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FRACTURE INITIATION OF LINE PIPE STEEL DURING TPBT ON ACOUSTIC EMISSION

Turbadrakh Chuluunbat[1, a*], Andrii Kostryzhev[2, b], Cheng Lu[3, c]

[1] Department of Science and Engineering, Mandakh University

[2] School of Material, Mechanics and Mechatronic, University of Wollongong, Australia,

[a] turbadrakh@mandakh.edu.mn, [b]andrii@uow.edu.au, [c] chenglu@uow.edu.au

Abstract

In this paper, the effect of loading conditions on fracture behavior was studied using AE monitoring during three point bending testing (TPBT) of a line pipe steel Charpy V-notch (CVN) specimen with different thicknesses at ambient temperature. The hardware and software produced by Physical Acoustics Corporation (USA) was used. Acoustic Emission (AE) parameters were analyzed and correlated to the load-deflection curves obtained during testing. AE features were analyzed using Wave Form and Power Spectrum methodologies and correlated to the fracture parameters and load-time/load-deflection curves obtained. AE analysis was observed an isolated AE signal generating from plastic deformation, crack initiation and propagation.

Keywords: pipeline steel, fracture initiation, acoustic emission, TPBT, CVN specimen

INTRODUCTION

In the pipeline industry, there is a significant issue to prevent the fracture of pipeline so it is basically demonstrated in terms of fracture initiation and fracture propagation of pipeline. The fracture initiation occurs due to manufacturing defect, design error, and mechanical damages, such as notch, crack, dent, and corrosion, and it reaches a critical defect length or a certain stress level and start to propagate (Rothwell 2001).

The main concern in fracture propagation control is specifying pipeline toughness that will arrest ductile fracture. Specifying minimum arrest toughness can be determined by the energy from CVN test (Server 2002). In regarding to fracture propagation control, it needs to determine fracture initiation point. Traditionally, it is assumed that fracture initiates at maximum load during CVN testing. However, Finite Element Method (FEM) simulations show that the fracture is initiated before or after the load attains its maximum value (Chuluunbat 2015). In the experimental work, the ductile fracture point must be detected during a relatively short time between the yield of the sample and maximum load or brittle fracture of the CVN specimen so a suitable method to investigate the pipeline steel fracture phenomenon is the AE monitoring technique.

Acoustic emission (AE) technique is commonly used in mechanical and material research for detection of plastic deformation, fracture initiation and propagation. AE method is a quite effective tool for detection of crack initiation during static and dynamic testing and measure fracture toughness of the material (Ono 2005 and Muravin 2011).

It has been found that the detecting of onset tearing of 10CrMo 9 steel using instrumented Charpy impact tester. It used piezoelectric AE sensor with a high of pass filter and located in inside of the hammer of the tester (Richter 1999). There are some approaches to determine the effective location of sensor based on a range of a high and low pass filter of AE transducers. Basically, the use of AE monitoring has shown that a growth of AE activity after yield point in steels because of an increase in dislocation motion during mechanical testing. Analysis of AE signature from different stage of fracture (load and displacement curve) identified by a characteristic change of AE features especially amplitude and count. The disadvantage of the use of AE may have distinguishing between high frequency AE from fracture initiation and background noise from friction between specimen and support, and striker impact. From the literature review, a few numbers of studies were found in related to fracture mode of pipeline steel by means of Charpy impact loading using acoustic emission signal evaluation processing (Kostryzhev 2012 and Tronskar 2003).

Based on this problem statement, the quantitative dependence of the AE parameters (such as amplitude and frequency) on fracture parameters of CVN specimen of pipeline steel is not fully understood as well less studied. For this reason, research is needed to develop a better understanding of the mechanical properties and fracture behaviour of line pipe steels to prevent fracture initiation. Identifying the crack initiation is significance from the point of pipeline fracture control. To investigate the correlation of AE characteristic and fracture behavior of pipeline steel, we analyzed a considerable number of small scale specimens tested under a variety of conditions such as static loading and different thicknesses. In the present study, the effect of thickness on fracture initiation and growth during a slow TPBT of X70 pipeline steel with CVN specimen were studied using AE monitoring technique. The load-time and load-deflection curves were correlated to the AE wave and its frequency content/distribution and dependence of AE features on fracture parameters were obtained.

1. EXPERIMENTAL PROCEDURE

The material used in this experimental work was API-X70 pipeline steel. The specimens were prepared from a 14.1 mm thickness and 106.8 mm diameter pipeline steel. The material composition is given in Table.1

Table. 1 Material composition of the X70 pipeline steel tested.

C	Mn	Si	Nb	Ti	V	Ni	Cr
0.0499	1.56	0.238	0.0576	0.0088	0.0256	0.214	0.028
Cu	Mo	Al	Ca	N	S	P	B
0.163	0.148	0.035	0.0015	0.0036	0.0014	0.0059	0.0001

Table. 2 Mechanical properties of the investigated pipeline steel

	Young modulus	Poisson ratio	Yield stress	Ultimate stress	Density	Elongation
X 70	190 GPa	0.31	530 MPa	605 MPa	7710 kg/m3	25%

Quasi-static three point bending tests were carried out using CVN specimen for different thicknesses: 5 mm and 7.5mm at ambient temperature. Tests were performed by an Instron machine at a constant crosshead speed of 1 mm/min.

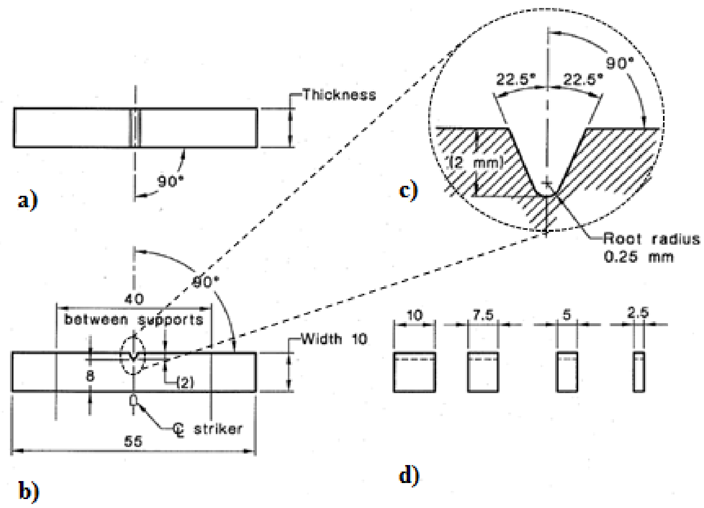


Figure 1. CVN specimen: (a) top view; (b) side view; (c) Notch detail; (d) Subsidiary specimens

The TPBT testing specimen has the same geometry as the CVN specimen in Fig.1 (AS-1544 2003). During the testing, acoustic emission was monitored and recorded by AE acquisition system produced by Physical Acoustics Corporation (Mistras-PAC 2012). AE monitoring of the test was carried out using the USB AE node which is basically a single channel Acoustic emission Digital Signal Conditioner with full set of AE hit and time based features, including waveforms. The AE node can accept single ended/differential sensors amplified by an internal low noise preamplifier. General purpose wideband sensor (WSα) is used in the study. The sensor location is based on combination of a high and a low pass filter (kHz) due to the saturation of AE signal. The sensor was permanently mounted using ultrasound treatment gel to the surface of specimens.

The AE signals associated with fracture mechanisms was investigated. In order to correlate fracture initiation and AE features, such tests were performed. AE measurements during the tests exhibit a variety of amplitude characteristics. The sources of the signals were consisted of continuous AE signals dominated due to plastic deformation and were a few burst types of AE signals at yield, fracture initiation and final separation. A schematic of the TPBT is shown in Fig.2

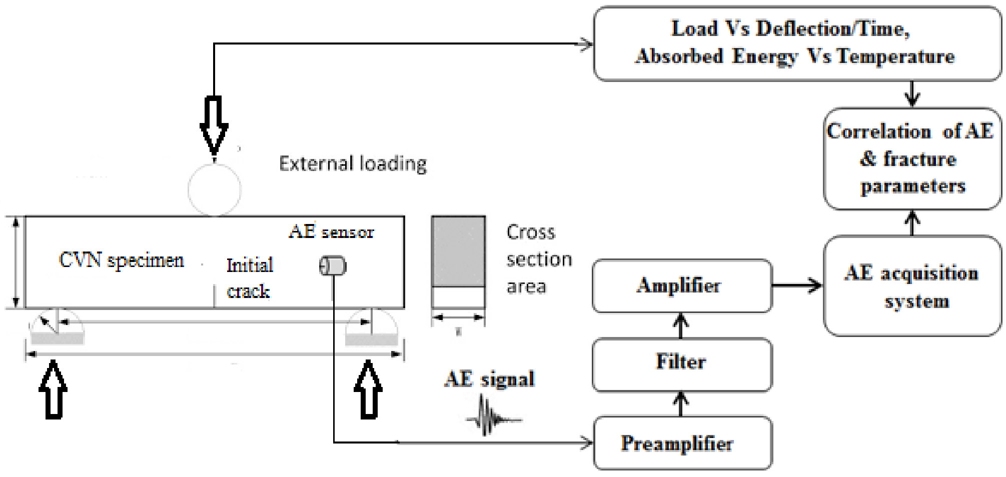


Figure 2. The schematic experiment setup of the TPBT

2. RESULTS AND DISCUSSIONS

Fig.3 shows the load- deflection curves obtained during the TPBT tests of three CVN specimens with different thickness at the ambient temperature. Four curves have similar shape and the load increases with the specimen thickness. All the specimens exhibit ductile fracture behavior.

Table.3 lists the load at yield and the maximum load for three specimens with different thicknesses. As the specimen thickness decreases from 7.5 mm to 3.3 mm, the Maximum load decreases from 9850 to 3205 Fig.2 plots the load (P max) as a function of the specimen thickness.

Table 3. Experimental results for testing at ambient temperature.

Specimen thickness, B [mm]	Load at general yield P_{yield} [N]	Load at maximum P_{max}, [N]
7.5	7050	9850
6.7	6500	8050
5.0	4250	5500
3.3	2850	3250

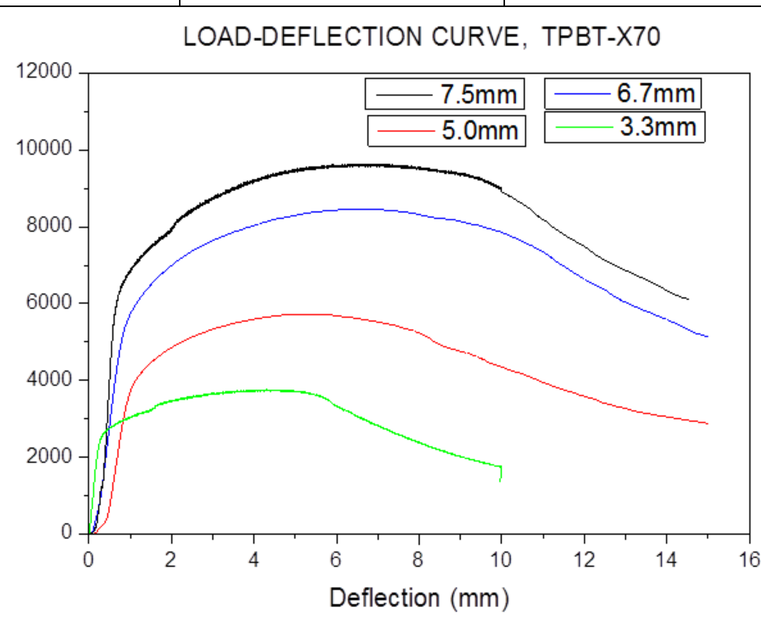
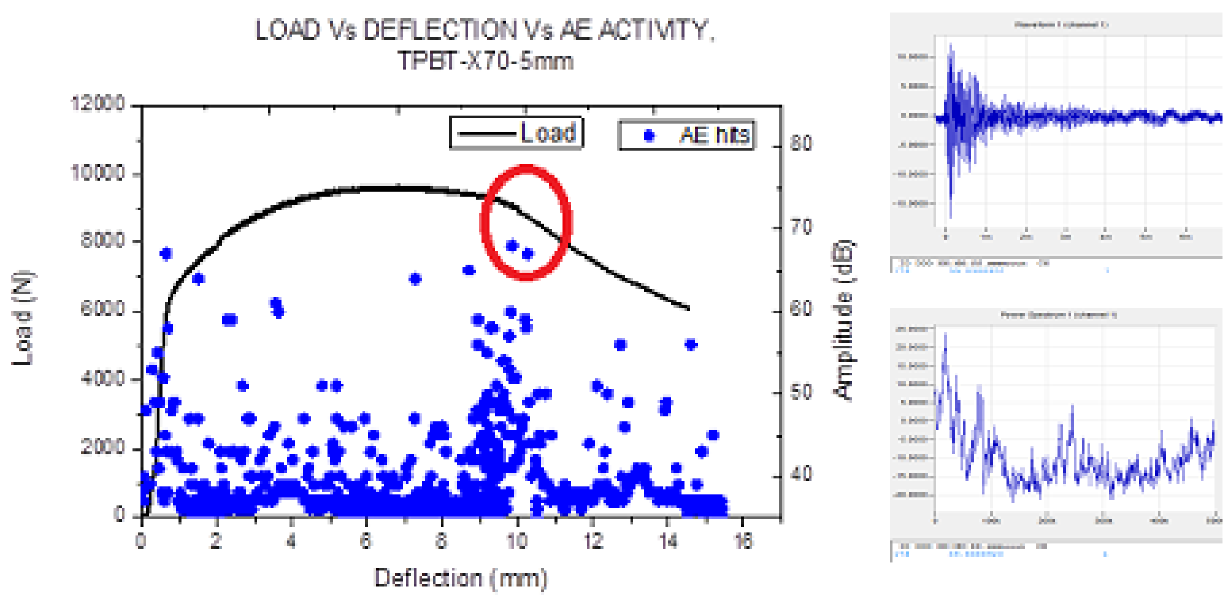


Figure 3. Typical Load-Deflection curve for TPB test at ambient temperature of specimens with various thicknesses.

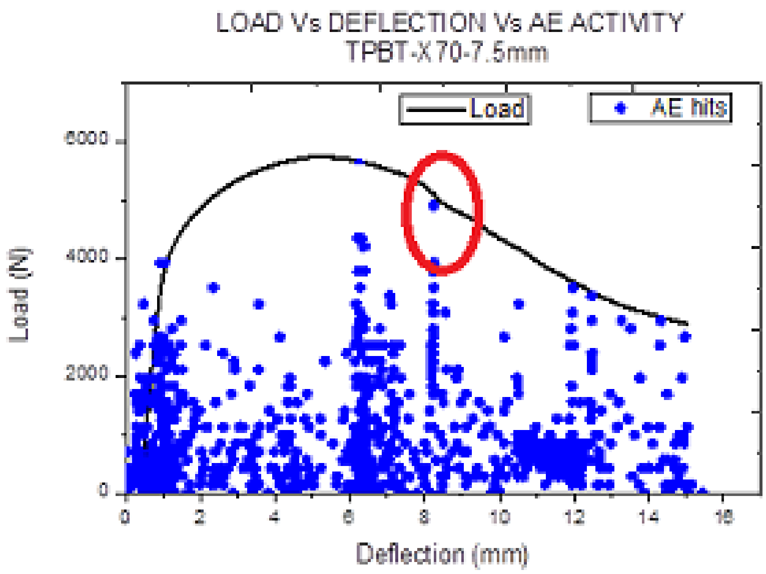
In this study the AE monitoring technique was used to investigate the effect of CVN specimen thicknesses. Load-Deflection curve for TPB test at ambient temperature of specimens with various thicknesses is shown Fig.3. For the AE signal analysis, the load-deflection curve was divided into three regions: 1- before the yield point, 2- between the yield point and the peak load, and 3- after the peak load. The AE signals of 5 mm and 7.5 mm CVN specimens are shown in Fig.4 and Fig.5, respectively.



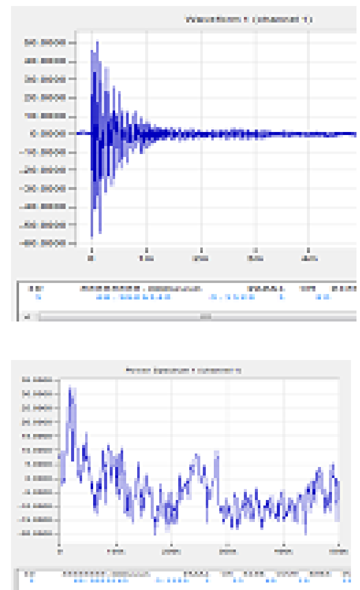
a. b.

Figure 4. The AE activity corresponding to the load-deflection curve obtained during testing of three point bending test (a) and its selected AE signal waveform and power spectra (b) corresponding to fracture initiation for CVN specimen with 5 mm thickness.

For 5 mm specimen, in Region I, a AE signal with a amplitude value of 20 is observed and the average frequency is in the range of 50-80 kHz. This frequency value is lower than the full size specimen. In Region II, a burst AE signal with 50-60 dB amplitude and an 90-100 kHz average frequency is generated before the maximum load. This signal is associated with fracture initiation. In Region III, the load drops and continuous AE signals with the average frequency in the range of 50-100 kHz are generated.



a.



b.

Figure 5. The AE activity corresponding to the load-deflection curve obtained during testing of three point bending test (a) and its selected AE signal waveform and power spectra corresponding to fracture initiation (b) for CVN specimen with 7.5 mm thickness.

In contrast, for the 7.5 mm specimen, the AE signal with high amplitude of 30-40 dB is generated and the average frequency is in range 60-80 kHz due to general yielding. In Region II, a burst AE signal with short duration and the average frequency of 150-200 kHz was observed. In Region III, a continuous signal with 50-70 dB amplitude and 80-100 kHz average frequency is generated. This is consistent with the finding in (Akbari 2010). The AE intensity observed in 7.5 mm specimen in Region III (between the maximum load and end of test) is relatively higher compared to the 5 mm specimen in the same region.

The AE signals of 5 mm and 7.5 mm CVN specimens are shown in Fig.4 and Fig.5, respectively. When the load reached 4000 to 5000 N, a few burst signals were generated due to the plastic deformation and the stress concentration at the crack tip. Just after the load attained its maximum value, a strong burst AE wave was observed for both CVN specimens 5 and 7.5 mm. Such AE phenomena corresponded to fracture initiation it was because the deformation smoothed out and destroyed some of the dimples. It has been found that before the peak load, a strong AE burst with larger amplitude, marked by a circle in the figure Fig.4 and Fig.5, was observed. Fig.4 and Fig.5 shows its whole AE signal waveform and power spectra. The fracture initiation identified by a strong AE burst signal with amplitude of 60-75 dB and an average frequency of 300-350 kHz. It is believed that these signals correspond to the fracture initiation. Such high amplitude AE phenomenon for crack initiation was recognized by 64 % total 15 of the tests performed.

CONCLUSIONS

It is believed that this work will help to achieve deeper understanding of fracture behavior of line pipe steel and can be concluded as follows:

1) The CVN specimens of X70 line pipe steels have been conducted at different specimen thicknesses at room temperature. In order to analyze the results, the measured load-deflection curves are divided into three regions: Regions I, II and III.

2) As the specimen thickness decreases from 10 mm to 5 mm, in Region I, the AE signal amplitude decreases from 40 dB to 30 dB and the average frequency range is in the range of 50-80 kHz. In Region II, the AE signal average frequency decreases from 200 kHz to 100 kHz. In Region III, AE amplitude decreases from 75 dB to 60 dB and the average frequency decreases from 200 kHz to 100 kHz.

4) It is impossible to observe directly the fracture initiation in the CVN impact test. Reason for that the quasi-static three point bending tests using the same CVN specimen have been carried out. It has been found that the fracture initiates before the peak load. During tests the strong AE signals were observed before the peak load. It is believed that these strong AE signals correspond to fracture initiation.

5) The fracture behavior of a line pipe specimen can be predicted using AE waveform and Power spectra methodology. It has been found that the fracture modes are characterized by the value of peak frequency. The range of 50 kHz-200 kHz corresponds to ductile fracture and the range of 250 kHz-350 kHz are indicative of the brittle fractures.

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