Mechanical Properties of Steel Plate Affected by the Hot-dip Al Coating Process

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1. Introduction Corrosion damage is an important reason to reduce the durability of steel structures. Hot-dip coatings have been widely used in the field of steel structure protection. In recent years, hot-dip Al and Al-based coatings are used as alternatives to Zn coating for their excellent anti-corrosion and better oxidation resistance.[1)] During the fabrication process, the steel structure was immersed in the molten metal solution. The bath temperature of the molten metal is about 440–460 °C (Zn), 595–610 °C (55Al–Zn), and 700–750 °C (Al). The heat input on the microstructure formed in the heat-affected zone is effective and affects the mechanical properties of steel structures. In this study, the heat effect of Al coating process on the steel plate was researched and the 55Al-Zn and Zn coatings were used for a contrast test.

2. Test method The specimens are made from common steel plates (JIS G 3106 SM490A) with two different thickness *t*: 9 and 12 mm. The types of tensile specimens are shown in Table 1. There are four groups of specimens, 1) Without coating, 2) Specimen coated by hot-dip Al coating, 3) Coated by hot-dip 55Al-Zn coating 4) Coated by hot-dip Zn coating. The dimensions of the specimen are specified in JIS Z2241-1A, the detailed configuration is shown in Fig.1. Moreover, all specimens were tested by the MTS machine, under displacement control with the tensile speed of 0.03 mm/sec. A specimen under the loading is shown in Fig. 2. During the test process, load *P* and displacement *δ* were measured and recorded by a data logger. Furthermore, the surface crack initiation behaviors of all specimens were recorded continuously by a camera. The hardness of the cross-section in the tensile test was obtained by the microhardness tester (HMV-G30S, Shimadzu Co. Ltd.). The micro-Vickers hardness was measured every 15μm from the top of the cross-section surface. The SEM image of the fracture surface was gained by the scanning electron microscope using the SE model (SU3500 Hitachi Inc.).

3. Test results After the tensile test, the relationship of load-displacement on the 9mm thick specimen is shown in Fig.3 (a). Comparing the four *P*-*δ* curves, only the mechanical properties of specimen coated by Al coating decrease can be found obviously. The decreasing yield limit and the maximum load limit can be easily detected. The detailed mechanical parameters (tensile strength, yield strength, elongation) are shown in Fig. 3 (b,c,d). No coating specimen was set as a standard, the other specimens are the relative percentages to no coating specimens. The tensile strength and yield strength of the Al-coated specimen have a decreasing trend compared with no coating specimen. The other types specimens, although there also have a decreased trend, the decline is not obvious. The effect of thickness of the specimens on the elongation is more obvious. For the 12mm thick specimens, the elongation of hot-dip coating coated specimens is similar to no coating specimen. For the 9mm thick specimens, the elongation of coated specimens decreased but the decline is also not obvious. The main factor affecting the elongation is the thickness of the specimens. To investigate the reason for

Table 1 Types of specimens in tensile test

Type	Coating condition	Molten metal temperature (°C)	Plate thickness *t* (mm)
N	Without coating	-	9, 12
Al	Al coating	700–750	
55Al-Zn	55Al-Zn coating	595–610	
Zn	Zn coating	440–460	

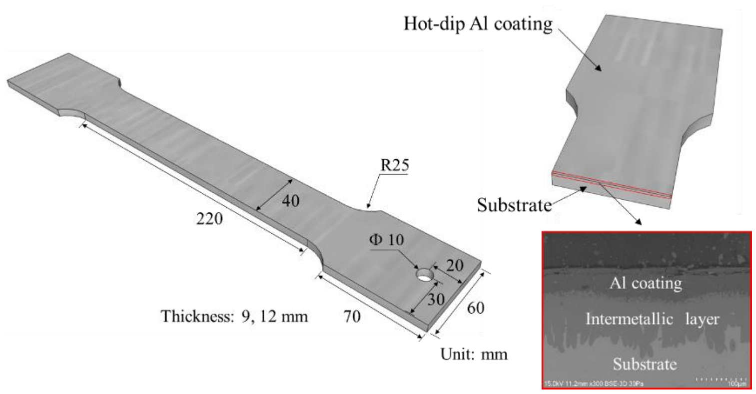


Fig.1 Schematic diagram of the test specimens

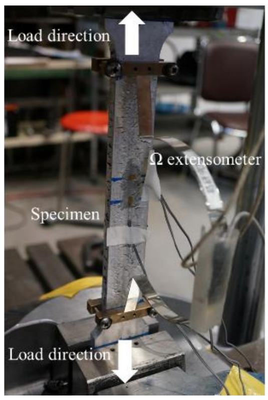
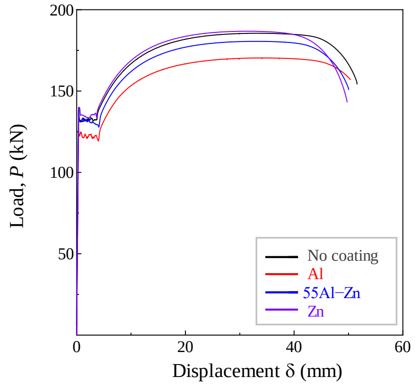
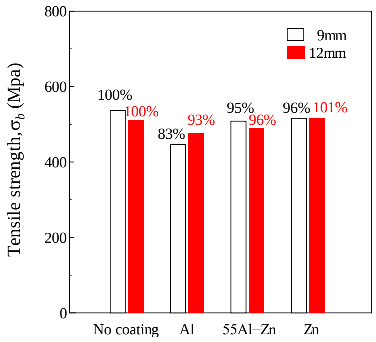


Fig.2 Set-up of test specimen



(a) P-δ cures of 9mm thick specimens



(b) Tensile strength

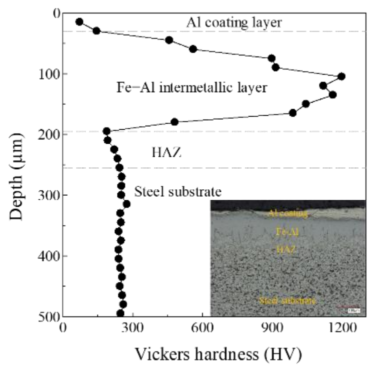
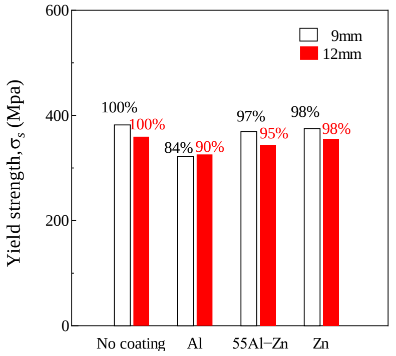
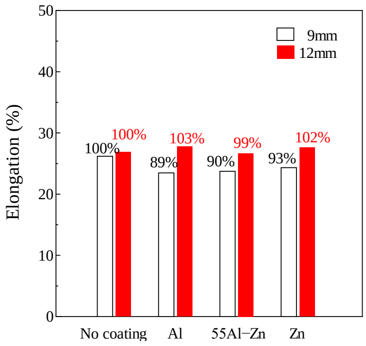


Fig.4 Vickers hardness



(c) Yield strength



d) Elongation

Fig. 3 The results of tensile test

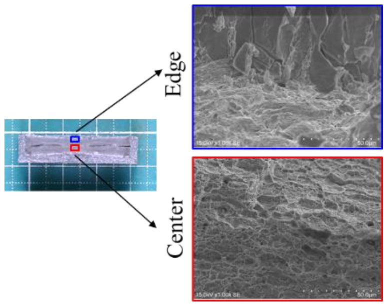


Fig.5 SEM image of the fracture surface

the decreasing mechanical properties of the Al coated specimen, the hardness measurement was carried out on the cross-section of tensile specimen. The hardness of the Al coating layer, intermetallic layer. HAZ and substrate can be easily distinguished. The hardness of the cross-section was shown in Fig.7. The intermetallic layer formed due to the fusion of molten Al and iron at a temperature over 700 °C. This layer consisted of the $FeAl_3$ and Fe_2Al_5 and has a higher hardness.[2)] The fractography of the fracture surface obtained on the 9mm specimen is shown in Fig. 8. The center part of the fracture surface is the typical ductile fracture. The edge of the fracture surface is the junction of the intermetallic layer and steel substrate. After the tensile test, the outermost Al layer cracked and occurred interfacial debonding behavior. Therefore, the Al layer cannot be observed on the fracture surface. The fracture behavior of the edge part is different from the center part, the main fracture model is a brittle fracture that is detected from the SEM image. The fracture surface of the brittle is relatively flat, the microstructure is similar to dimple that cannot be observed. The tensile strength of brittle materials is generally poor. In addition, the microstructure of HAZ consisted of acicular ferrite and grain boundary ferrite at prior austenite grain boundaries. The Austenite grain size of HAZ increases with heat input increasing due to long holding time at peak temperature.[2)] The Vickers hardness of HAZ was decreased with the increase of heat input. The hardness has a positive correlation with tensile properties of the steel substrate.[3)] It indicated that the tensile properties decreased in the HAZ. The mechanical properties decreasing of hot-dip Al coated specimen was composed of two reasons. One is the brittle fracture of the intermetallic layer and the other is the mechanical properties decreasing behavior in the HAZ.

4. Summary 1) The mechanical properties of Al coated steel plate in tensile strength, yield strength are lower than 55Al-Zn, Zn coated steel plate and no coating specimens

The mechanical properties of Al coated steel plate has a clear downward trend to 55Al-Zn, Zn and no coating specimens, especially in tensile strength and yield strength. 2) The mechanical properties decrease of hot-dip Al coated steel plate is due to the brittle fracture of the intermetallic layer and heat affected zone. 3) In the hot-dip Al coated process, the mechanical properties decreasing effect on the thinner steel plate is relatively obvious.

References 1) B. Lemmens, Y. Garcia, B. Corlu: Study of the electrochemical behaviour of aluminized steel, Surf. Coatings Technol. Vol.260, pp. 34-38, 2014. 2) W.J Chen, C,J Wang: Growth of intermetallic layer in aluminide mild steel during hot-dipping. Vol.204, pp.824-828,2009 3) M. Gaško, G. Rosenberg: Correlation between hardness and tensile properties in ultra-high strength dual phase steels–short communication, Mater. Eng, Vol. 18, No. 4, pp.155-159, 2011.