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Improvement of Crashworthiness by Application of High-Strength Steel

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Abstract

Flow stress of TRIP-steel and DP-steel is lower at a low strain rate (10^{-3}/s), but higher at a high strain rate (10^3/s) compared with ordinary HSLA steel, which indicates that they have superior combination of the press formability and the energy absorption capability. It was shown here that the crashworthiness of modeling components of a front-side-member was possibly improved by applying the two steels to the components and changing the welding method from conventional spot welding to laser-continuous welding. This technique is also beneficial to reduce the weight of auto bodies.

1. Introduction

The average car weight has increased noticeably (**Fig. 1**) in the vehicle market that requires increasingly stringent car crash safety standards and greater enhancements to vehicle performance and function[1)]. This runs counter to a specific demand originating from an environmental issue, that is, the demand for improved fuel efficiency through reduced car body weight. In order to meet these apparently contradictory needs, various types of high-strength steel have been developed. This paper explores two representative types of high-strength steels (TRIP steel and DP steel). In addition, the advantages of using either TRIP or DP steels for the front-side member of a car are discussed . In the event of a head-on collision, this member collapses before the other members to absorb the impact energy. A discuss also follows in relation to improvements in impact absorption characteristics of the front-side member by applying continuous laser welding, rather than ordinary spot welding, to its flange.

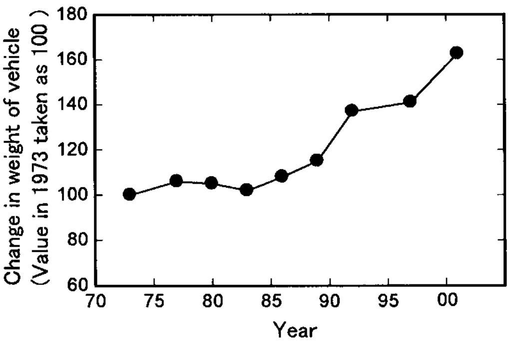

Fig. 1 Change in weight of Japanese middle-class vehicle

2. Features and Utility of High-Strength Steel

High-strength steel sheets are increasingly adopted for automobiles to reduce their weight. Among others, the demand for TRIP (Transformation Induced Plasticity) steel and DP (Dual Phase) steel is expected to increase rapidly because they offer good formability and are suitable as front-side members of vehicles. **Fig. 2** shows the features of these steel products, specifically the influence of the strain rate on flow stress (average in the strain range 3% to 10%)[2)]. At quasi-static strain rates (10m^{-3}/s), TRIP and DP steels showed smaller average stress than high-strength low-alloyed (HSLA) steel. At dynamic strain rates (10^3/s), however, TRIP and DP steels

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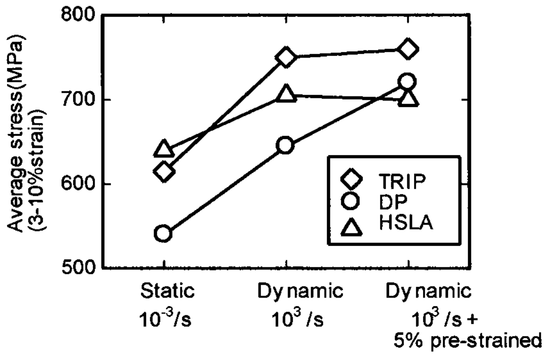


Fig. 2 Effect of strain rate on average stress in the strain range of 3-10% for the steels (TS = 590MPa)

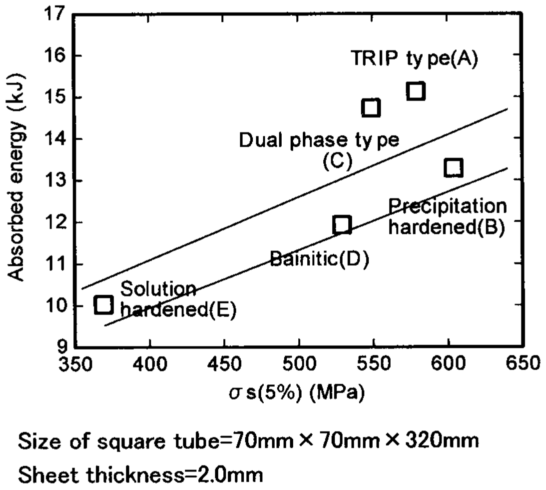


Fig. 3 Relationship between flow stress at 5% strain and absorbed energy in square tube

showed larger gains in flow stress than HSLA.

In addition, when a 5% pre-strain and BH treatment (170℃ for 20 min) were applied to the three types of steel simulating the press forming, painting and baking of actual car members, DP steel showed a marked improvement in dynamic flow stress. Although TRIP and DP steels are already known to have good press formability, the above experimental results suggest that they are also effective in absorbing impact energy. It is considered that TRIP steel shows high strain rate dependency as the TRIP effect is enhanced during deformation at high strain rates and causes the deformation stress to increase markedly, and that DP steel shows a large high-speed deformation stress as a result of mobile dislocation fixation by pre-straining and BH treatment.

Fig. 3 shows the relationship between steel strength (flow stress at 5% strain) and absorbed energy in a square tube, obtained by an FEM analysis[2]. It can be seen from the figure that TRIP and DP steels display better impact absorption characteristics than other types of steel. This is probably because the above base metal characteristic works favorably even at the member level.

3. Influence of Joints

In recent years, automakers, especially those in Europe, are increasingly employing the laser welding process not only to weld tailored blanks and some other parts but also to assemble car bodies, including the roof. Apparently, the main purpose of applying laser welding is to increase the car body rigidity by continuous welding and decrease the car body weight by re-forming of structural members.

A typical example of the application of laser welding is flange welding of a front-side member. The impact absorption characteristic of a laser-welded member is described below. An ordinary front-side member is a single-hat type hollow component having flanges as shown in **Fig. 4**. The flanges are spot-welded and the interval between welding points is generally 30 to 50 mm. The model component cross-sectional shape is shown in Fig. 4 (a = 60 mm, b = 40 mm). The model component length was 300 mm. The flanges were subjected to either continuous laser welding or spot welding (interval between welding points: 50 mm). In order to evaluate the impact absorption characteristic of the model component, an axial crus test in which a 110 kg weight is allowed to fall free from a height of 10 m onto the test piece was carried out.

Fig. 5 shows the test results, specifically the relationship between displacement (extent of crushing) of the component and the force acting on the component end. In terms of the absorbed energy at a displacement of 150 mm, for example, the laser-welded component showed a value about 15% greater than the spot-welded component did. The force increases and decreases after the initial peak is reached. This phenomenon occurs as a result of repetitive buckling of the corner (rounded part) and flat part of the component. **Fig. 6** shows

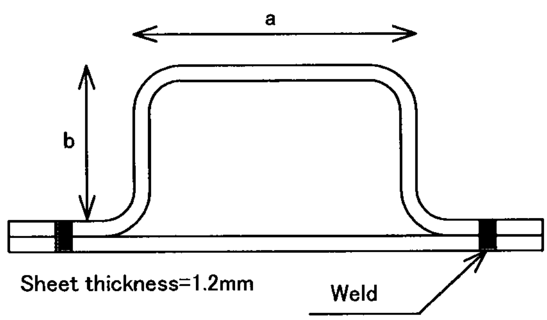


Fig. 4 Cross-sectional shape of single hat type component

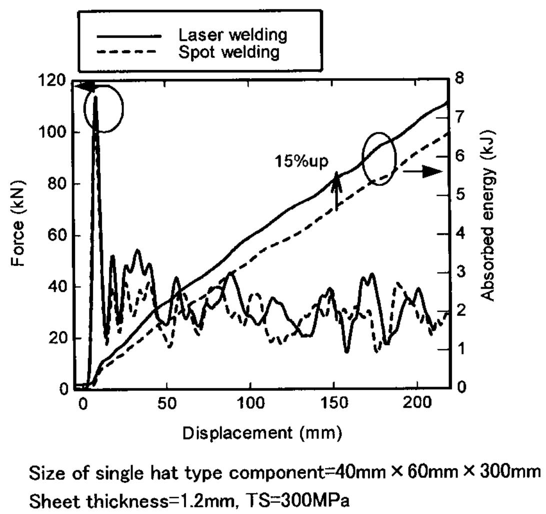
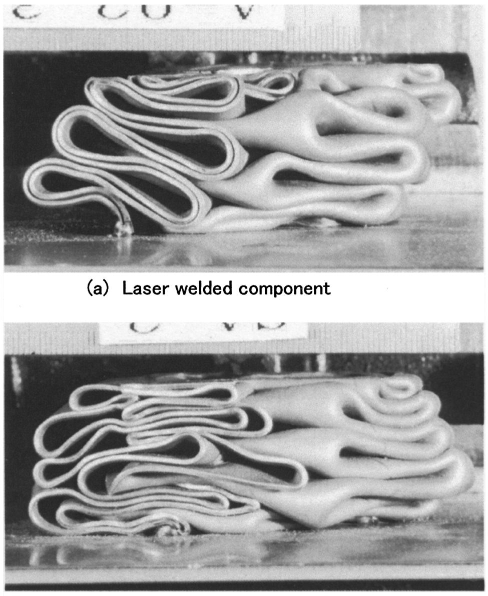


Fig. 5 Comparison of absorption property between spot-welded and laser-welded component



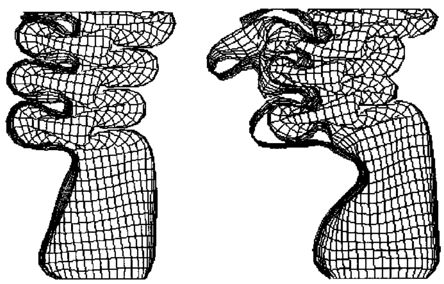
(a) Laser welded component

(b) Spot welded component

Fig. 6 Comparison of side-view between laser welded and spot welded component after crash test

side views of the laser-welded and spot-welded components after the crush test. Both components were crushed in the same mode (compact mode) in which they looked like bellows, but the flange deformation behavior was different. Namely, the two sheets forming the flange of the laser-welded component were deformed without separating from each other, whereas those of the spot-welded component were deformed while separating from each other except at points other than the welded points. This difference in flange deformation behavior between the two types of welding is considered to explain why the force applied to the laser-welded component was larger than that applied to the spot-welded component.

In recent years, the CAE analysis technique has been more actively applied to the analyses of vehicle crashes because there have been dramatic changes to that technique which make it more convenient.. In order to make an in-depth study of the axial crush behavior of the model component, an FEM analysis of the crushing of the model component was carried out. As shown in **Fig. 7**, the actual crush behaviors of welded components were reproduced in the analysis. Concerning the force-displacement relationship, most of the experimental results were reproduced too. As a result of the FEM



(a) Laser welded component (b) Spot welded component

Fig. 7 Crush mode of components obtained by FEM analysis

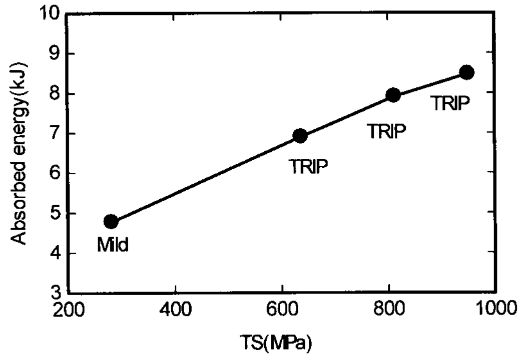


Fig. 8 Effect of TS of steels on crashworthiness of laser welded component

analysis, it was found that the spot-welded component shows an irregular crush mode and that the component can turn over as it continues to be crushed. Therefore, considering that there are cases in which the component axial direction does not coincide with the input direction, it can be estimated that the laser-welded component will be able to withstand the desired absorbed energy more stably than the spot-welded component. It is expected that in the future, materials and structural member shapes that offer superior impact absorption characteristics will be more clearly identified through effective application of FEM analysis.

Fig. 8 shows the relationship between tensile strength (TS) and impact absorption characteristic of steel (experimental results). The component size, steel sheet thickness and crush conditions used in the experiment are the same as shown in Fig. 5. The flanges were continuously welded by laser. All the high-strength steel sheets tested are TRIP steel. With the increase in TS, the absorbed energy at a 150 mm crush increased linearly. Thus, it is possible to effectively improve the impact absorption characteristics of steel sheets by increasing the strength of the steel sheet and the strength of the joints (by application of continuous welding).

4. Influence of Member Cross-Sectional Shape

The cross-sectional shape of a member also has significant influence on the impact absorption characteristic of the member. For example, a double-hat type member is superior in impact absorption characteristics to a single-hat type member of the same cross-sectional area. The reason for this is that the double-hat type member has more corners than the single hat type member, and hence can bear more buckling force.

Fig. 9 shows the influence of sheet thickness (t) / average member side length (D) on impact absorption characteristics (experimental results). In the experiment, only D was varied, with t kept unchanged (1.2 mm). The average member side length, D, is expressed as (a+b) / 2 (see Fig. 4). The smaller the value of t / D, or the larger the value of D, the greater was the absolute value of absorbed energy.

Compared in terms of the absorbed energy divided by the member mass (i.e., absorbed energy per unit member mass), the largest value was obtained when t / D was 0.024. When t / D was 0.024, the crush mode became “compact” (see Figs. 6 and 7). In this case, the greater part of the member contributed in the deformation, raising the level of force. When t / D was 0.012, the member was subjected to local buckling and crushed in a non-compact mode, excepting the linear part, as shown in **Fig. 10**. In this case, the efficiency expressed in terms of the ratio of absorbed energy to member mass was inferior. It

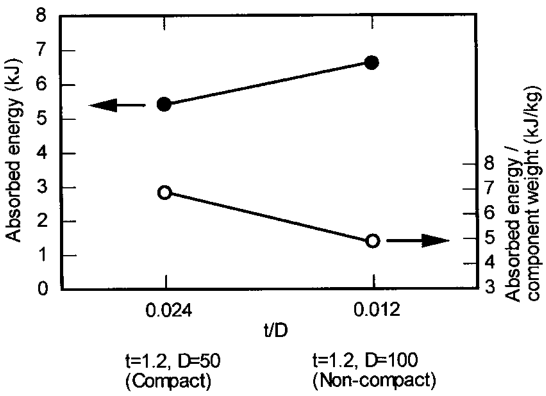


Fig. 9 Effect of cross-sectional dimension on crashworthiness of laser welded component

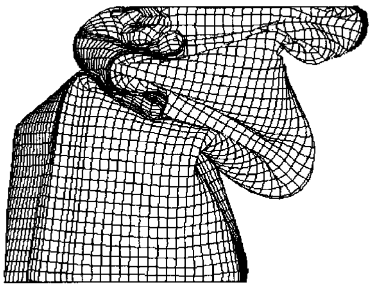


Fig. 10 Change of crush mode with the decrease of t/D

has been known that the crush mode of a member changes when t/D is in the range 0.015 to 0.020[3]. In the present experiment also, the crush mode changed in that range. Thus, the member cross-sectional shape is another important factor that influences the impact absorption characteristic of the member.

5. Estimation of Effect of Weight Reduction

Fig. 11 shows the relationship between sheet thickness and impact absorption characteristics of square tubing of varying steel strength (analysis result). The absorbed energy increased with the increase in sheet thickness and tensile strength. With the increase in sheet thickness, the gain in absorbed energy by an increase in TS became larger. By using this relationship, it is possible to estimate the effect of reduction of the weight of a member. For example, assume that the absorbed energy of a given member is targeted at 6 kJ or more. With a type of steel having a tensile strength of 348 MPa, a sheet thickness of 1.8 mm or more is required to attain the target. However, when the tensile strength is increased to 644 MPa, the sheet thickness required can be reduced to 1.4 mm (indicated by an arrow in Fig. 11). By a simple calculation with the general vehicle construction left out of consideration, it was estimated that the square tubing would permit reducing the member weight by a little more than 20%. Aya et al. permit handling even the impact absorption characteristic of a single-hat type member in the same way as that of a square tube[4]. Thus, it is considered possible to estimate the effect of weight reduction of a single-hat type member as well.

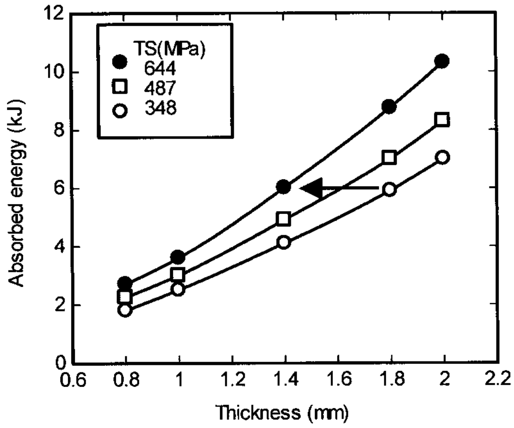


Fig. 11 Relationship between sheet thickness and crashworthiness

6. Conclusion

This paper described the typical characteristics and applications of high-strength steels, such as TRIP and DP steels, which are considered effective in improving crash safety and reducing the weight of automobiles. There is the possibility that the performances of car components can be further enhanced not only by employing suitable steel sheets, but also by optimizing the joint structure and component shapes. The authors intend to continue our efforts to improve material characteristics and develop new methods for effectively utilizing materials, thereby contributing to both enhanced crash safety and the reduction of car body weight.

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