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CRUSHING CHARACTERISTIC OF DOUBLE HAT-SHAPED MEMBERS OF DIFFERENT MATERIALS JOINED BY ADHESIVE BONDING AND SELF-PIERCING RIVET

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ABSTRACT−The development of a light-weight vehicle is in great demand for enhancement of fule efficiency and dynamic performance. The vehicle weight can be reduced effectively by using lightweight materials such as aluminum and magnesium. However, if such materials are used in vehicles, there are often instances when different materials such as aluminum and steel need to be joined to each other. The conventional joining method, namely resistance spot welding, cannot be used in joining different materials. Self-piercing rivet (SPR) and adhesive bonding, however, are good alternatives to resistance spot welding. This paper is concerned with the crushing test of double hat-shaped member made by resistance spot welding, SPR and adhesive bonding. Various parameters of crashworthiness are analyzed and evaluated. Based on these results, the applicability of SPR and adhesive bonding are proposed as an alternative to resistance spot welding.

KEY WORDS : Different materials, Self-piercing rivet, Adhesive bonding, Crush test, Double hat-shape

1. INTRODUCTION

Recently, automotive manufacturers have focused on three issues: reduction of vehicle weight, increase in the use of modular structures, and increase in the use of electronic parts. To enhance fuel ratio and improve traveling performance, etc., automotive manufacturers, in particular, are seeking ways to reduce vehicle weight. Vehicle weight can be reduced effectively by using light-weight materials, such as aluminum and magnesium. However, lightweight materials are not used for some vehicle parts because of the lack of an effective joining method and related application technology. To apply the lightweight materials for vehicle pasts, an effective joining method of different materials must be developed.

The conventional joining method, namely spot welding, is not effective for joining different materials, and thus, adhesive bonding and self-piercing rivet (SPR) have been applied. The adhesive bonding method offers advantages such as simple combination design and easy joining process. Compared with the conventional joining method, SPR, on the other hand, can only be applied to limited types of materials but excellent joining properties. To test the applicability of these joining methods to automotive joints, we first performed basic tests on the strength of these joints. Then, the crashworthiness of the simple structures that were adjoined by these joining methods was evaluated. Many researches from strength of joint to crashworthiness of simple structure joined by spot welding have been conducted. Some experimental studies have been performed to test the crashworthiness of quasi-static and dynamic of the simple structure joined by spot weld (Ohkubo *et al.*, 1974; Kim *et al.*, 1995; White and Jones, 1999a, 1999b; Cho *et al.*, 2004). Some researchers examined the static collapse and the bend behavior of hybrid hat section stub columns (Schell *et al.*, 1993; Pan and Yu, 2002). These papers carried out the static and dynamic crushing tests of the spot welded steel sections.

In this paper, double hat-shaped section members composed of different materials were joined by SPR and adhesive bonding and the crashworthiness of each member was evaluated. To compare the crashworthiness of different materials composed of steel and aluminum, the steel member of same shape as that composed of different materials was joined by spot weld, and crush test was performed. Through the crush test, the crashworthiness of each joining method was evaluated.

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2. EXPERIMENT

Double hat-shaped specimens, which were composed of different materials such as SPCEN (cold rolled coil) and Al 5J32-T4, were fabricated by SPR and adhesive bonding. The mechanical properties of specimens are shown in Table 1 and the geometrics of the hat-shaped section are shown in Figure 1. Part A of Figure 1 shows the collapse initiator for the initial deformation which was fabricated by press forming. The self-piercing rivets used to construct the SPR specimens was C50541 designed by HENROB. The SPR specimens had the following characteristics: a rivet barrel diameter of 5 mm, a shank length of 5 mm and the rivet material is an ALMAC(Zn-Ti-Al)-coated 0.35% carbon steel.

Table 1. Mechanical properties of substrate.

	Thickness (mm)	Young's modulus (GPa)	Tensile strength (MPa)	Yield strength (MPa)
SPCEN	1	206	410	250
Al 5J32-T4	1	70	195	117

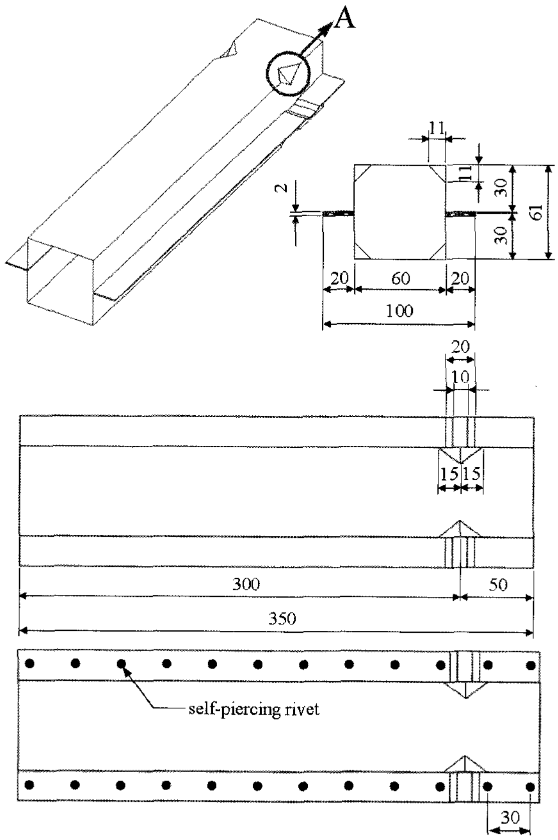

Figure 1. Dimensions of specimens.

Table 2. Properties of adhesive.

Chemical type	Two part methacrylate
Cure method	25°C, 15–20 min
Shear strength (ASTM D1002)	18.6–20.7 N/mm^2
Tensile strength (ASTM D639)	20–22.7 N/mm^2

There are two types adhesive, namely heat cure and room temperature cure type, among which the latter is more generally used in automotives. For the convenience of experiment, the room temperature type adhesive was used in this study. The adhesive bond used to fabricate the adhesive-bonded members was PLEXUS® MA822 structural adhesive, a type of methacylate, which was two-component product, and the properties of the adhesive are shown in Table 2. When the specimens were prepared, surface preparation was omitted because it was omitted in the general automotive industry.

Double hat-shaped specimens were fabricated by SPR and adhesive bonding in flange of hat-shaped section and the two-types members, prior to, crush test, are shown in Figure 3. In the case of SPR-joined specimen, a self-piercing rivet pitch was 30 mm as shown in Figure 1. In the case of a spot welded hat-shaped specimen, Lee *et al.* (2002) suggested that the optimal weld pitch for the maximum energy was 40–50% of the hat-shaped specimen width. In this study, the hat-shaped specimen width was 60 mm, so that self-piercing rivet pitch was 30 mm.

An axial crushing test was performed with a high-speed crushing test equipment (POSCO, Automotive Steel Research Center) by using the potential energy of a spring, as schematically shown in Figure 2. The weight of the crosshead and the potential energy of spring in launcher were used to control the impact velocity, and therefore, the amount of energy to be ab-sorbed by the specimens. The crosshead weight of 215 kg and crush velocity of 5.8 m/sec (20.9 km/h) were used in the crush test. The value of the impact energy was similar with that

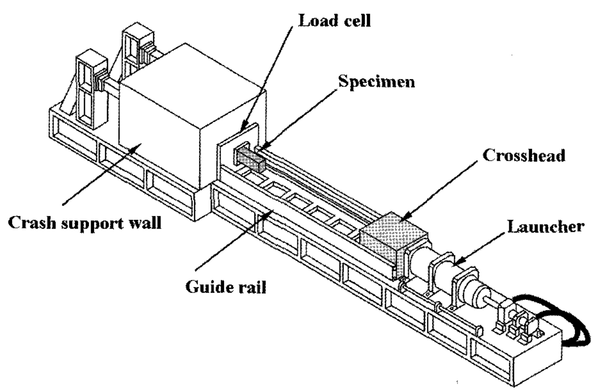

Figure 2. Schematic of impact test set-up.

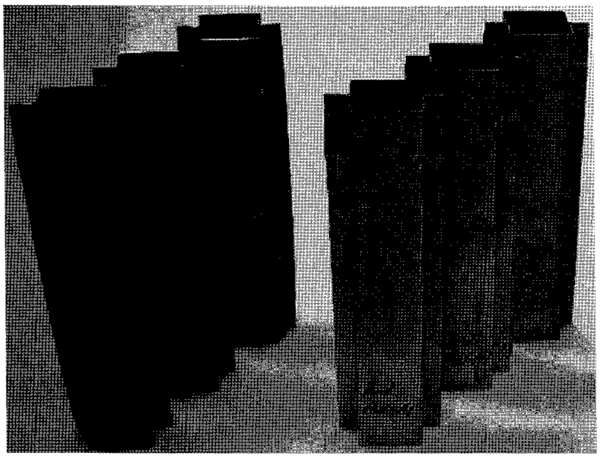

Figure 3. Specimens for the impact test.

given in Equation (1): 3616 J, 5.8 m/sec at double hat-shaped section.

$$E=\frac{1}{2}mv^2 \quad (1)$$

where m is the mass of the crosshead and v is the crush velocity.

3. RESULTS AND DISCUSSION

To prepare the standards of crashworthiness of double hat-shaped sections for each joining method, a 1 mm thick spot welded double hat-shaped section was made from SPCEN and examined by crush test at a speed of about 5.8 m/sec. Spot-welded pitch of these double hat-shaped structures were 30 mm.

Figure 4. Deformed shape after the crush test.

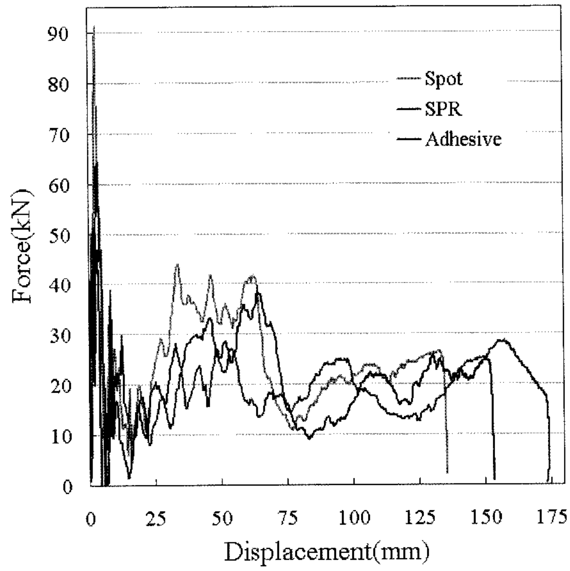

Figure 5. Force-displacement curve of each joining method.

Force-displacement curves of the double hat-shaped section joined by spot-welded, SPR, and adhesive bonding, respectively, are shown in Figure 5. Figure 4 shows the shape of collapsed specimens. The absorbed energy, mean crush load, specific energy absorption (S.E.A), and deformed length of each joined specimens are listed in Table 3. The values in Table 3 are the average of the results, which were obtained by testing three specimens for each case.

3.1. Absorbed Energy

The absorbed energy of double hat-shaped specimens is shown in Figure 6. The absorbed energy is represented by the area below the force-displacement curve, and absorbed energy of this test is calculated using the curve of Figure 5. The absorbed energy of SPR joined specimens is about 93% of the impact energy calculated by Equation (1), and the absorbed energy of adhesive joined specimens is about 90% of the impact energy calculated by Equation (1). In addition, the absorbed energy of SPR joined specimens is higher than the absorbed energy of adhesive

Table 3. Experiment results for double hat-shaped members.

Materials	Joining method	Absorbed energy (J)	Mean crush load (kN)	S.E.A (J/g)	Deformed length (mm)
SPCEN–SPCEN	Spot weld	3476.03	38.32	3.98	136
SPCEN–Al 5J32-T4	SPR	3374.72	27.25	5.68	179
	Bond	3253.28	20.36	5.48	157

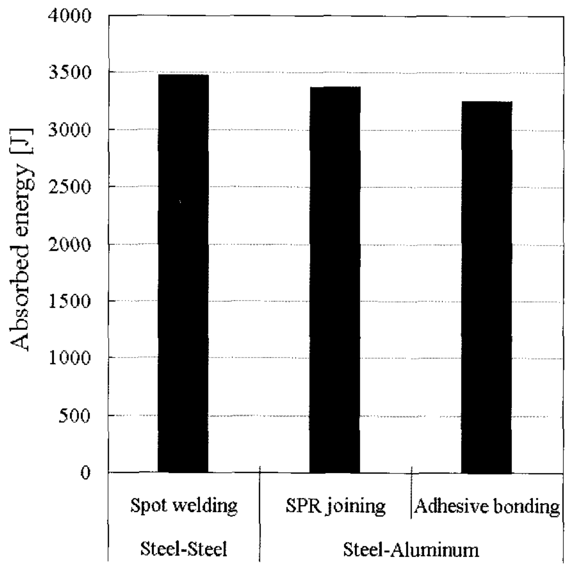

Figure 6. Absorbed energy vs. joining method.

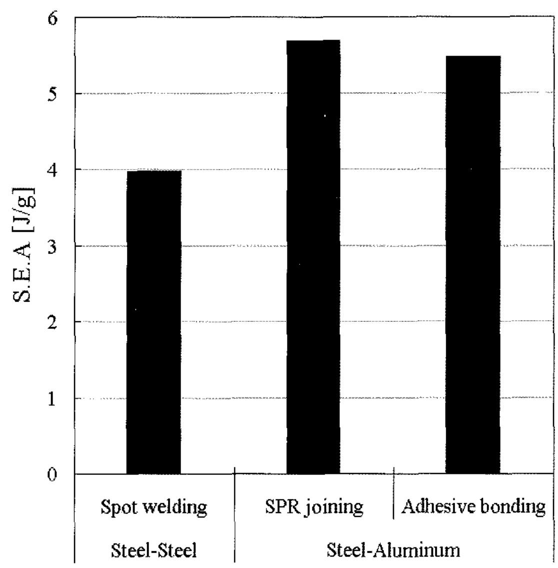

Figure 7. S.E.A vs. joining method.

joined specimens. The force-displacement curve of SPR is slightly different from that of adhesive joined specimens. However, the deformed length of SPR joined structure is about 20 mm longer than that of adhesive joined structure. After all, the difference of absorbed energy between SPR and adhesive joined structure is influenced by the difference of the deformed length. Figure 5 shows little difference between absorbed energy of section of different materials applied with SPR and that of similar materials applied with spot weld. And, in the study of Booth *et al.* (2000), the static strength of SPR joints was similar to that of resistance welded joints for some material combinations. Based on these result, self-piercing rivet can be substituted for spot weld to join different materials.

3.2. Specific Energy Absorption

The S.E.A, which demonstrates the weight efficiency of the structure, is defined as the ratio of energy absorption to mass, as follows.

$$\text{S.E.A}=\frac{\text{Absorbed energy}}{\text{Structure weight}} \tag{2}$$

In Figure 7, the S.E.A of SPR-joined section is about 43% higher than the corresponding spot-welded section, and that of adhesive-bonded section is about 37% higher than the S.E.A of spot-welded section. Generally, the mass density of aluminum is only one-third of that of steel. If the specimens, which are members of different and similar materials of the same shaped section, absorbed same energy, S.E.A of different materials member was higher than that of similar materials member. In our experiment condition, the weight reduction of structure, which was made of different materials, was about 33% of the steel structure. The sections weight of different materials for the same energy absorption was about 70% of the sections weight of the same materials.

3.3. Deformed Length

In Table 3, the deformed length of SPR-joined structure is about 31% longer than that of the spot-welded structure, and the deformed length of adhesive-bonded structure is about 15% higher than that of the spot-welded structure. This result may be due to the decrease in the strength of different material section. The deformed length in SPR-joined structure was longer than the corresponding adhesive bonded structure. This difference of deformed length is illustrated in Figure 4. In the SPR joined member, a part, besides the SPR joined part, was deformed because SPR was joined at the same distance as in flange. Yet, the deformation, as observed in the case of SPR-joined member, was not observed in the adhesive bonded member because adhesive bonded members were joined in the all flange.

3.4. Mean Crush Load

A mean crush load is an indication of the energy absorbing ability of a structure and is defined as the ratio of energy absorption to deformed length. The mean crush load of SPR is about 27% lower than the corresponding value of spot-welded structures, and that of an adhesive joined section is about 46% lower than that of spot welded section. This result is due to the fact that the deformed length of a similar material section is smaller than that a different materials section, and the energy absorption of a same material section is higher than that a different materials section.

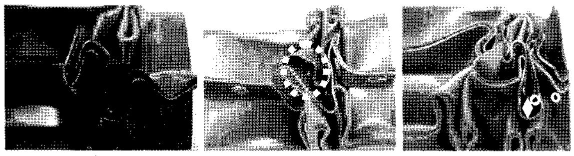

Figure 8. Collapsed mode: (a) spot weld; (b) rivet tail pull-out of self-piercing rivet; (c) bulk failure of adhesive bonding.

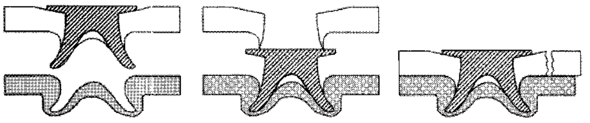

Figure 9. Typical failure modes of SPR joint: (a) rivet tail pull-out; (b) rivet head pull-out; (c) substrate failure.

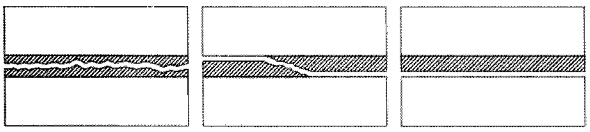

Figure 10. Typical failure modes of adhesive joint: (a) bulk failure; (b) transition failure; (c) interfacial failure.

3.5. Collapsed Mode

Each failure mode of the joining part is shown in Figure 8. The failure of the spot welded specimen did not occur, unlike the other specimens. Generally, there are three failure modes of SPR-joined structure: rivet tail pull-out, rivet head pull-out, and substrate failure as shown in Figure 9. In this crush test, the failure mode of SPR joined structure with the rivet tail in the aluminum sheet was the rivet tail pull-out, which represents the separation of rivet and the bottom member. This rivet tail pull-out occurred at joints with small strength of bottom member, which was joined by rivet tail, and small expansion of rivet tail.

Typically, there are three failure modes of adhesive-bonded joint: bulk failure, transition failure, and interfacial failure as shown in Figure 10. In this crush test, the failure mode of adhesive bonded structure was the bulk failure. This failure is caused by peel stress of the adhesive due to the separating the upper and lower plate.

4. CONCLUSION

In this paper, double hat-shaped section members composed of different materials were made through SPR and adhesive bonding, and the crashworthiness of each member was evaluated.

The absorbed energy of SPR joined section was higher than that of adhesive-bonded section. The absorbed energy of different materials joined by SPR was similar to that of similar materials joined by spot weld. The specific energy absorption of different section member, which is composed with steel and aluminum, was higher than that of steel section member. The deformed length of the SPR joined structure and the adhesive bonded structure was higher than that of the spot welded structure. The mean crush load of SPR joined structure and the adhesive bonded structure was lower than that of the spot welded structure. The failure mode of SPR joined section was rivet tail pull-out, which is the separation of rivet and bottom member. The failure mode of adhesive bonded section was bulk failure, which is the separation of upper and bottom member.

These result showed the crashworthiness of double hat-shape specimens of different materials. Steel and aluminum structures weight is less than structures of steels. Self-piercing rivet can be substituted for spot weld to join different materials. Specimens of different materials deformed more than that of specimens of same material. This result may be used in the safety design of vehicles. Therefore, we are studying the crashworthiness, which is related with deformed length due to a crush.

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