The Journal of Applied Science
วารสารวิทยาศาสตร์ประยุกต์
ISSN 1513-7805 Printed in Thailand

Vol. 16 No. 2: 15-22 [2017]
doi: 10.14416/j.appsci.2017.12.001

Research Article

Bendability evaluation of sheet metals in three-point bending test by using acoustic emission features

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Received: 7/11/2017; Accepted: 1/12/2017

Abstract

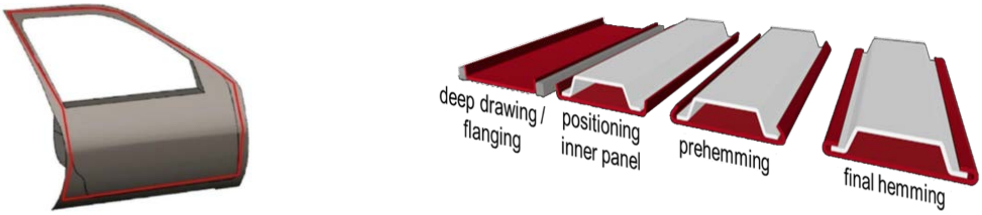
In this work, bendability evaluation of three sheet metals, a galvanized steel (JAC780Y), a stainless steel (SUS304) and a cold rolled steel (SPCC) was precisely investigated using an acoustic emission (AE) technique. A three-point bending test, with three different punch plate radii, was performed to evaluate the formability of the metal sheets in bending and hemming processes. Bending force–displacement curves were derived from the results of the tests and were correlated with AE features (Root Mean Square and Peak-to-Peak) that were extracted from data obtained during those tests. These correlations showed for the first time that AE techniques could be used to detect an intercrystalline fracture from bending behavior and also to evaluate the bendability of the given materials.

Keywords: bendability, acoustic emission, sheet metal, three-point bending

Introduction

In manufacturing, automotive body panels, consisting of inner and outer panels (skins), are normally assembled by bending and hemming processes as illustrated in Figure 1. Cracks can sometimes be found along the edges of the stamped panels where bending and hemming have taken place. Thus, the investigation of bendability of sheet metals is of great importance to evaluate process robustness for the production of mechanically-joined sheet metal assemblies. The classical material properties commonly used to assess the deep-drawing process can be used to describe the material failure in bending process although they have different failure mechanisms. However, the Bending Limit Curve (BLC) based on the assessment of deformation changes at the bending edge, is often used as mentioned in Panich (2017) and Saxenal et al. (2017).

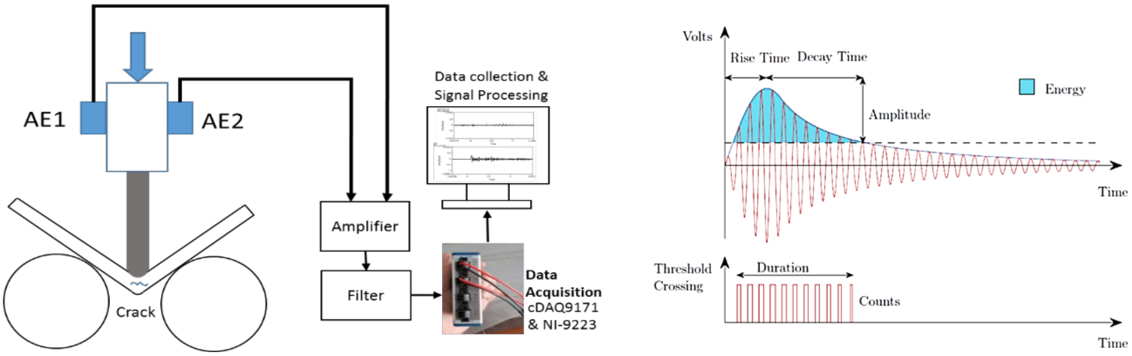
The acoustic emission (AE) technique is based on detecting sound (frequency range of 20 kHz to several MHz) in metallic materials generated by cracking, deformation, slip-band formation and dislocation movement. AE monitoring techniques can be applied in various applications such as machine condition/structure health monitoring, and tool condition monitoring. Many studies have attempted to use this technique to monitor crack initiation in forming process by investigating AE activities or extracted AE features (Grosse, 2008; Behrens et al., 2011; Behrens et al., 2016). They suggested that the extracted AE features could be used to indicate crack initiation and growth during the deformation process. The technique was used to characterize bendability in terms of crack initiation, which was practically used to describe formability under pure or combined stresses in deep-drawing and stretch drawing as bending behaviour. AE techniques have also been used to monitor external cracks of Q235 steel box beam during the bending test (Wu et al., 2008) and to detect cracks of galvanized steels during the three-point bending tests (Gallego et al., 2010).



(a) (b)

Figure 1. (a) The edges of an automotive panel (solid line) which are subjected to bending/hemming operations, (b) Schematic illustration of the process chain for producing a hemmed joining

Figure 2a showed the block diagram of the AE monitoring system used in this study. An AE monitoring system typically comprises: AE sensor, signal-conditioning units (amplifier and filter), data acquisition, and data processing. Generally, raw AE signals are extremely large due to high sampling rate required for anti-aliasing of the signal in data collection. Therefore, traditional AE features/parameters, such as RMS, peak-to-peak, peak count or cumulative count (Figure 2b) have been widely used to represent the AE activities and to correlate with the physical properties.



(a) (b)

Figure 2. (a) Diagram of AE system used in this study, (b) Typical AE features of a burst signal

This work proposed a method of online monitoring by using an AE technique to evaluate bendability and to determine crack in three types of steel sheets, namely high-strength steel, stainless steel, and deep drawing steel. The bendability was experimentally determined using three-point bending test with varying punch plate radius. The influence of the bending radii on the bendability and AE signals during the test were investigated.

Materials and methods

Testpiece material, test rig, and testing machine

Bendability evaluation was precisely investigated on 3 different steels commonly used in sheet forming processes: a galvanized steel (JAC780Y), a stainless steel (SUS304), and a cold rolled steel (SPCC) as they offered different levels of bendability. The chemical composition of selected sheet materials is listed in Table 1. The square shape workpiece (60 x 60 mm) with the thickness of 1.0 mm was prepared using shearing machine. The three-point bending tests according to VDA 238-100 (Saxenal et al., 2017; Panich, 2017) were conducted with varying punch plate radii (0.4, 1, and 2 mm) due to obtaining the sufficient difference of bendability levels (Figure 3). The testing apparatus was set up on a 25 tons universal 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 for all tests.

Table 1. Typical composition of testpiece materials (%wt, %Fe bal.)

JAC780Y

C	Mn	P	Cr	Ni	Mo	Si
0.123	2.706	0.01	0.192	0.009	0.064	0.016

SUS304

C	Mn	Si	Cr	Ni	P	S
0.08	1.5	1.5	18	8	0.1	0.1

SPCC

C	Mn	P	S			
0.12	0.5	0.04	0.045			

Figure 3. Roller die and varying punch radius used in the bending tests: 0.4, 1.0, and 2.0 mm.

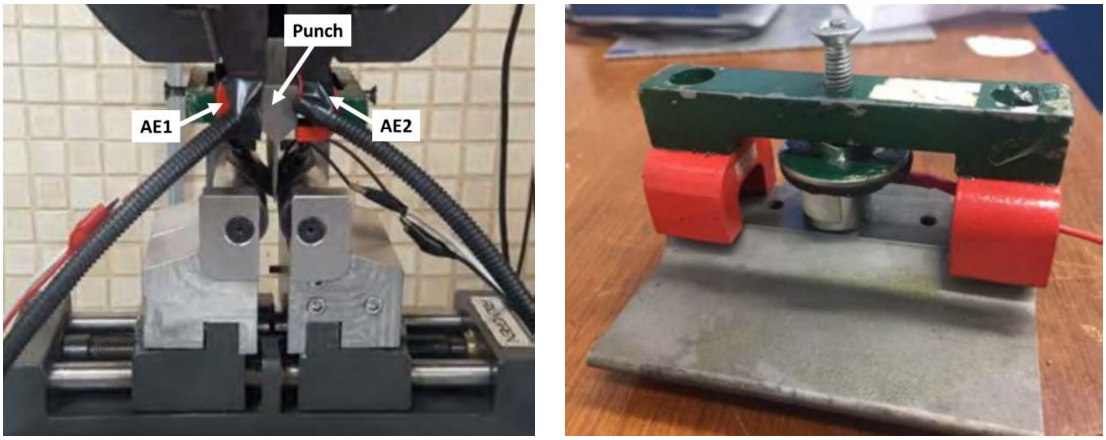
Data acquisition and AE features

As shown in Figure 2a, two AE sensors (R15S, PAC with capability of detecting in the 50-400 kHz frequency range), were used in this study as they were suitable for crack detection in metallic materials. Signal conditioners (60 dB pre-amplifiers and band pass filters) were used to improve the levels and quality of the acquired signals from both sensors before performing data processing. The conditioned signals were connected to a personal computer via NI-9223 and cDAQ-9170 for data collection and data processing. The scan rate of AE signals was 500 kS/s. Root mean square (RMS) value and peak-to-peak amplitude (AEp-p) were extracted from the raw AE signals during bending tests in order to investigate crack initiation and propagation. The data collection and post signal processing were performed by using LabVIEW software (National Instruments, USA).

Experimental procedures

The three-point bending tests with varying punch plate radius were performed on a tensile testing machine and a schematic setup of the experiment is demonstrated in Figure 4a. The bending force and displacement during the test were gathered by a load cell unit attached to the testing machine. The square specimen was placed on two rollers in such a way that it was central and parallel to the bending punch. The specimen was bent with constant bending rate until crack occurred.

The bendability of sheet materials was precisely evaluated through the bending force-displacement and displacement of crack occur. Concurrently, the sensors were mounted on two sides of the punch by magnetic clamps as shown in Figure 4b in order to ensure detection of cracking signal in deformation zone of the testpiece. Industrial grease used as couplant substance was applied on the punch plate-sensor interface in order to improve acoustic transmission from the deformation zone to the sensors. The acquired signals were processed and sensory features were extracted to be correlated with the bendability data of test materials. The tests were repeated three times.



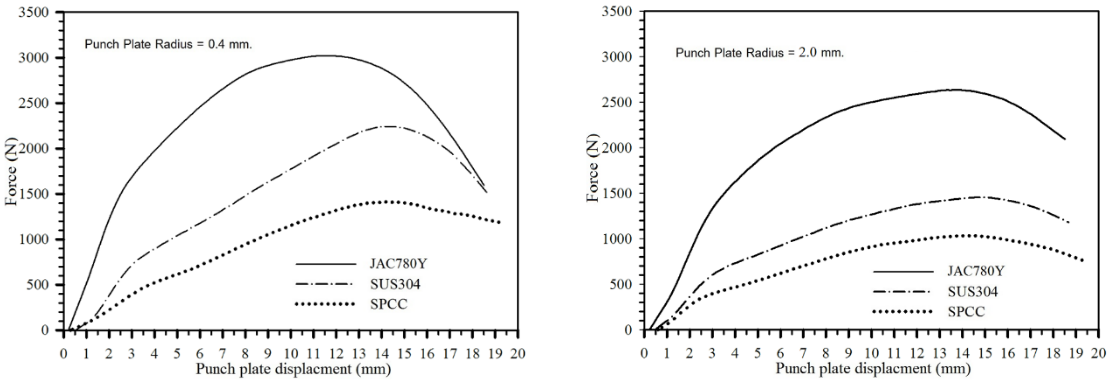
(a) (b)

Figure 4. (a) Experimental setup, (b) AE sensor mounting by magnetic clamps

Results and discussion

Bendability of workpiece materials

The bendability of investigated steel sheets is shown in Figure 5. By comparing the bending force-displacement curves, it could be seen that JAC780Y required maximum punch force and showed crack initiation before any other materials. This was because it had high strength, but low ductility and resistance to plastic deformation. On the other hand, SPCC used the minimum bending force and showed cracking on the outer surface (e.g. in Figure 6) later than other materials. The SUS304 had punch force between that of the JAC780Y and the SPCC, and its failure point was closed to SPCC. Thus, we concluded that SPCC had better bendability and formability than SUS304 and JAC780Y, respectively.



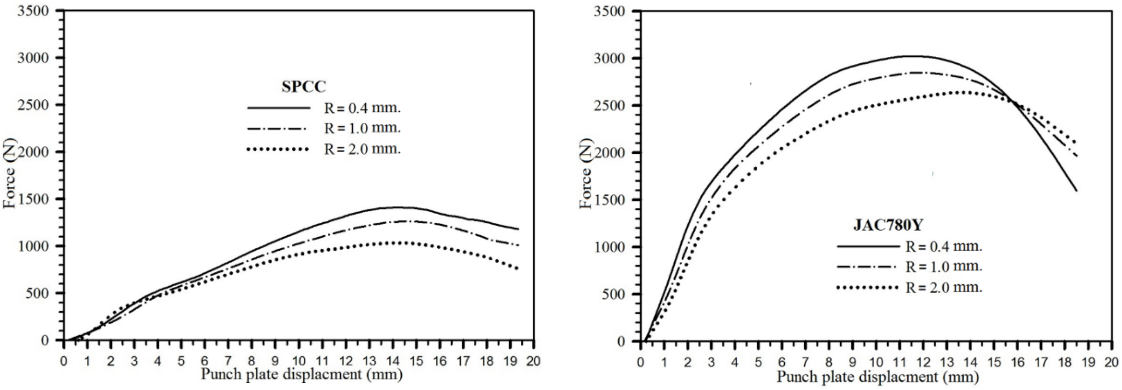
(a) (b)

Figure 5. Bending force - displacement (a) Punch plate radius 0.4 mm, (b) Punch plate radius 2.0 mm

Figure 6. Example of cracks on the testpiece

Effect of punch radius

Influence of punch radius on bendability was investigated in terms of bending force as depicted in Figure 7. Clearly, use of the larger punch plate radius resulted in a lower bending force and the presence of cracks could be found later than in the case of smaller radius. It was due to the fact that a punch with larger radius had smaller punch-plate contacting area, or the curve of punch radius could not fully contact the radius area of bending edge, resulting in lower contact pressure as well as lower shear force on the contacting area. On the other hand, a punch with smaller radius could exert higher contact pressure due to large contacting area to cover the area of bending edge. This required higher bending force. Additionally, the smaller punch led to higher stress concentration to the bending point. The workpiece materials were consequently easy to crack due to excessive stress over yielding.



(a) (b)

Figure 7. Bending force-displacement with punch radii 0.4,1.0, 2.0 mm:
(a) SPCC, (b) JAC780Y

AE features and bendability

Observations made during the experiments confirmed that that all of the AE sensors could detect a change in plastic deformation as well as the signals emitted by the samples during cracking. The typical AE signal during the bending test is presented in Figure 8. It could be seen that the AE signal during bending test consisted of continuous and transient (burst) signal types. The continuous signal representing acoustic sound emitted from deformation process of samples as higher signal amplitude could be recognised from the punch engaging to the sample throughout the end of applied bending, while burst signals representing cracks were initiated and propagated in the sample during the bending test.

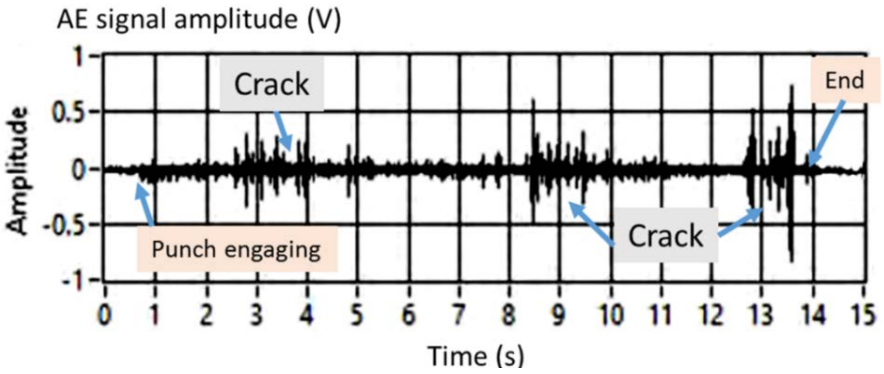
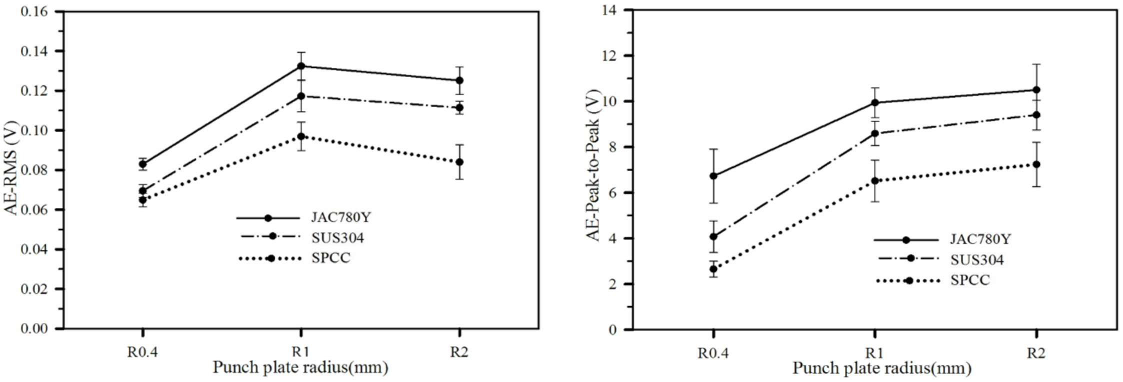


Figure 8. Typical AE signals during three-point bending test

Many AE features were extracted from the raw signals in order to correlate with the formability of sheet materials. However, only two significant features were identified and presented here (Figure 9).

Root mean squared values (AE$_{RMS}$) representing an average signal are commonly used to correlate with physical properties. Figure 9 illustrated an interesting feature where the higher bendability metals had lower AE$_{RMS}$ values. AE$_{RMS}$ extracted from the highest bendability material (SPPC) had the lowest values when compared to other materials and this result was in agreement with other punch radii. This could be explained by considering that sheets with high bendability also had high ductility. Therefore, they were capable of elongating the workpiece without crack formation compared to low bendability (e.g. JAC780Y). Cracks were easily initiated in JAC780Y during bending test resulting in high signal amplitude of AE burst type. This had a major influence on high RMS value in JAC780Y.



(a) (b)

Figure 9. AE features correlated to bendability: (a) AErms, (b) AEpeak-to-peak

AE$_{peak\text{-}to\text{-}peak}$ is generally used to represent the level of signal energy emitted from cracks in materials. The results in Figure 8b showed the lower bendability material (JAC780Y) had higher peak-to-peak amplitude as the cracks in this material could easily occur with high stress energy, while the cracks in high bendability material (SPCC) had lower peak-to-peak amplitude.

It was proposed based on the data in Figure 9 that the punch radius had a direct influence on AE signals as AE features extracted from the larger punch radius had higher values compared to the smaller ones. This was assumed that AE signal could be transmitted easily in the larger punch-workpiece contact area and the use of large punch radius promoted more material deformation and cracks than smaller radius. Also, AE signals in deformation zone were attenuated in case of using smaller punch radius or contacting area.

Conclusion

The relationship between acoustic emission features and bendability of three types of sheet metals (SPPC, JAC780Y, and SUS304) during the three-point bending test were investigated. Some sensing features extracted from the raw signals were used to correlate with formability and to detect crack initiation in samples. These led to the conclusion that:

1. JAC780Y had the lowest bendability and it was the most difficult to bend and easy to crack as it had higher strength compared to SUS304 and SPCC.
2. The punch radius had a direct influence on contact pressure or shear force between punch surface and workpiece where larger punch radius required lower bending force compared to lower punch radius.

3. AE_{RMS} extracted from AE continuous type was a meaningful feature commonly used to represent the crack initiations and propagations during plastic deformation in bending test. AE burst type signal was used to indicate cracks in metal sheets.

4. Bendability of sheet materials could now be evaluated by AE_{RMS} and $AE_{peak\text{-}to\text{-}peak}$ effectively. AE_{RMS} and $AE_{peak\text{-}to\text{-}peak}$ were low in the case of high bendability materials subjected to bending load, and the features were high for high strength or low ductile materials.

Acknowledgements

The experimental facilities and financial support of this research have been supported by the Department of Production Engineering, KMUTNB and Department of Mechanical Engineering, University of Sheffield. Also, the authors wish to express our appreciation to Mr. Kraisit Sarakham and Mr. Punnachai Meknopparat for their support regarding some experimental tests.

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