

CRACKING MECHANISMS IN A HOT-DIP ZINC COATED STEEL

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ABSTRACT

Hot-dip galvanizing is one of the most used methods to apply zinc-based coatings on steels in order to provide sacrificial protection against corrosion over all the steel surface. The efficiency of the protection is affected by the coating mechanical response to loading: cracking and coatings delamination during forming and/or during service could decrease the corrosion resistance and could allow the contact between the environment and the substrate (the steel). The aim of this work is the analysis of the hot dip zinc coated steel plates mechanical properties by means of a non-standardized bending test performed minimizing both the bending moment differences along the bending axis and the interactions between the clamping system and the specimen coating. Bending tests are performed both on non-coated and on hot dip zinc coated plates, correlating the measured variables (applied load and crosshead displacement) with the bending moment and the specimen bending angle. Tests are characterised by a good repeatability. Results show that the main damaging mechanisms depend on the different mechanical behaviour of the intermetallic phases and on their thickness. For all the investigated coating conditions, radial cracks are observed. They initiate corresponding to the Γ phase and propagate up to the ζ - η interface. The coating thickness increase implies both an increase of the importance of the cracks in δ and ζ phases and the presence of cracks at ζ - δ interfaces. As a consequence, the increase of coating thickness implies an increase of the susceptibility to a coating-steel debonding damage mechanism, with a consequent loose of the coating adhesion and a decreasing of the capability of the zinc coating to improve the steel corrosion resistance.

1 INTRODUCTION

Hot-dip zinc coating is known as one of the most used technique for protecting cold rolled steels against corrosion (ASTM [1], De Abreu [2]). The steel to be coated is first cleaned to remove all oils, greases, soils, mill scale and rust. Cleaning usually consists in a degreasing step followed by acid pickling, in order to remove scale and rust, and by fluxing, in order to apply a protective surface and inhibit the steel oxidation before dipping in molten zinc. As result of this procedure, the coating is constituted by the succession of the intermetallics observed in the Fe-Zn system. Starting from the α (Fe) substrate, Γ (constituted by very thin Γ_1 and Γ_2 compounds, Marder [3]), δ , ζ , and η phases are more or less evident, according to the zinc coating procedure. These phases are characterized by different mechanical and physical properties (Reumont [4]): Young module ranges between 75 GPa (corresponding to the Zn layer) and 140 GPa (corresponding to the δ phase); 0.25 N microhardness ranges between 70 VHN (corresponding to the Zn layer) and about 280 VHN (corresponding to the δ phase). Although the microstructure and the phases growth kinetics have been investigated in detail, poor efforts have been made on the analysis of Zn coatings adhesion and mechanical properties (Tzimas [5]).

This work analyses the mechanical behavior of hot dip galvanized Zn coatings submitted to a bending test by means of a non-standardized procedure that allows to obtain pure moment loading conditions (Duncan [6] and [7]).

2 MATERIAL AND EXPERIMENTAL PROCEDURES

For all the investigated Zn coatings procedures, 3 mm thick commercial carbon steel plates are considered. Table I shows the steel chemical composition. Zn bath is Fe saturated.

Table 1: Chemical composition of the steel used as substrate (wt%).

C	Si	Mn	P	S	Al	Fe
0.090	0.167	0.540	0.010	0.004	0.051	Bal.

Prior to galvanizing, steels samples are degreased and rinsed with alcohol. Subsequently they are pickled in an aqueous solution 20% H_2SO_4 at $50^\circ C$ for 10 minutes, washed in fresh water, fluxed in an aqueous solution containing 280 g/l $ZnCl_2$ and 220 g/l NH_4Cl at laboratory temperature for 2 minutes and then they are dried for 10 minutes at $100^\circ C$. After this procedure, they are immediately dipped into the galvanizing bath, that is held at $440 \pm 2^\circ C$, for different durations (respectively 15, 60, 180, 360, 900 seconds). Finally, they are water cooled.

Bending test are performed by means of a non-standard device (figure 1, on the left) and they are repeated at least three times for each considered dipping duration. Tests are performed using an electromechanical 100kN testing machine, considering a crosshead displacement equal to 35 mm, that corresponds to a bending angle equal to 30° (figure 1b). Furthermore, in order to analyse the coatings damage development, bending tests are performed up to bending angles respectively equal to 10° and 20° , considering a dipping duration equal to 60 s. Finally, in order to identify the damaging mechanisms for each investigated dipping duration and loading conditions, longitudinal sections of the bended specimens are metallografically prepared and observed by means of an optical microscope (LOM). The damage level was evaluated in term of “cracks density”, that corresponds to the cracks number contained in a specimen length equal to $1000 \mu m$ (Kim[9, 10]).

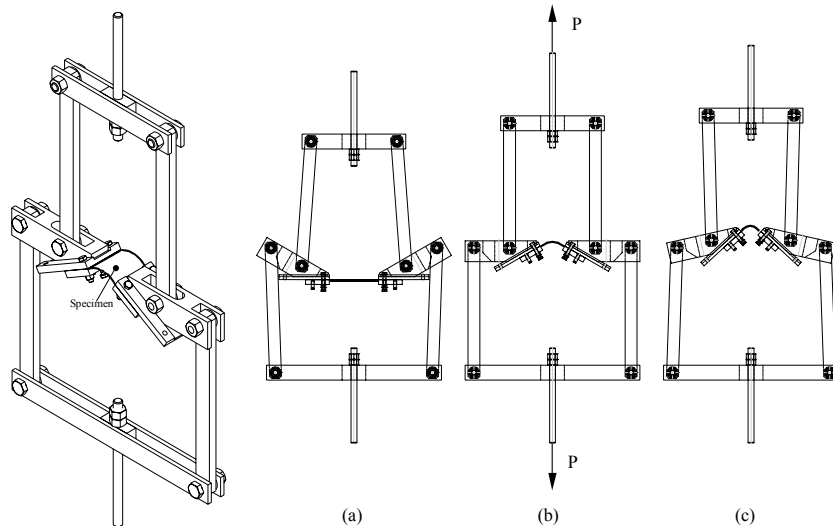


Figure 1: Clamping system for bending test (on the left). Different clamping configurations (on the right): a) Starting position; b) Pure applied bending moment; c) generic position. (Natali [8]).

3 RESULTS

Zn based intermetallic phases are characterised by a different growing kinetic (figure 2). After 15 seconds, the thickness of the η phase (Zn) is negligible. Between 60 and 360 s, thickness of η phase is almost constant, and, corresponding to longer dipping times, it decreases. The presence of intermetallic phases implies an evident modification in the applied bending load displacement experimental curves with respect to the non-galvanised steel. These modifications depend on the dipping time (figure 3) and they consist both in an increase of the applied load for the same bending angle, and in a modification of the deformation curve, with the minimum that slowly disappears. No differences are measured in the elastic stage.

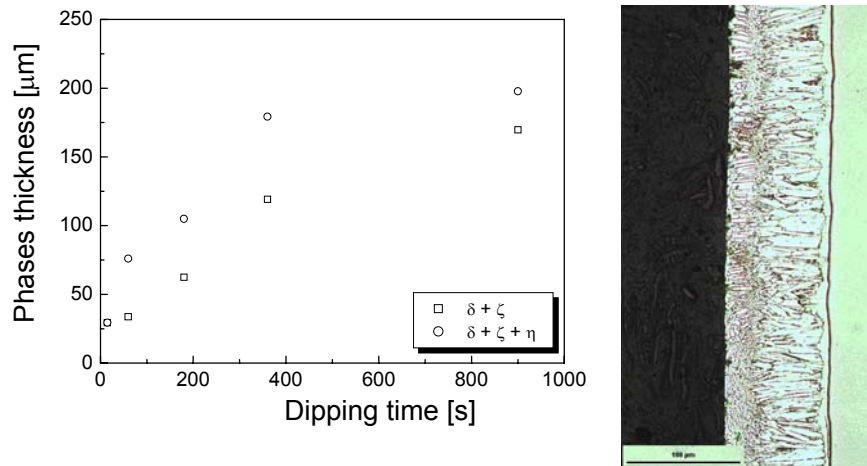


Figure 2: Dipping time influence on intermetallic phases thickness (on the left); Coating metallography, on the right (dipping time equal to 180 s; Nital 2 for 5 s).

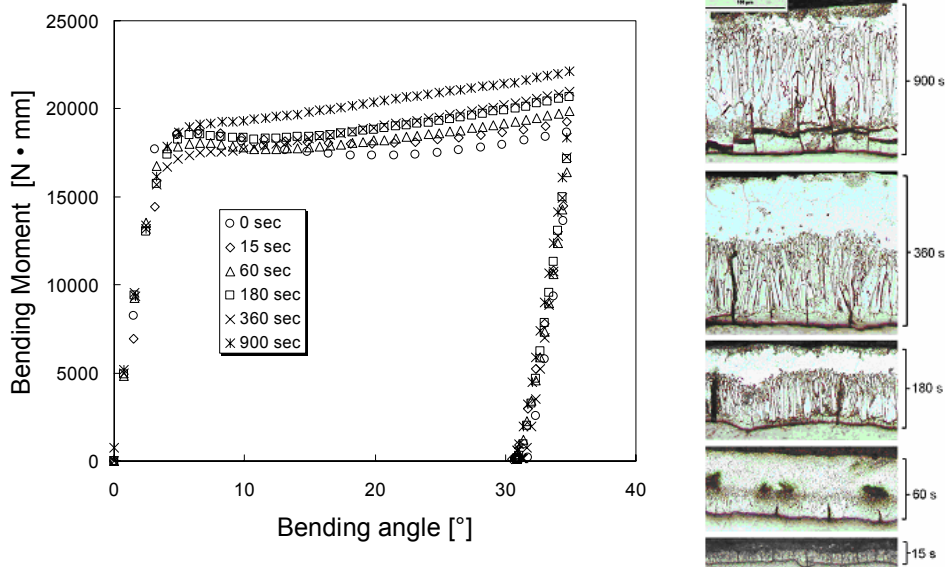


Figure 3: Influence of the dipping time on the bending tests results (on the left). Influence of the dipping duration on cracks development (on the right; bending angle equal to 30°).

The LOM analysis of the longitudinal sections of the bended specimens allows to show the presence of cracks in some intermetallic phases. Cracks initiate in the most brittle intermetallic phases (in the δ phase and, probably, in the not visible Γ) and propagate in the ζ phase. Cracks do not propagate in the most ductile phase that corresponds to the external η phase layer (figure 3, on the right). As a consequence, the presence of the η phase layer does not allow the contact between the substrate (the steel to be protected) and the environment. This phenomenon can be observed considering the steel galvanized with a dipping time of 15 seconds, for whom no η phase is measured (figure 3). Furthermore, the absence of the η phase implies a high value of the radial cracks density (figure 4, on the left). In fact, considering well developed zinc coatings (it means well developed δ , ζ , and η phases), it is possible to identify a linear relationship between the cracks density and the galvanizing time. The increase of the galvanizing time, implies the increase of the radial cracks density. If the η phase is absent, a very high radial crack density is obtained. If a longest dipping time is considered, it is evident both an increase of the radial cracks density, and the development of longitudinal cracks at the δ - ζ interfaces. This is probably due to the difference of their mechanical behavior: corresponding to high deformation values, that is consequent to a bending angle of 30° , a shear stress state could develop at the phases interfaces and generate the longitudinal cracks (Kim [9, 10]).

The proposed initiation and propagation mechanism of the radial cracks is confirmed by the bending tests performed for different bending angles (dipping time equal to 60 s; figure 4, on the right). It is possible to observe that a bending value equal to 10° does not imply the development of cracks. Higher bending angle values imply the increase of the damage level, with an increase of the cracks density.

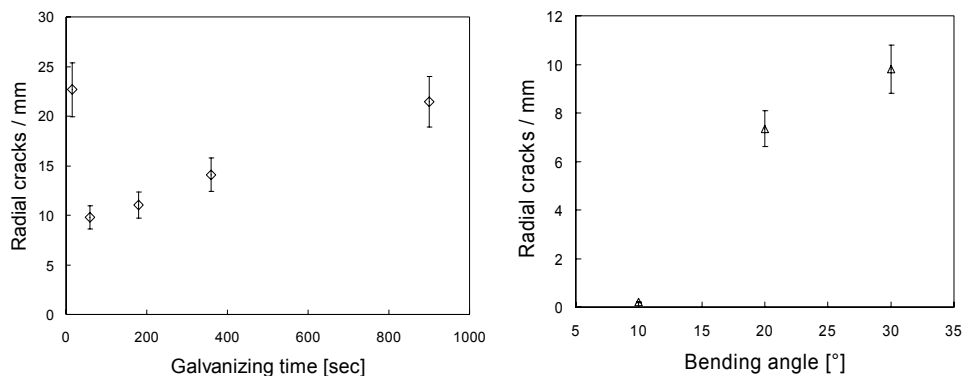


Figure 4: Influence of the dipping time on the radial cracks frequency (on the left). Influence of bending angle on the radial cracks frequency (on the right).

4 CONCLUSIONS

In this work the mechanical properties of hot dip zinc coated steel plates are investigated by means of a non-standardized bending test performed minimizing both the bending moment differences along the bending axis and the interactions between the clamping system and the specimen coating. Bending tests are performed both on non-coated and on hot dip zinc coated plates, correlating the measured variables (applied load and crosshead displacement) with the bending moment and the specimen bending angle, and damage mechanism are investigated by means of a LOM analysis of metallographically prepared bended specimens.

Considering the hot dip galvanized thin plates, the non-standardized bending mechanism confirms its advantages with respect to the standardized three points or four points bending tests, allowing to perform bending tests in non contact conditions and to obtain a pure constant bending moment for all the specimen length.

For all the investigated coating conditions, radial cracks are observed. They initiate corresponding to the most fragile phases (δ and probably Γ phases) and propagate up to the ζ - η interface. The coating thickness increase implies both an increase of the importance of the cracks in δ and ζ phases and the presence of cracks at ζ - δ interfaces. As a consequence, the increase of coating thickness implies an increase of the susceptibility to a coating-steel debonding damage mechanism, with a consequent loose of the coating adhesion and a decreasing of the capability of the zinc coating to improve the steel corrosion resistance. Furthermore, corresponding to higher bending angles (30°), it is observed the development of longitudinal cracks at the δ - ζ interface. This is probably due to the difference of their mechanical behavior that could allow the development of a shear stress state at the phases interfaces.

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