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An Experimental Study on the Axial Impact Collapse Characteristics of Spot Welded Section Members

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ABSTRACT

The spot welded sections of automobiles (hat and double hat shaped sections) absorb most of the energy in a front-end collision. The target of this paper is to analyze the energy absorbing capacity of the structure against the front-end collision, and to obtain useful information for designing stage. Changed the spot welded pitches on the flanges, the hat and double hat shaped section members were tested on the axial collapse loads at various impact velocities. It was expected that para-closed sections would show collapse characteristics which be quite different from those of perfectly closed sections. Hat shaped section members were tested at the impact collapse velocities of 4.72m/sec, 6.54m/sec and 7.19m/sec and double hat shaped section members were tested at the impact collapse velocities of 6.54m/sec, 7.19m/sec and 7.27m/sec.

Keywords : Spot welded, Hat and double hat shaped sections, Front-end collision, Impact collapse, Collapse characteristics

1. Introduction

The purpose of automobile design is to satisfy the standards and the requirements of general performance, stability, calmness and firm handling. The ability to protect passengers in a car accident is influenced by the conditions of the collision, structural integrity and passenger protecting equipment. Front-end collisions, including the inclined collisions, amount to about 70 percent of all accidents. Thus, attention to safety has increasingly been focused on the front-end collisions in recent years[1,2].

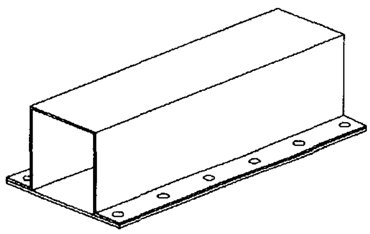
Section members in the front-head absorb most of the energy in a front-end collision. Many vehicles have been designed to absorb the impact energy during front-end collision through plastic deformation using hat shaped section members. It is important that we understand the characteristics of energy absorption and the collapse behavior of plastic deformation on a simple structure which endures a massive collision[3,4].

Studies on the collapse characteristics of spot welded section members are extended to analyze the mean collapse loads theoretically assuming they as perfectly seamless in section and to estimate the static mean collapse loads experimentally[5,6]. With the breakthrough developments of computer and finite element methods, many researchers have used computers to predict the collapse characteristics[7,8]. However, it is very difficult to analyze impact behavior of the section members theoretically ,because they are not closed except the area of the spot welded. And it is hard to find literature on defining the optimal conditions on the shift of spot welded pitch and the section dimension in the impact collapse.

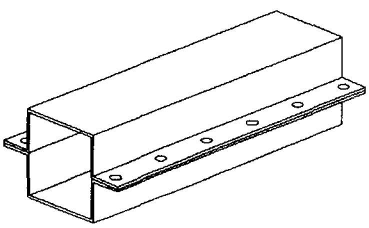
In this study, we analyzed the collapse characteristics of spot welded hat and double hat shaped section members under the impact collapse, at various spot welded pitches. In particular, the spot welded hat shaped section members were not perfectly closed sections but para-closed sections. Impact collapse experiments were performed with respect to the various impact velocities, because it was expected that para-closed sections would show collapse characteristics which be quite different from those of perfectly closed sections.

2. Specimens

The specimens, hat and double hat shaped section members, were manufactured by welding two parts as shown in Fig. 1 using SCP1 cold rolled sheet. Section members of 0.78mm thickness, width ratio of 30×30mm, and 12mm width flange were selected. By doing several preliminary tests, the length of 120mm was selected in order for Eulian buckling not to occur, and in order to obtain repetitive and agreeable experimental results. Three types of spot welded pitch were chosen; 18.3mm, 22mm and 27.5mm. Table 1 shows the material constants of specimens and Table 2 describes the specimens.



(a) Hat shaped section member



(b) Double hat shaped section member

Fig. 1 Configuration of the specimens

Table 1 Material constants of SCP1 cold rolled sheet

Yield strength [MPa]	Tensile strength [MPa]	Young's modulus [GPa]	Poisson's ratio	Elongation [%]
166.7	308.4	203	0.31	46.4

3. Impact Collapse Experiment

The axial impact collapse testing device, which uses compressed air is presented in Fig. 2, and a system diagram is shown in Fig. 3. In the impact collapse test, the cross head is pressured by the axial impact collapse testing device using an air pressure accelerator.

Table 2 Definition of specimens

H(D) E(F, G) I_n	
Type	H : Hat shaped D : Double hat shaped
Spot weld pitch	E : 18.3mm F : 22.0mm G : 27.5mm
Impact Velocities	n=0 : 4.72m/sec n=1 : 6.54m/sec n=2 : 7.19m/sec n=3 : 7.27m/sec

The testing device consists of an air pressure accelerator, a cross head, a load cell, base plate, an anti-vibration rubber, an air cylinder, guide bars and frames. The cross head, which is accelerated by the compressed air and guided by the four guide bars, drops and collides with the load cell. These four guide bars are designed to protect two-story cross head from colliding off-center with the testing specimen.

The cross head strikes the specimens and is a two-story structure which two mild steel plates (thickness of upper plate 18mm, thickness of lower plate 23mm, side length 320mm) are connected with four posts. The plate has a hole at each corner to lead four guide bars. The cross head weighs 40 kilogram. On its front side, a target is placed to measure the displacement, and on the opposite side a barrier is used to check the velocity.

The load cell is composed of two mild steel circle plates which are connected by a round column. Specimens are put on the upper plate and the lower plate has three holes to be fixed on the base. Two semiconductor strain gages (KYOWA, KSP-2-120 E4) are symmetrically placed on both sides of the load cell.

The load cell was designed to remove the bending effect.

In the tests, the impact loads were obtained by converting the electrical resistance variations on semiconductor strain gage into loads. In collision, the resistance variations on semiconductor strain gage going through the shield line and bridge box, are fed into a dynamic strain amplifier which converts the signal into variations of voltage. The signals are finally amplified.

Deformation on a specimen is measured by using an Optical Deformation System (ZIMMER OHG Co.) which captures the movement of target on the cross head.

The impact velocity was measured by a laser system before the cross head collided with the specimen. The relationship between the air pressure in the impact testing device and the impact velocity is shown in Fig. 4.

A load-displacement curve which showed the collapse history was obtained by eliminating the time axis from the measured time-load and time-displacement curves. The absorbed energy is equal to the area below the load-displacement curves, and is calculated by integrating the load with respect to the displacement, Eq. (1).

$$E_a = \int_{\ell_0}^{\ell} P\, d\ell \qquad (1)$$

where E_a is the absorbed energy in the specimen and P is the collapse load.

The mean collapse load (P_{mean}) is obtained by dividing the absorbed energy (E_a) by the displacement.

Based on the load-displacement curve, total absorbed energy (E_L), maximum collapse load (P_{max}) and deformed length (S) were derived. The absorption characteristics of each specimen was studied. The specimens did not collapse equally in length, though the cross head imposed the same impact energy under the same condition. It was assumed that specimens would collapse as much as the total length of 120mm in order to analyze the total absorbed energy quantitatively. The total absorbed energy (E_L) is given as below Eq. (2).

$$E_L = E_a \overline{J} \qquad (2)$$

where $\overline{J}\,(=L/S)$ is the inverse stroke efficiency, S is the deformed length and L is the total length before deformation.

The value of the impact energy (E_I) is similar to that given by Eq. (3): 446J at 4.72m/sec, 855J at 6.54m/sec, 1034J at 7.19m/sec and 1057J at 7.27m/sec.

$$E_I = \frac{1}{2} m v^2 \qquad (3)$$

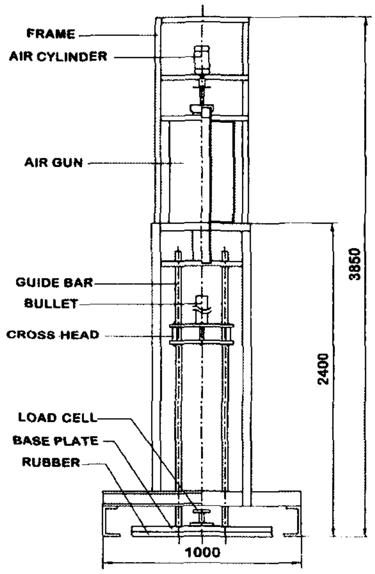


Fig. 2 Impact testing setup for crushing

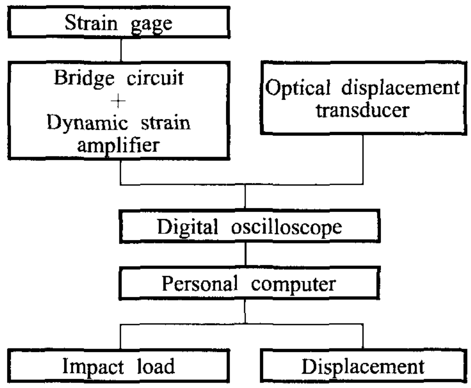


Fig. 3 Diagram of measurement system

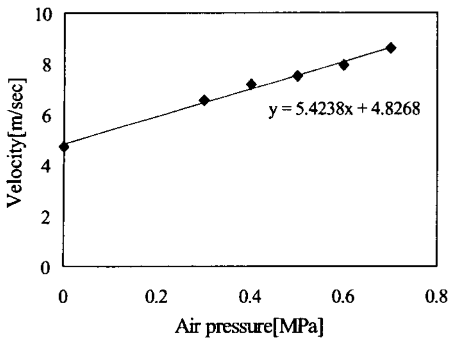


Fig. 4 Relation between air pressures and velocities

where m is the mass of the cross head (40 kilograms) and v is the impact collapse velocity.

The impact collapse velocities were selected as follows: the velocities in the hat shaped section members were 4.72m/sec, 6.54m/sec, and 7.19m/sec and those in the double hat shaped section members were 6.54m/sec, 7.19m/sec, and 7.27m/sec. The velocities were selected due to the energy absorbing capability of section members during the impact collapse. The higher velocity could not be selected owing to the limits of energy absorbing capability of section members.

Figure 5 is the load-displacement diagrams of hat and double hat shaped section members with a spot welded flange pitch of 18.3 mm which were acquired from the impact test(impact velocities of 7.19m/sec and impact energy of 1034J). The solid line is for the double hat shaped section member and the broken line is for the hat shaped section member. Fig. 6 represents the shape of collapsed specimens of hat and double hat shaped section members with a spot welded flange pitch of 18.3mm which were collapsed at a velocity of 7.19 m/sec and were imposed collapse energy of 1034J. Fig. 6 (a) is the shape of collapsed hat shaped section members and Fig. 6 (b) is that of collapsed double hat shaped section members.

4. Results and Discussion

In Table 3, the absorbed energy (E_a), total absorbed energy (E_L), mean collapse load (P_{mean}), maximum collapse load ($P_{max.}$) and deformed length (S) in the experiment are compared with respect to various section dimensions. In Fig. 7, the mean collapse loads of the hat and double hat shaped section members are compared with respect to the variations of the spot welded pitch on the flanges at respective velocities. In Fig. 8, the mean collapse loads of the hat and double hat shaped section members are compared with various velocities (impact energies) at spot weld pitches.

In Fig. 7, in the hat and double hat shaped section members at the respective velocities, the larger the flange welded pitch is, the lower the mean collapse load is. And, the decrease ratio of mean collapse load upon increasing welded pitch in the double hat shaped section members appears higher than that in the hat shaped section members. The collapse characteristics of the hat and

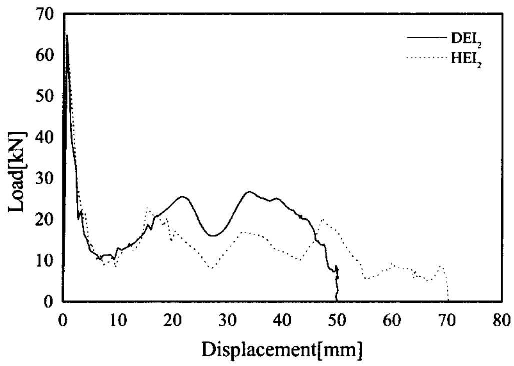
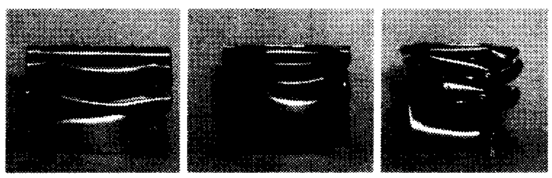
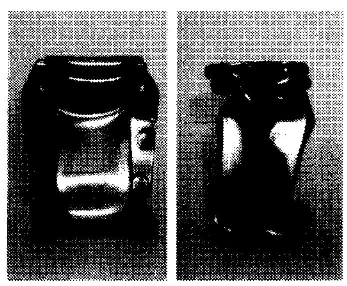


Fig. 5 Relationship between load and displacement



(a) HEI_2



(b) DEI_2

Fig. 6 Shape of collapsed specimens

double hat shaped section members is affected by the size of welded pitch, but the hat shaped section members are not greatly affected by the size of welded pitch because the welding line is some distance away from the center-line of the collapse load. In the double hat shaped section members, the strength between the section member of ⊏-shape and that of flange increases significantly with the welded pitch because the welding line is at the action point of the collapse loads. For this reason, while the hat shaped section members are easy to collapse sequentially, the double hat shaped section members are difficult to be expected to do in the sequential collapse mode. Therefore, because these effects in the double hat shaped section members are greater than those in the hat shaped section members, the larger the welded pitch is, the larger the decrease ratio of the mean collapse load is.

Table 3 and Fig. 8 show the relationship between velocity change and mean collapse load at the respective spot welded pitches. In the case of the hat shaped section members, the mean collapse load increases as the velocity increases. but in the case of the double hat shaped section members, the mean collapse load decreases as the velocity increases. The reason is as follows, and is similar to the explanation of the collapse characteristics with respect to welded pitch, the welded line in the hat shaped section members is some distance away from the center-line of the collapse load, and that in the double hat shaped section members is at the action point of the collapse loads. In the hat shaped section members, if the velocity increases, the kinetic energy increases and the sequential collapse is as expected. On the first impact, the first damage to the hat shaped section members is less than that to the double hat shaped section members, because the number of corners in the hat shaped section members is half of those in the double hat shaped section members. Therefore, in the case of hat shaped section members, the characteristics of spot welded section members do not appear greatly, because the sequential collapse mode occurs under impact collapse at a certain velocity, as the perfectly closed section members do. But, in the case of the double hat shaped section members, as the velocity increases the mean collapse load decreases, because it cannot be expected to collapse sequentially as shown in the hat shaped section members and the limit of spot welded section members appears at lower impact collapse velocities. This result shows that increased strength is important during impact collapse, but the inducement of sequential collapse is more important than that.

Also, the maximum collapse load did not appear to depend upon changing flange welded pitch, but in the hat and in the double hat shaped section members, the higher the impact collapse velocity is, the higher the maximum collapse load is.

On examining the results of the collapse characteristics with respect to welded pitch and the impact collapse velocity in the hat and double hat shaped section members, the total absorbed energy and mean collapse load in the double hat shaped section members are about 51% higher and the maximum collapse load is about 4.7% higher than those in the hat shaped section members under the impact collapse velocity of 6.54m/sec. Also, the total absorbed energy and mean collapse load in the double hat shaped section members appear about 39% higher and the maximum collapse load is about 6.5% higher than those in the hat shaped section members under the impact velocity of 7.19m/sec.

Table 3 Collapse test results for hat and double hat shaped section members at different flange spot-weld pitches and impact velocities

Spec.	E_a[J]	E_L[J]	P_{mean}[kN]	$P_{max.}$[kN]	S[mm]
HEI_0	438.5	1315.5	11.0	59.3	40
HFI_0	434.5	1212.4	10.1	60.2	43
HGI_0	424.1	1156.6	9.6	58.6	44
HEI_1	826.2	1458.0	12.2	61.0	68
HFI_1	826.5	1437.4	12.0	60.3	69
HGI_1	824.5	1355.3	11.3	61.4	73
HEI_2	1007.1	1678.5	14.0	64.8	72
HFI_2	995.4	1571.7	13.1	61.9	76
HGI_2	994.4	1529.8	12.8	62.5	78
DEI_1	831.0	2374.2	19.8	62.3	42
DFI_1	833.2	2221.7	18.5	62.4	45
DGI_1	822.0	1934.1	16.1	63.2	51
DEI_2	984.7	2317.0	19.3	66.1	51
DFI_2	1004.8	2232.8	18.6	68.1	54
DGI_2	984.6	1875.5	15.6	62.8	63
DEI_3	1029.8	2168.1	18.1	62.0	57
DFI_3	1026.6	2087.9	17.4	71.4	59
DGI_3	1020.6	1774.9	14.8	70.3	69

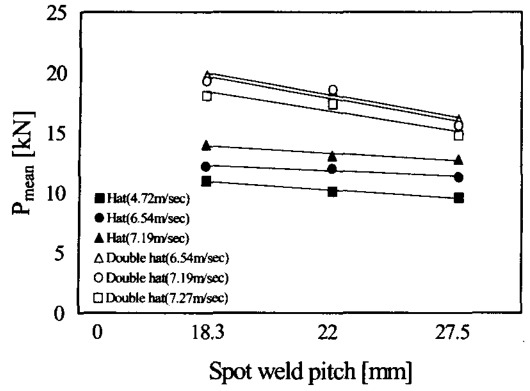


Fig. 7 Relationship between spot welded pitches and mean collapse load at respective velocities

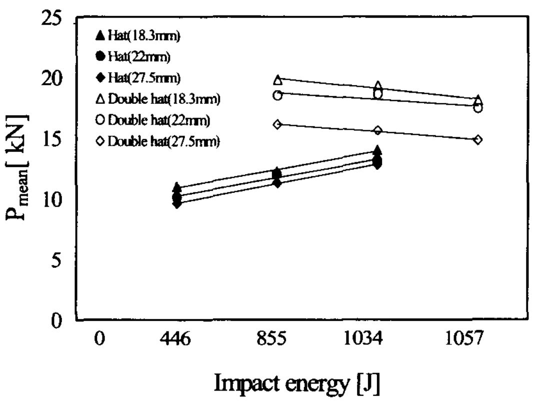


Fig. 8 Relationship between impact energies and mean collapse load at spot weld pitches

5. Conclusions

In order to analyze the variation of flange welded pitch under impact collapse and to analyze collapse characteristics under changing impact collapse velocities in spot welded hat and double hat shaped section members, the impact collapse experiments was carried out. Our conclusions are as follows:-

(1) The total absorbed energy and mean collapse loads of the hat and double hat shaped section members are lower at larger flange weld pitches. Moreover, the double hat shaped section members is much affected by weld pitch. But, the tendency of maximum collapse loads could not be found according to the variations in the size of the flange weld pitch.

(2) In the hat shaped section members, the total absorbed energy and the mean collapse loads increased as the impact collapse velocity increased, but in the double hat shaped section members, the total absorbed energy and the mean collapse load decreased. This shows that the strength is important, but it is more important to induce a sequential collapse mode under impact collapse.

(3) The total absorbed energy and the mean collapse loads in the double hat shaped section members were about 51% higher than those in the hat shaped section members, and the maximum collapse load in the double hat shaped section members was about 4.4% higher than that in the hat shaped section members at the impact collapse velocity of 6.54m/sec. Under the impact collapse velocity of 7.19m/sec, the total absorbed energy and mean collapse loads in the double hat were about 39% higher than those in the hat shaped section members, and the maximum collapse load in the double hat shaped section members was about 6.5% higher than that in the hat shaped section members.

Acknowledgment

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