sample geometries induce crack initiation appearance lately from stress distribution to notch area. The early crack initiation was obtained from U-shape since the small geometry notch sample. Simultaneously, the force value depends on cross section area.

Also, the investigation has shown that all AE sensors can detect the crack signals emitted in the testpiece. Typical AE signal during tensile test is shown in figure 2b and it can be seen that AE signal is comprised of two types: transient (burst) and continuous signals. The first burst immensely emerges while the grips of tensile machine start to apply tensile load the testpiece. Then, the deformation of the testpiece are represented by AE continuous signal until the last burst at the point of crack extension associated with final failure. Interestingly, crack initiation in testpiece can be indicated by small bursts on the transition state changed from pure elastic deformation to a combination of elastic and plastic deformation region.

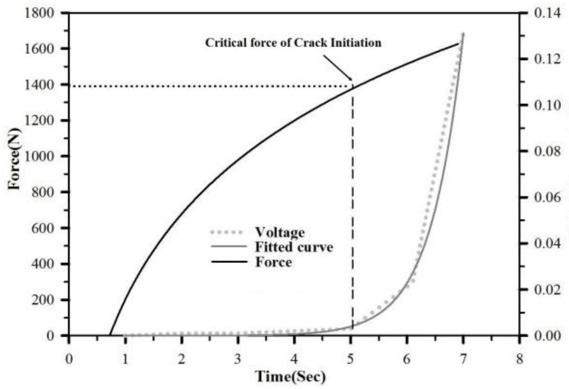
The AE feature (AE_{rms}) of three notched samples were extracted and compared with tensile load as shown in figure 4b-6b. On average, AE_{rms} in R-notched sample have higher signal amplitude compared with other notched samples, while AE_{rms} in U-notch have the lowest values. It is speculated AE signal can be transmitted well in the larger cross sectional area and the cracks in the larger area have higher signal energy or signal amplitude than the cracks in small cross section.

Comparing these two techniques, clearly seen that AE technique can detect micro-cracks effectively and can indicate the crack initiation much earlier (up to 50%) than DCPD technique (Fig. 7). It can be concluded that the AE technique is the more useful method for on-line crack monitoring during forming process.

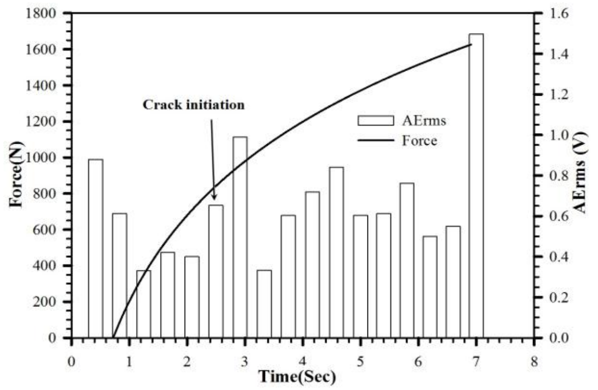


(a) Semi Circle-notch –DCPD (b) Semi Circle-notch -AE

Figure 4. Semi-circle notch:(a) DCPD voltage potential and tensile load, (b) AErms and tensile load

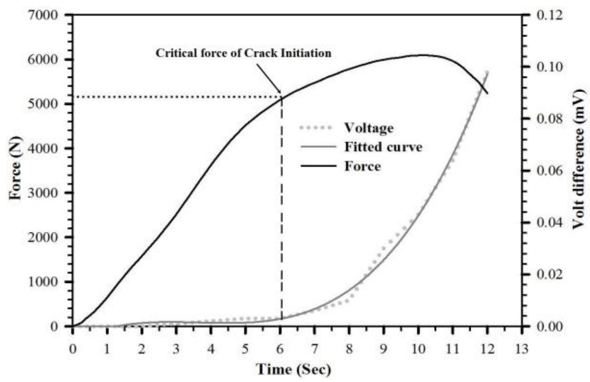


(a) U-notch - DCPD

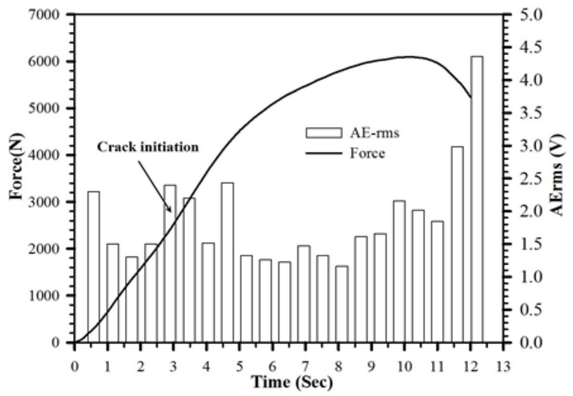


(b) U-notch – AE

Figure 5. U-notch: (a) DCPD voltage potential and tensile load, (b) AErms and tensile load



(a) R-notch - DCPD



(b) R-notch-AE

Figure 6. R-notch: (a) DCPD voltage potential and tensile load, (b) AErms and tensile load

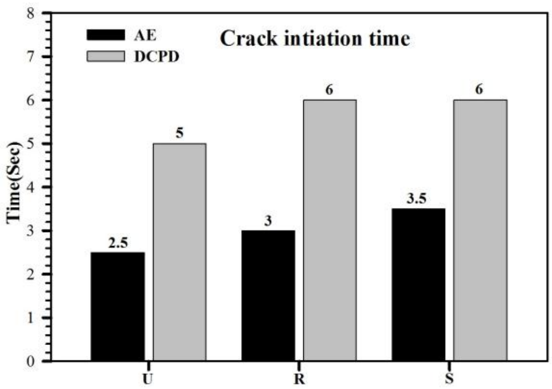


Figure 7. Comparison of crack initiation time between DCPD and AE technique

IV. Conclusion

In this paper, we investigated the use of Crack Monitoring Techniques (AE and DCPD) for detecting crack initiation of AHSS during tensile tests. Three-notched samples (U-shape, radius, and semicircle) with two sensing signals were monitored and evaluated. The conclusions of this work are as follows:

- The abrupt change in the potential curve in the DCPD method can definitely indicate the initial cracks.
- The AE technique shows better results and has a faster response time in crack detection during the tensile test compared with the DCPD method.
- A simple AE feature (RMS) can be effectively used to detect the crack initiation and can also be used as a warning signal before the notched samples break.
- The cross sectional area of the notched samples has a direct influence on the signal transmission.

It might be possible to extract different AE features for detecting the crack initiation and propagation in metal forming parts. This will continue a further investigation and more research on this topic needs to be undertaken in order to find the best feature for use.

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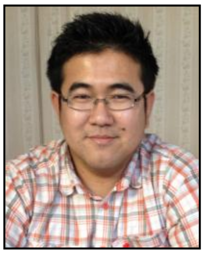

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Tom Slatter graduated from the University of Sheffield in 2010 with a PhD in Mechanical Engineering. He worked for the Ford Motor Company in powertrain CAE and diesel engine engineering. His PhD was sponsored by the Ford Advanced Research and Materials Group in Aachen, Germany and concerned the wear of automotive valvetrain components. His research interests have expanded into manufacturing with projects investigating the design, performance and instrumentation of manufacturing machines, processes and tooling. He also continues to be involved in automotive research and works at a more fundamental level investigating topics including impact wear and the cryogenic treatment of metals.