Simple prediction method for the edge fracture of steel sheet during vehicle collision (1st report)

- Evaluation of fracture limit from the edge using small-sized test pieces -

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Summary:

At vehicle collisions, fractures occur from the edge of steel sheet. Existence of any fracture has an influence on the accuracy of vehicle crash simulations. In order to obtain a simple evaluation index of the fracture limit, fracture limits around the holes processed using several methods were measured. It was clarified that these fracture limits are represented by a combination of the elongation and the hole expansion ratio of steel sheet.

Keywords:

Safety, CAE, Steel Sheet, Collision, Fracture, Edge, Piercing, Laser cutting, Milling

1 Introduction

While CAE technology has been used increasingly in the automobile development process, CAE technology during vehicle collisions has been extensively used to ensure the crash performance, and it is now a critical technology to shorten the vehicle development period and to achieve an advanced balance between a target performance and weight reduction.

It is noted that a fracture, if any, in a vehicle structure member during vehicle collisions, the deformation mode of the vehicle collision changes, and it is supposed that the vehicle deformation mode is diffrent from the result of FEM. Prediction of the fracture behavior using CAE has been attempted by various theoretical approaches [1)]. Some vehicle structure members of steel sheet may fracture from the edge at vehicle collisions, however, fracture limits originating from the edge of the steel sheet may vary significantly depending on the edge processing conditions[2) 3)]. This makes theoretical simulation difficult.

In order to obtain the simple evaluation index of the fracture limit for such a behavior that some steel sheet parts fracture from the edge at vehicle collisions, fracture elongation around hole edges was experimentally determined for various types of steel sheet including high strength steel sheets, using small sized test pieces having a hole processed using several methods. Then, research was done to determine which properties of steel sheet can represent these fracture limits.

Table 1. Mechanical properties of steel sheets

Class	Coating	t mm	YP MPa	TS MPa	EL(%) GL=50mm
JAC270D	GA	1.4	180	292	49
JAC440W	GA	1.4	380	452	36
JAC590(High YP)	GA	1.4	463	614	27
JAC590(Low YP)	GA	1.4	373	598	28
JSC780Y	Cold	1.4	518	831	18
JSC980Y(Bending)	Cold	1.4	823	982	13
JSC980Y(Drawing)	Cold	1.4	696	1074	17

2 Tests method

2.1 Material

Seven different types of steel sheet 1.4mm in thickness and270 to 980MPa in tensile strength were used. The mechanical properties of the test material are shown in Table1.

For 590MPa grade, two types of steel sheet were used: High yield stress and low yield stress types, which could be determined by controlling the microstructure of the steel sheet. For 980MPa grade, two types of steel sheet were used: Bending and drawing types with different forming properties suitable for bending and deep drawing, respectively.

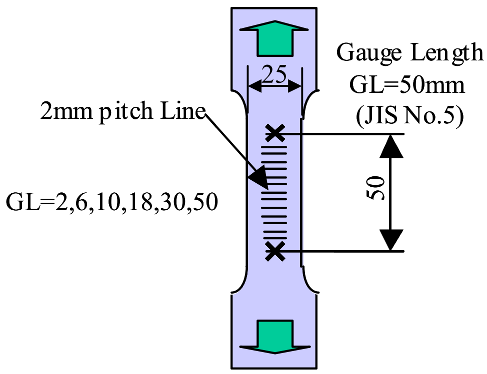

Fig.1 Schematic of tensile test (JIS No.5)

2.2 Test conditions

Relations between the basic mechanical properties of steel sheet and the fracture limits from the edge of steel sheet were examined by carrying out the following three types of tests.

2.2.1 JIS No. 5 tensile test

To examine the tensile property of steel sheets, tensile tests were carried out with n=3, using the JIS No. 5 test pieces (JIS Z 2201 and 2241) shown in Fig.1, which were marked with lines at a 2mm pitch across a gauge length (GL) of 50mm, which is used to measure the elongation in the standard. After the tensile tests, fracture elongation was measured at the fracture points for GL=2, 6, 10, 18, 30 and 50mm.

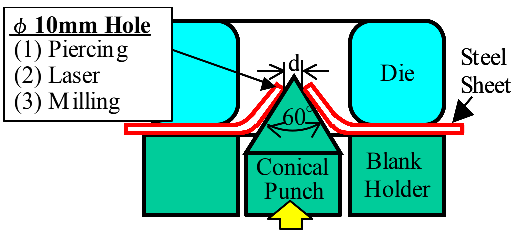

Fig.2 Schematic of hole expanding test

2.2.2 Hole expanding test

The generally used hole expanding test (Japan Iron and Steel Federation Standard JFST1001) was carried out to examine the stretch flangeability of steel sheet. This test expands the hole of 10 mm in

Fig.3 Appearance of a test piece after hole expanding test

diameter generally processed by piercing on steel sheet until a crack from the hole edge penetrates completely in the thickness direction, using a cone punch with a cone angle of 60 degrees. Fig.2 shows a schematic of the hole expanding test, while Fig.3 shows a test piece after the test. The hole expansion ratio λ is determined by equation (1), which represents the stretch flangeability.

Hole expansion ratio $\lambda = (db - do) / do \times 100$ (%) (1)

Where, do: Original hole diameter (10 mm), db: Hole diameter after rupture

The edges and holes of steel sheet parts are mostly processed by piercing in mass production; however, they are processed by laser cutting or milling in many cases in a trial production stage. For this reason, holes were processed by three different methods to clarify the influence of the hole-processing method on the λ-value: Piercing, Laser cutting, and Milling. When piercing, the clearance between a punch and die was set to be 14% of the thickness of steel sheets for every case, and the hole expanding test was carried out with n=5.

To examine the influence of the hole edge processing history on the fracture limit around hole edges, the hole areas were cut out from every test piece to observe the microstructure, as well as to measure the hardness distribution.

2.2.3 Hole tensile test

The purpose of the hole tensile test is to simulate the case when a steel sheet fractures from the hole edge as though it were being torn during a vehicle collision. It uses test pieces 40 mm in width, as shown in Fig.4, which have a hole 10 mm in diameter at the center processed using three different methods in the same way as for the hole expanding test. Tensile strain was applied at a rate of 10 mm/min using a tensile test machine, and it was stopped when any fracture occurred from the hole edge. This test was carried out with n=3 for every processing method.

The potential fracture area around the hole edge was marked with lines of GL=2.0mm in advance, and the strain around the fracture was measured at 1 mm away from the hole edge.

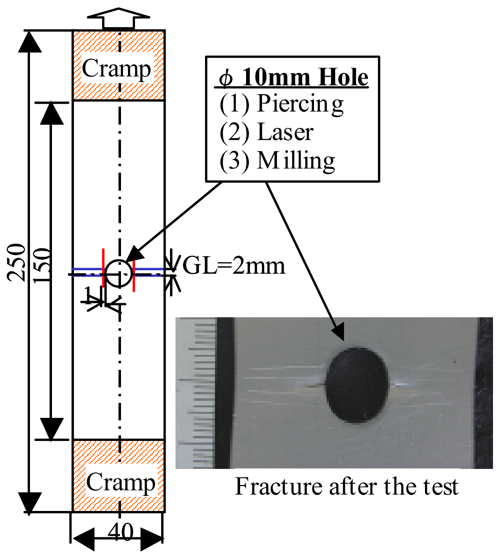

Fig.4 Schematic of hole tensile test

3 Test result

3.1 JIS No. 5 tensile test

Fig.5 shows the fracture elongation measured for every gage length after the JIS No. 5 tensile tests. For every steel sheet, when the gage length is smaller, the fracture elongation increases, because the local necking proportion in the range of the gauge length increases. As for JSC980Y, the drawing type suitable for deep drawing shows a higher fracture elongation than the bending type for GL=50mm, while the bending type suitable for bending shows a higher fracture elongation than the drawing type for GL=2 mm. This means that the influence of the gage length on the fracture elongation may vary depending on the microstructure of the steel sheet.

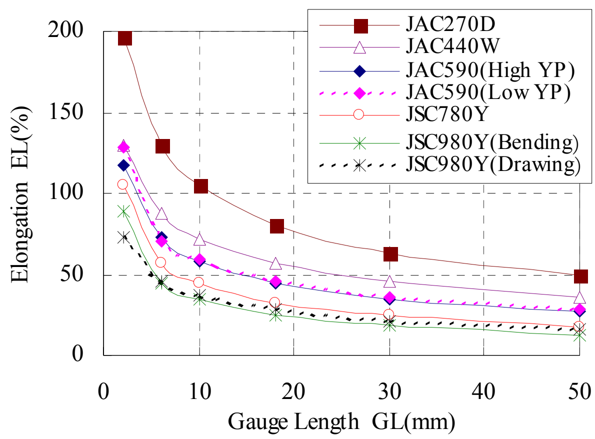

Fig.5 Relation between elongation (EL) and gauge length (GL) on tensile test

3.2 Hole expanding test

Fig. 6 shows the hole expansion ratio λ for every steel sheet after the hole expanding test. The λ-value for the holes processed by milling decreases almost uniformly as the tensile strength increases, while the λ-value for the holes processed by piercing has less correlation with the tensile strength and fluctuates significantly with some steel types, but not for JAC270D of mild steel. The λ-value for the holes processed by laser cutting has almost the same tendency as for the holes processed by milling, except for JAC440W.

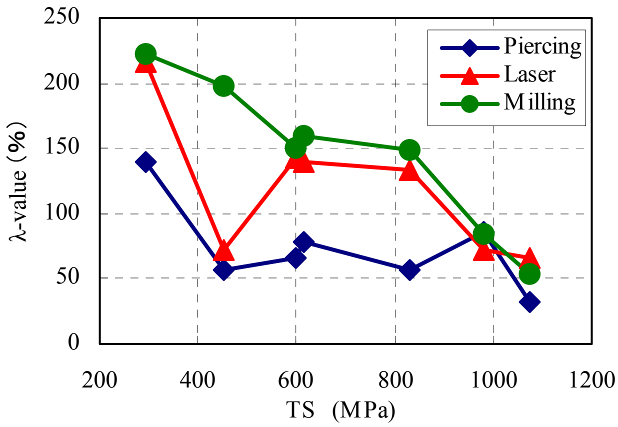

Fig.6 Relation between λ-value and tensile strength on hole expanding test

3.3 Influence of processing method on the microstructure at hole edges and the hardness distribution

Fig.7 shows a photo of the microstructure at a hole edge of JAC440W, and the hardness distribution from the hole edge measured in the center of the thickness. Fig.8 shows the relation between the hardness Hv and the λ-value at 0.05 mm away from the hole edge measured in the middle of thickness for every steel sheet.

The Hv around the hole edge almost never increases for the milling; however, it increases for the laser cutting in the range up to 0.2 mm away from the edge, and also for the piercing it increases due to the influence of processing. The λ-value decreases as the Hv increases for all the cases; however, milling in which hole edges seem not to be damaged at all is different from the laser cutting and the piercing in the λ-value decreasing behavior. This is due to the fact, for laser cutting, that the hole edge is influenced by heat during laser cutting, and for the piercing, that it is influenced by work hardening when shearing.

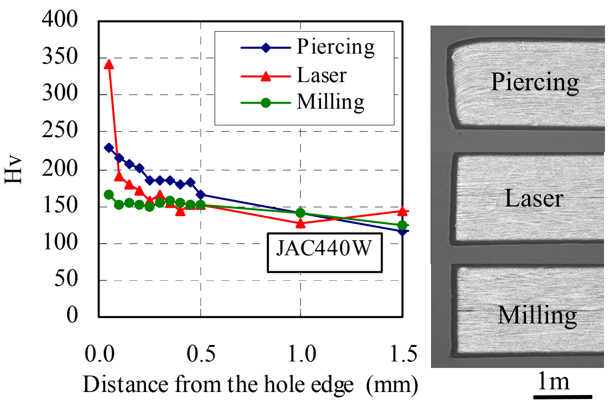

Fig. 7 Hv distributions and microstructures on the hole edge

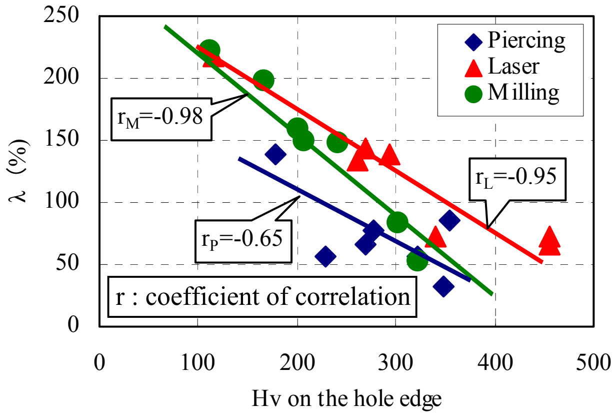

Fig. 8 Relation between λ and Hv on the hole edge

Thus, the fracture limit from hole edges cannot be evaluated only by a single mechanical property of the base material, but needs to take account of the influence of work hardening of the steel sheet microstructure around hole edges, as well as changes in the microstructure influenced by heat.

3.4 Hole tensile test

Fig. 9 shows a comparison of the fracture elongation for gage length GL=2mm(ELH2) at fractures during the hole tensile test. The fracture elongation around the hole processed by milling decreases almost

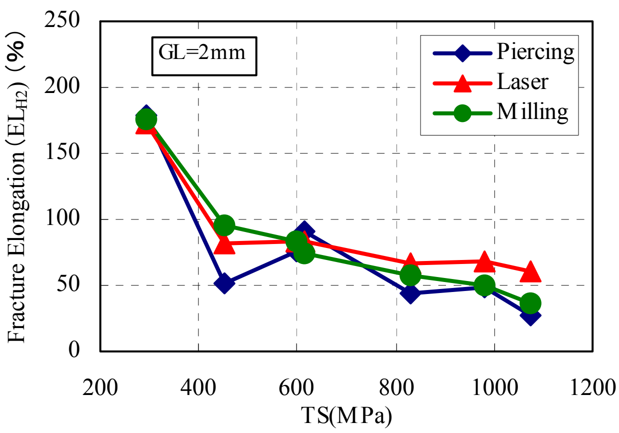

Fig.9 Relation between fracture elongation and tensile strength on the hole tensile test

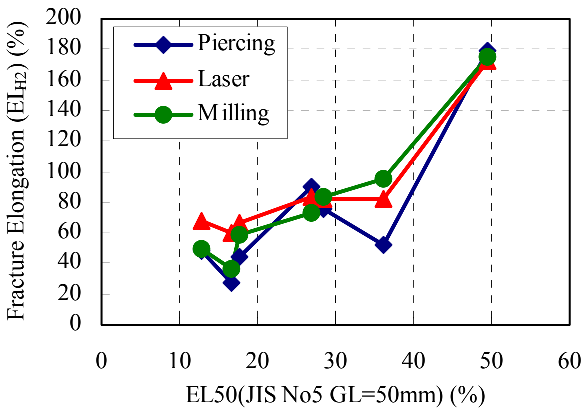

Fig.10 Relation between fracture elongation on hole tensile test and elongation (GL=50mm) on tensile test

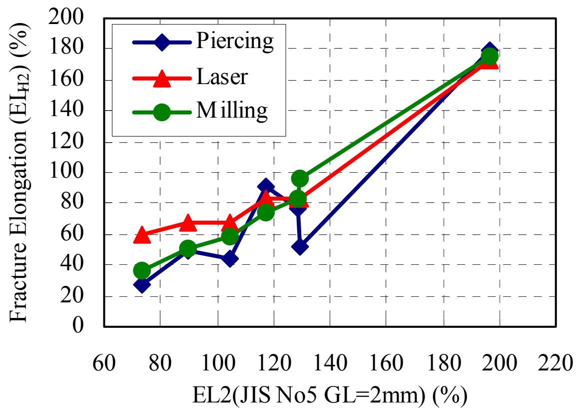

Fig.11 Relation between fracture elongation on hole tensile test and elongation (GL=2mm) on tensile test

uniformly as the tensile strength increases, in the same way as shown in the hole expanding test. The holes processed by laser cutting and piercing are somewhat correlated with the tensile strength, but are different from those shown in the hole expanding test.

4 Evaluation index of the fracture from hole edges

Whether or not the fracture limit from hole edges can be evaluated using some basic mechanical properties of steel sheet was examined. Relations of the fracture elongation for gage length GL=2mm (ELH2) in the hole tensile test, and results from the JIS No. 5 tensile test and the hole expanding test are shown in Fig. 10 to Fig. 12. The λ-value on the abscissa in Fig. 12 uses the test results on the holes processed using the same method as for the hole tensile test.

Evaluation based on the JIS No. 5 tensile test reveals a relatively good correlation between the milling and the laser cutting for both gage lengths of 50 mm and 2 mm; however, it fluctuates significantly for the piercing. Evaluation based on the hole expanding test, in consideration of the hole processing history, fluctuates significantly as shown in Fig. 12. These results prove that the fractures from hole edges cannot be evaluated properly using a single index of the mechanical properties of steel sheet.

Therefore, in consideration of the easy measurement of the test data, the elongation from the JIS No. 5 tensile test (EL50, GL=50mm) and the λ-value were combined as in equation (2), and appropriate parameters were fitted and obtained.

$$EL_{H2} = a \times \lambda^{b} \times EL50^{c} \qquad (2)$$

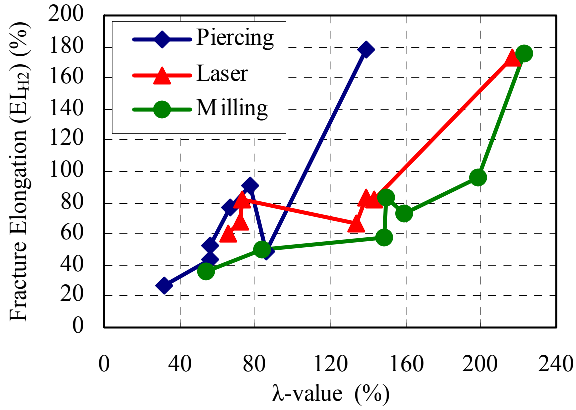

Fig.12 Relation between fracture elongation on hole tensile test and λ-value on hole expanding test

Table. 2 Coefficients of equation (2)

	Coefficients of Equation (2)			Correlation Coefficient
	a	b	c	r
Piercing	0.24	0.94	0.51	0.98
Laser	1.77	0.39	0.62	0.94
Milling	1.17	0.10	1.12	0.97

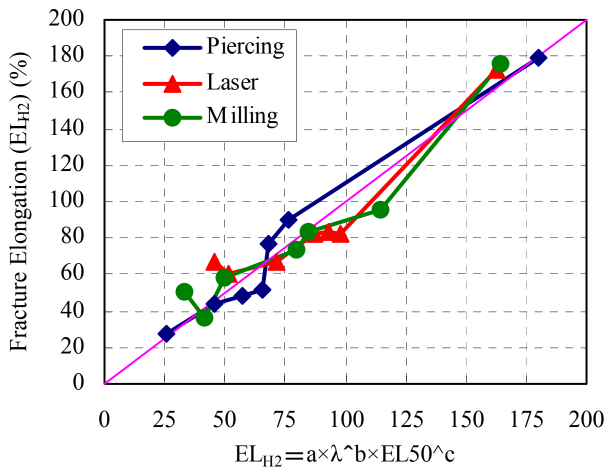

Fig.13 Correlation between measured and calculated fracture elongation (ELH2)

The fitted coefficients for respective processing methods are listed in Table. 2. Fig. 13 shows the relation between the EL_{H2} obtained from equation (1) and the EL_{H2} measured in the test. Both data show a good correlation. As for coefficient b to λ and coefficient c to EL50, the piercing has a high b-value, the milling has a high c-value, and the laser cutting has an intermediate value.

Consequently, it was clarified that the fracture limit could be evaluated simply in consideration of the hole edge processing history, with equation (2) using the mechanical properties obtained from general material tests for general purposes, such as the tensile test or the hole expanding test, without any special material test.

5 Conclusion

A hole tensile test was carried out to simulate the situation when part of a steel sheet fractures from the hole edge as though being torn during a vehicle collision, using strip test pieces with a hole. Then, the fracture limit was evaluated using some basic mechanical properties obtained from the JIS No. 5 tensile test and the hole expanding test. It can be concluded as follows.

(1) A fracture limit originated from a hole edge cannot be evaluated only with a single mechanical property, such as the λ-value, since the hole processing history has to be taken into consideration.

(2) An index that combines the elongation of steel sheet and the λ-value according to the processing history may be effectively used to carry out a simple evaluation of the fracture limit around hole edges.

6 Reference

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