Damage investigation of Zn-Al alloy coatings on steel wires

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ABSTRACT. Generally speaking the rockfall protection net wires are Zinc or Zn-Al coated. This provides to the net a durable protection against corrosion. Due to their function, the rockfall protection nets can be damaged over time, and must be replaced. The aim of this work is to investigate the damage that the wire undergoes when subjected to "U" bending, in order to obtain a significant stress. Furthermore it has been analyzed the behavior of a Zn-high Al coating in comparison with the coatings normally used.

SOMMARIO. I fili delle reti paramassi vengono rivestiti con Zn puro o con leghe Zn-Al 5% per proteggerli dall'aggressione dell'ambiente esterno. Le reti, proprio a causa della funzione che svolgono, possono rovinarsi nel tempo, e devono quindi essere sostituite. In questo lavoro si è indagato il danneggiamento che subisce il rivestimento del filo se sottoposto a piegatura ad "U", in modo da ottenere una sollecitazione sensibile. In particolare si è analizzato il comportamento di un rivestimento realizzato con una lega ad alto contenuto di alluminio ed è stato confrontato con quello dei rivestimenti normalmente utilizzati.

KEYWORDS. Zinc-high Al coatings; Galfan® coatings; Zn coatings; Cracks; Rockfall protection nets.

INTRODUCTION

The rockfall protection nets stabilize rock walls, carrying out an effective containment function. The wires used for the production of rockfall nets are zinc or Galfan® coated [1], that is to make them resistant to oxidation.
In case of marine environments or particularly polluted areas, an additional plastic coating is used.
The erosion of soil and rocks may cause substantial damage to the coating of the nets, thus inducing a rapid deterioration of them.
In this work we investigated the damage that a coated wire undergoes when subjected to a considerable bending.
The investigated coatings were made of zinc, of Galfan® and of ZnAl22Si0.4.
The Galfan® is an eutectic alloy ZnAl5 boasting exceptional corrosion resistance and a considerable endurance.
This alloy is characterized by a melting temperature point lower than the zinc one (Fig. 1) [2] and generates a thinner coating compared to a classic galvanized one, with equal dipping time and using the same steel.
The ZnAl22 eutectoid alloy is the subject of numerous studies because it shows characteristics of superplasticity in appropriate conditions [3]. An alloy suitable for hot dip galvanizings is obtained by adding silicon [4]. The alloy is characterized by high plasticity, and it has a lighter weight than zinc or Galfan® coating, considering the same thickness obtained.
The purpose is to control the adherence of the coating and to verify the damage that it can possibly suffer.

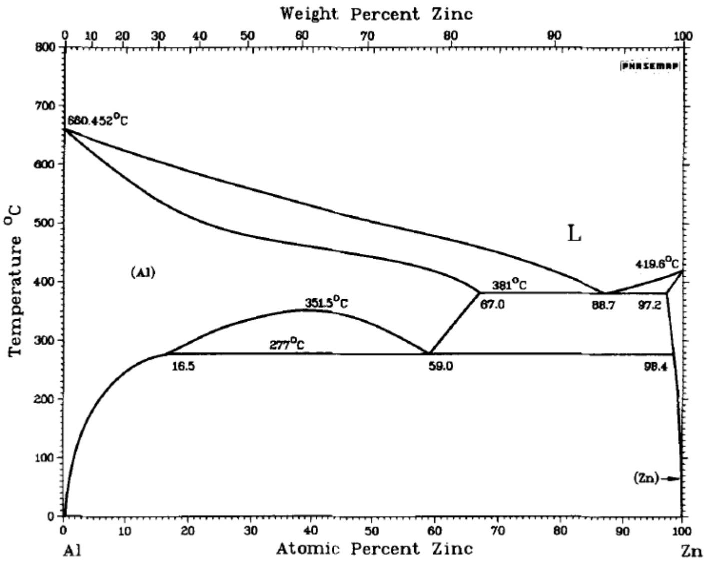

Figure 1: Al-Zn Phase Diagram.

MATERIALS AND EXPERIMENTAL PROCEDURES

The coatings obtained with the continuous galvanizing were simulated in our labs, in particular respecting the short immersion times used in this process.

C	Si	Mn	P	S	Cr	Mo	Ni	Al
0.0549	0.0138	0.332	0.005	0.005	0.0254	0.0064	0.0186	0.0309

Table 1: Chemical composition of the steel.

The wires, 2.6 mm diameter and 30 cm long, were pickled in an aqueous solution 15% of HCl at room temperature for 15 minutes, washed in water, fluxed in an aqueous solution containing 250 g/l of $ZnCl_2$ and NH_4Cl at room temperature and dried for 10 minutes at 120°C.
Three different bath compositions were considered: pure Zn, Zn+5wt%Al (Galfan®), Zn+22wt%Al+0.4wt%Si.
All the wires were dipped in molten zinc, in order to use this coating as "fluxant" for the two Al-alloys.
Zinc coatings were performed at 450°C ± 2°C, with a dipping time of 5s.
ZnAl5 coatings were performed at 420°C ± 2°C, with a dipping time of 5s (on the previous zinc coating dipped for 5s).
ZnAl22Si0.4 coatings were performed at 520°C (the melting point of the alloy is about 480°C), with a dipping time of 5s (on the previous zinc coating dipped for 5s).
All the wires were cooled in water after few seconds in air.
Microstructure analysis was performed by means of scanning electron microscope (SEM), with EDS.
Each wire has been bent into a U-shape on a cylindrical mandrel with a diameter of 10.4 mm (same diameter of mandrel for adherence wrapping test [5]) , stretching the material on the outer surface of the "U", while compressing the material on the inside surface.

EXPERIMENTAL RESULTS

Three types of coating were obtained and compared.
The micrographs related to the 3 coatings are shown below.

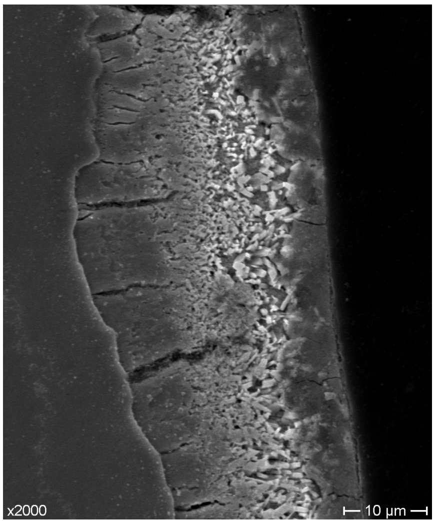

Figure 1: Pure zinc coating

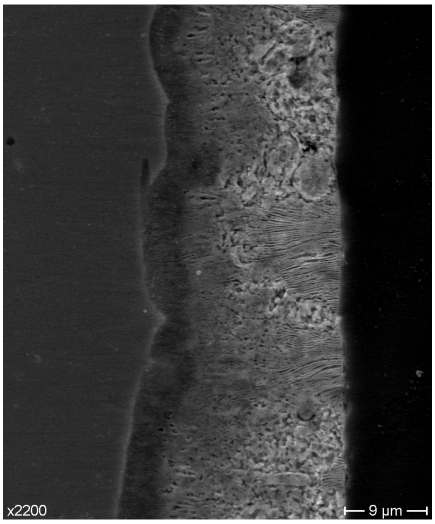

Figure 2: ZnAl5 coating

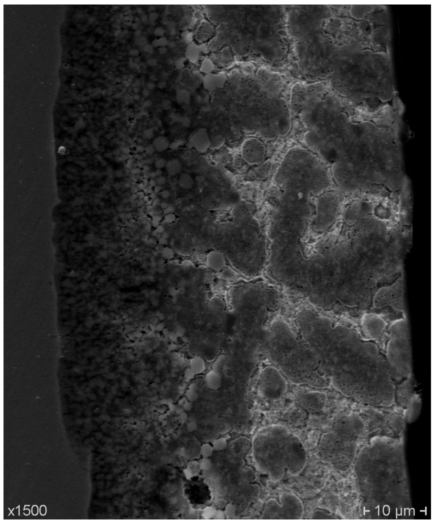

Figure 3: ZnAl22Si0.4 coating

Fig. 1 shows the pure zinc coating. It has an average thickness of about 20 µm.
It highlights the morphology of the coating, that consists of the classical Γ (23.5-28% Fe), δ (7-11.5% Fe), ζ (5-6% Fe) phases, with a little η (almost pure zinc) on the outside part [6]. The presence of the phases has been confirmed by several EDS analysis.
In Fig. 2, the coating ZnAl5 shows a first phase near the substrate composed by Zn-Fe-Al intermetallic (40 wt% Al, 25wt% Fe, and Zn 35wt%), with rising Zn and decreasing of Fe and Al going towards the outside.
The outer part of the coating shows the typical slats of an eutectic composition. The coating has a thickness of about 25 µm.
Fig. 3 shows a coating obtained with the ZnAl22Si0.4 alloy, and it has an average thickness of 30 µm.
The phase at the interface is composed of Zn-Al-Fe-Si intermetallics, the outer part has an average composition 40wt% Al and 60wt% Zn with traces of Fe.
Some wires have been subjected to bending. Some samples have been taken containing the apex of the bend and mounted using a resin. Then they have been metallographically prepared to observe the section in which the damage could be greater.
The micrographs of the stretched material on the outer surface of the "U" are shown below.

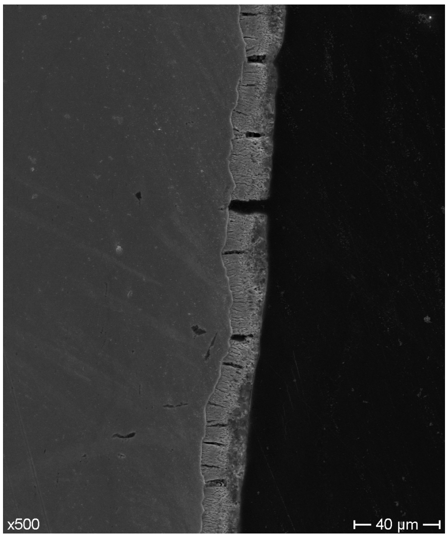

Figure 4: Apex of the bending of the zinc coating (stretched area)

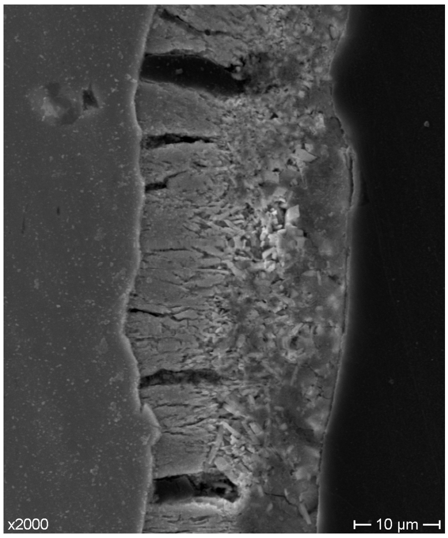

Figure 5: Top of the bending of the zinc coating (stretched area)

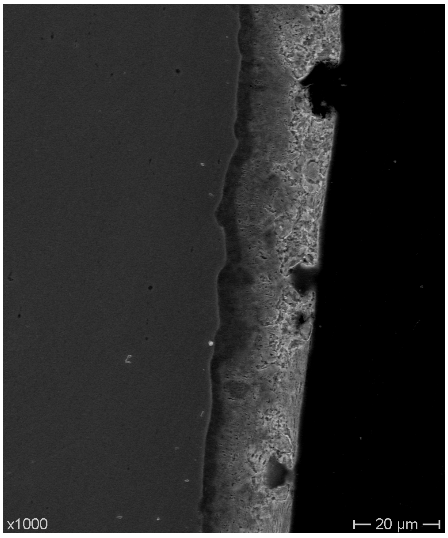

Figure 6: Apex of the bending of the ZnAl5 coating (stretched area)

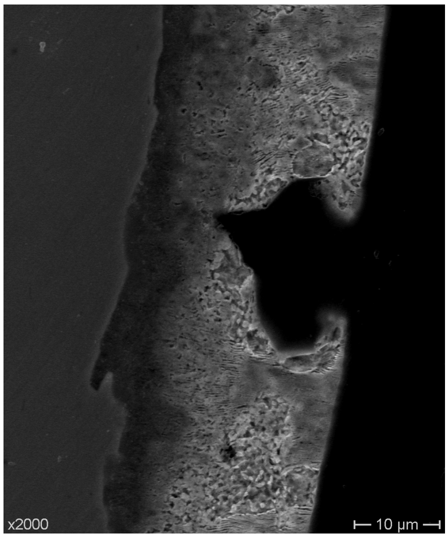

Figure 7: Top of the bending of the ZnAl5 coating (stretched area)

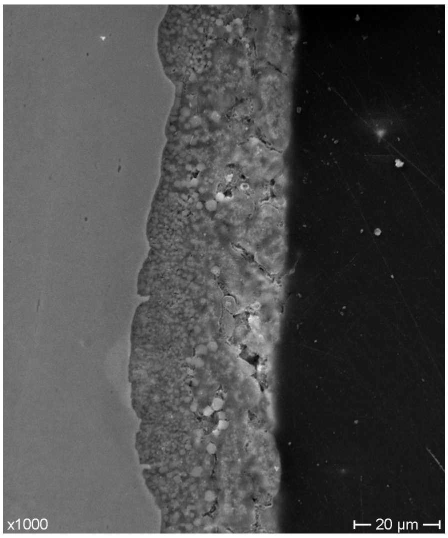

Figure 8: Apex of the bending of the ZnAl22Si0.4 coating (stretched area)

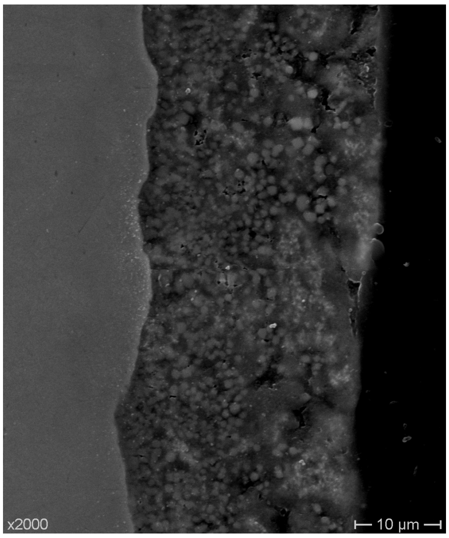

Figure 9: Top of the bending of the ZnAl22Si0.4 coating (stretched area)

Fig. 4 and 5 show the classical zinc coating. The top of the bending is visibly damaged in the stretched area.
The cracks take origin in Γ phase and they propagate in δ phase, that features a columnar morphology [6]. These cracks are partially arrested in ζ phase, characterized by a good ductility [7].
Fig. 6 and 7 show the ZnAl5 coating.
This undergoes a stretching near the bend, and the damage is evident only through some tears on the surface of the coating. However Galfan® shows also good adhesion to the substrate.
Fig. 8 and 9 show the ZnAl22Si0.4 coating. It is the only coating that has not suffered damage.
In correspondence with the apex it has only a slight thinning of the coating, which remains perfectly adherent to the substrate, proving to be able to follow completely the plastic deformation of the wire.
No damage in the compression zone of all coatings was remarked.

CONCLUSIONS

The aim of this work was to characterize three types of alloy coatings on a steel wire for rockfall protection nets. The coating process performed in lab has tried to simulate the one used in the actual manufacturing process. The coated wires were bent in a "U" shape to evaluate both the adhesion to the substrate, both the presence of cracks.

The three coatings tested showed all a sufficient adhesion to the substrate. However, the classic zinc galvanized has, at the apex of the curvature, radial cracks that nucleate in the Γ phase, propagate in δ and stop in ζ.

The presence of such damage, induced by the intrinsic fragility of the phases involved, can limit and compromising the corrosion resistance.

The Galfan® coating shows some superficial tears, induced by the tensile stress that can compromise the thickness and therefore its resistance to corrosion.

The coating obtained with the ZnAl22Si0.4 alloy, as well as showing the adequate adhesion, exhibits no cracking both internal (near the substrate), both external and is therefore the one that offers the best guarantees of reliability.

The presence in the alloy of a high aluminum content (22 wt%), combined with an adequate amount of silicon (0.4%) [8] added to limit the chemical reaction between Al and Fe [9], creates two positive effects on the coating: the first is due to a greater resistance to corrosion [10], and the second to the characteristics of high plasticity, which ensures an excellent resistance to plastic deformation.

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