PhD project Arcelor-Mittal / Mines ParisTech
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Title : ***Multiscale approach of the mechanical behaviour of hot-dip Zn-Al-Mg coatings on a steel sheet***

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Arcelor-Mittal is carrying out a research program aiming at determining the forming and mechanical properties of Zn-Al-Mg coatings on hot-dip galvanized steel sheets, depending on the solidification microstructures. The research strategy is developed along 5 lines: material selection, advanced characterization techniques, macroscopic mechanical properties of coatings, mesoscale modelling of microstructures and identification of deformation and inter- and transgranular damage mechanisms.
The proposed PhD project aims at applying advanced characterization and modeling techniques for a better understanding of the mechanical properties of Zn-Al-Mg coating along the previous lines. The objective is to draw from these observations new guidelines for the microstructure optimization.

1. Selected materials

Arcelor-Mittal has selected three types of coating on steel sheets having different compositions in Al and Mg. These coatings exhibit complex multiphase microstructures. Tensile tests will be performed on all three materias in order to identify the respective deformation and damage modes at the macroscopic scale (crack density and size) and at the mesoscopic scale (SEM analysis). One material will then be selected to perform the full proposed multiscale analysis.

2. Identification of deformation and damage mechanisms in the various phases

The experimental techniques are the following

- ionic polishing of surfaces, analysis of morphological and crystallographic textures by means of EBSD, chemical analysis;
- SEM analysis of surface and transverse sections of the coating for the identification of deformation modes (dislocation slip systems) and damage (cleavage planes, intergranular fracture);
- « Slice&View » au SEM-FIB characterization of the morphology and distribution of phases and defects; cross-sections to connect surface observations and underlying damage up to steel/coating decohesion;

Lattice orientation fields in the grains will be determined before and after tension. The crystallographic texture will be connected to the orientation of observed cracks. FIB observations by serial sectioning of the full coating thickness will be performed for some selected zones in the grains. This methodology has been successfully tested in [1].

3. Strain and damage field measurement at the macroscopic scale

Non-homogeneous deformation of the surface of coated tensile specimens can be quantified by means of digital image correlation methods providing the two-dimensional strain field and the distribution of cracks on representative surfaces. Notched samples will be used to concentrate the damage zones. The work-program contains: (i) strain field measurements (DIC), (ii) characterization of the crack networks depending on the overall strain level, and (iii) the description of the final crack distribution, following a methodology well-established in the lab [2]. These technique will be applied to all three materials. Finite element simulations will be performed to optimize the notch radii to study the influence of stress triaxiality on damage.

Some tests will be performed on the biaxial machines with cross-shaped samples. Combinations of tension and shear loading will be tested to trigger specific damage modes.

The obtained results, combined with suitable finite element computations, will be used to determine a macroscopic constitutive law and the toughness of the coatings.

4. Strain and damage fields at the mesoscale

High resolution microscopy, together with SEM, will be used to characterize the deformation and damage modes of the individual phases inside the grains. In situ tensile tests will be performed in order to extract the chronology of deformation and damage events, and also to determine the yield stress and cleavage stress of the various phases.

The surface roughness will be measured before and after deformation in order to distinguish the existing thickness fluctuations and the roughness induced by plasticity and damage.

5. Modeling and simulation

Finite element simulations at various scales will be performed all along the study either for preparation of the tests or for their interpretation.

Homogenization theory will be applied to estimate the stress level in the various phases and predict the inception of plasticity and damage. The homogenization models will be used to study the impact of the crystallographic texture on damage initiation [3,4,5].

Full field simulations are also planned using the 3D FIB images for a more detailed description of local fields and better identification of the constitutive laws of the phases.

Cohezive zone models can be used to predict damage initiation at grain boundaries or at the interfaces between the phases or at the coating/steel interface. The propagation of cracks from the surface to the steel/coating interface will be studied.

6. Guidelines for microstructure optimization

The results of this ambitious work will be used to derive guidelines for the design of tougher coatings by optimizing their microstructure. Degrees of freedom are the possible thermomechanical treatments and thermodynamic considerations possibly coupling CALPHAD predictions and the phase fied approach.

Références

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