CORROSION SCIENCE AND TECHNOLOGY, Vol.9, No.1(2010), pp.16~19

Development of Ultra-High Strength Galvannealed Steel Sheets

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(Received July 31, 2009; No Revisio, 2010; Accepted February 16, 2010)

Application of ultra-high strength steel sheets is one of the most important methods to satisfy weight reduction and crash safety of a vehicle. Recently, there has been a trend to apply ultra-high strength steel sheets widely to underbody parts in which corrosion resistance is required. In this work, ultra-high strength galvannealed steel sheets with a tensile strength of 1180 MPa were developed. Newly developed ultra-high strength galvannealed steel sheets have comparable properties, such as mechanical properties, spot weldability, crashworthiness and adhesion of coatings, to conventional steel sheets.

Keywords *: coating, ultra-high strength, galvanneled steel, weldability, adhesive resistance*

1. Introduction

Protecting the environment from global warming is a very important issue. Recently, the regulations for greenhouse gas emission have been becoming increasingly strict. For example, the Japanese Government officially announced the plan, in which the fuel consumption of gasoline-fueled automobiles should be reduced by approximately 20% by fiscal year 2010 as shown in Fig. 1.[1)] Automobile manufacturers are therefore making great efforts to improve fuel economy, which leads to reducing CO_2 emission. One of the most efficient methods of improving fuel economy is weight reduction of a vehicle body. On the other hand, the regulations regarding crashworthiness have also been strict[2)] so that additional reinforcement may be required, resulting in heavy weight.

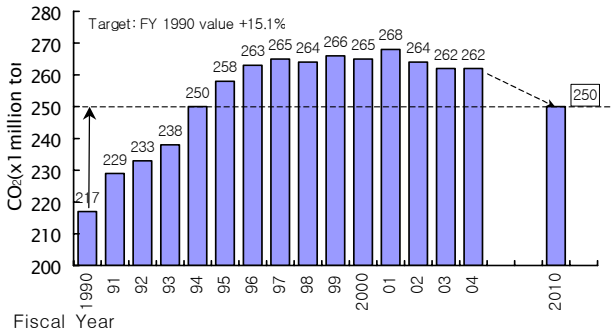

Fig. 1. CO_2 emission of transport group in Japan.

To achieve both weight reduction and crash safety, the application of ultra-high strength steel is essential. Several types of ultra-high strength cold rolled and galvannealed steel sheets with a tensile strength of 980 MPa have been developed[3),4)] and are being applied to automobile parts.[4)] To obtain more reduction in weight of a vehicle body, it might be useful to obtain a higher range of tensile strength, which leads to more applications of ultra-high strength steel sheets to a wide variety of car components.

In this study, ultra-high strength galvannealed steel sheets with a tensile strength of 1180 MPa were developed. Various characteristics of newly developed steel are introduced.

2. Experimental procedure

2.1 Manufacturing materials

Galvannealed steel sheets in this study were produced with a thickness of 1.6 mm using industrial production processes, such as a continuous galvannealed process line. The main compositions of galvannealed steel sheets are carbon and manganese, with wettability in mind. The coating weight of galvannealed steel sheets used in this work was controlled to approximately 40 g/m^2.

Certain properties were measured and analyzed as follows:

1) Mechanical properties; tensile tests
2) Spot weldability; joint strength tests
3) Adhesive resistance of coatings; V-bend tests

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4) Crashworthiness; weight drop tests

2.2 Mechanical properties

Tensile tests were performed under JIS (Japanese Industry Standard, Z 2201).

2.3 Spot weldability

Weldability was evaluated in terms of joint strength and the available welding current ranges were decided as follows. The lower limit of the welding current value was defined as a current for which the weld diameter was equal to four times the square root of the sheet thickness. On the other hand, the upper limit of the welding current value was defined as the maximum current in the current range with no expulsion. Joint strengths were measured using both tensile shear and cross tension tests. The developed steel sheets were compared with other conventional ultra-high strength steel sheets with a tensile strength of 980 MPa.

2.4 Adhesive resistance of coatings

Adhesive resistance of coatings was evaluated by V-bend tests shown in Fig. 2, where specimens were bent using a V-shaped punch at an angle of 90 degrees. When the punch was forced, metal powders were peeled from the surface of the specimen. After applying cellophane tape to the compressive surface of the specimen, the metal powders on the cellophane tape were dissolved in 5% HCl solution. The amounts of metal powders (Zn and Fe) were quantified by Inductively Coupled Plasma spectroscopy and their sum was regarded as the amount of powdering. X-ray diffraction of each of the coatings was also performed for quantitative analysis for the Γ phase (Fe_3Zn_{10}), which would influence the adhesive resistance of coatings. The adhesive resistance of newly developed steels was compared with conventional galvannealed steel sheets with tensile strengths ranging from 270 MPa to 980 MPa.

2.5 Crashworthiness

To evaluate crashworthiness, a drop test shown in Fig. 3 was performed. Specimens had a square cross section of 70 mm x 50 mm with spot-welded flanges. The tests were performed under conditions where weights were between 145 kgf and 160 kgf and heights were between 5 m and 9 m. The absorbed energies were measured in bending crash modes considering general usage of ultra-high strength steel sheets. Displacements and loads during crash were measured using laser distance measurements and load cells, respectively. The absorbed energies were obtained at a crash displacement of 100 mm.

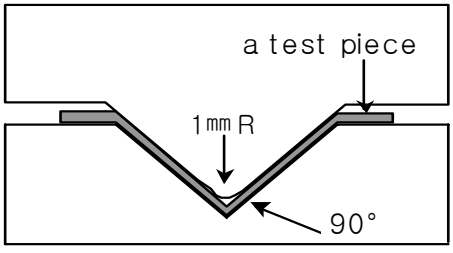

Fig. 2. Schematic illustration of the V-bend test.

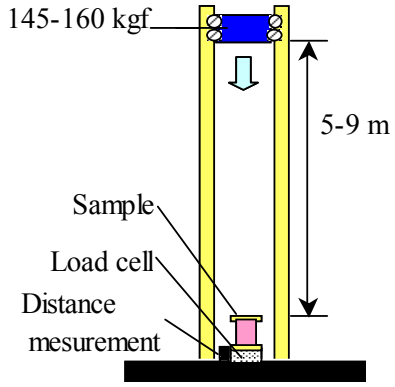

Fig. 3. Schematic illustration of drop weight test.

3. Results

3.1 Mechanical properties

Table 1 shows the mechanical properties of ultra-high strength steel sheets. The combination of tensile strength and elongation and yield ration for newly developed galvannealed steel sheets is comparable to conventional ultra high strength steel sheets with a tensile strength of 980 MPa. In this work, microstructure, which would influence mechanical properties, has been controlled as finely and homogenously as possible. As a result, newly developed steel had a good combination of mechanical properties.

3.2 Spot weldability

Fig. 4 shows the relation between the tensile strength and spot-weld joint strength of ultra-high strength steel

Table 1. Mechanical properties of ultra-high strength steel sheets steel

	YP/MPa	TS/Ma	El/%
Newly developed galvannealed steel	777	1199	13
Cold-rolled steel with tensile strength of 980 MPa	624	1009	17
Galvannealed steel with tensile strength of 980 MPa	640	1030	16

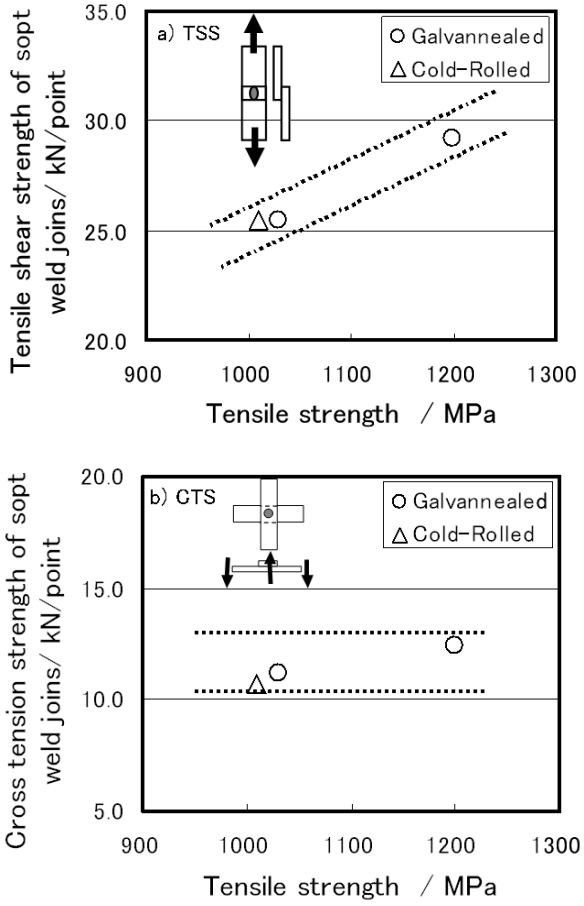

Fig. 4. Relationship between tensile strength and spot weld joint strength of ultra-high strength steel sheets.

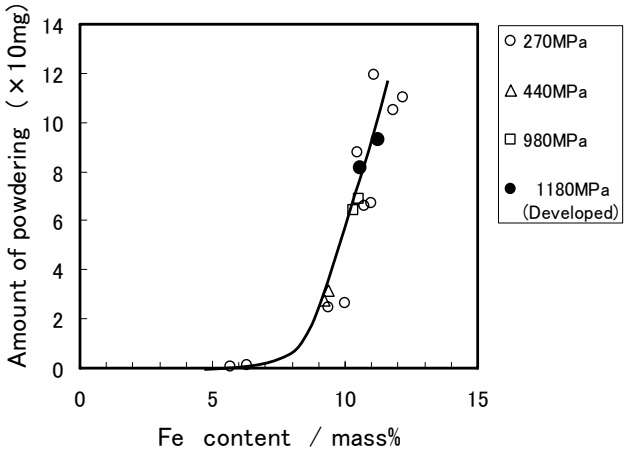

Fig. 5. Relationship between Fe content of coatings and amount of powdering of steel sheets.

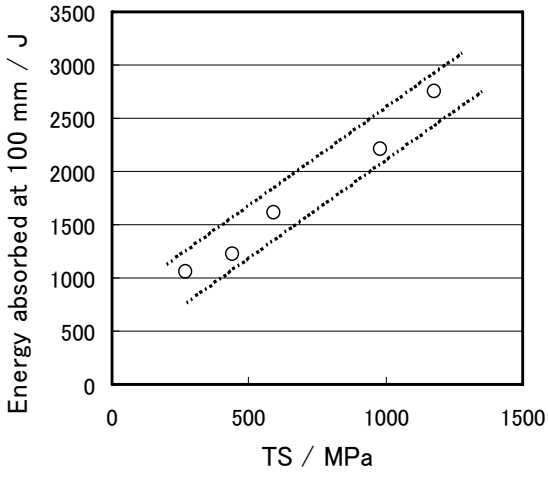

Fig. 6. Changes in the absorbed energies of galvannealed steel sheets with tensile strength evaluated by bending mode drop tests.

sheets with tensile strengths ranging from 980 to 1180 MPa. As the sheet strength increases, the tensile shear strength of the spot-weld joint increases, while the cross tension strength remains almost unchanged. This is a general phenomenon for high strength steel sheets.[5] All the joints fail, not in the weld area but in the base metal of the sheets.

3.3 Adhesive resistance of coatings

Fig. 5 shows the relationship between the Fe content of coatings and amount of powdering. Adhesive resistance of developed steels tends to show the same behaviour as conventional steels with tensile strengths ranging from 270 MPa to 980 MPa. The higher the Fe content, the greater the amount of powdering in all cases.

The relationship between the Fe content and X-ray diffraction intensity of the Γ phase (Fe_3Zn_{10}) was also investigated. It was found that the diffraction intensity of the Γ phase became higher as the Fe contents increased. This implies that the growth of a hard and fragile Γ phase causes adhesive resistance of coatings to deteriorate. This is a general phenomenon affecting galvannealed steel sheets[6] and it thus shows that developed galvannealed ultra-high strength steel sheets have adhesive resistance of coating behaviour equivalent to those of conventional galvannealed steel sheets.

3.4 Crashworthiness

Fig. 6 shows changes in the absorbed energies for galvannealed steel sheets with tensile strength evaluated by drop tests for bending crash mode. Even when the tensile strength increases up to 1180 MPa, the absorbed energies, measured at 100 mm displacement, increase in proportion to the sheet tensile strength. Furthermore, no failures at spot-welded points in the specimens were found after collision.

According to this increase in absorbed energy, the application of ultra-high strength steel sheets can be very useful

in reducing the thickness of reinforcement parts.

4. Summary

In this study, ultra-high strength galvannealed steel sheets with a tensile strength of 1180 MPa were developed and their performances were evaluated as follows.

1) Comparable mechanical properties and weldability, such as a good combination between tensile strength and elongation and spot-weld joint strength, to conventional galvannealed ultra-high strength steel sheets.

2) The same adhesive resistance as those of conventional galvannealed steel sheets

3) Absorbed energy increase corresponding to ultra-high strength

Applications of the developed ultra-high strength galvannealed steel sheets can therefore contribute to both weight reduction and improvement of crashworthiness for a vehicle body.

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