Interfacial forming limits of polymer-coated steel: a multi-scale numerical-experimental analysis

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Polymer coated metals are nowadays used as a packaging material for a large variety of products, e.g. in beverage and food cans. The polymer layer is applied to the steel before a product is formed, after which it is subjected to the same forming process as its sheet metal substrate. Besides the traditional forming limits of the metal sheet, additional limits result from the behaviour of its coating, e.g. through roughening, delamination and cracking. This causes a loss of protective and attractive properties of the product and is therefore unacceptable. If delamination can be predicted, the processing routes, parameters and tooling can be adjusted a priori to prevent it. The behaviour of a coated sheet relies on the intrinsic properties of the metal, the polymer and their evolving bonding interface. This presentation focuses on a multi-scale numerical-experimental method to characterize delamination-driven forming limits of a polymer coated metal sheet, used for packaging applications.

Peel-off tests have been carried out inside an environmental scanning electron microscope (ESEM) allowing to study the delamination process at several length scales. A 3D constitutive model is introduced for the PET coating, describing the large strains and the time dependent behavior of the thin polymer layer. The interfacial properties are assessed in a 3D cohesive zone element, which is developed and implemented in a large deformation context. This interfacial model relies on experimental observations, showing that interfacial fibrilation is the relevant mechanism governing the delamination process of interest. Fibrilation involves large displacements at the interface as well as large deformations in the surrounding bulk materials, for which an improved interfacial description has been developed. A numerical 3D peel test is carried out, permitting to extract the interfacial properties from the experiments conducted.

Plastic deformation of the metal substrate results in substrate roughening and the loss of adhesion. A relationship between the metal pre-deformation and the roughness is established as well by coupling the interfacial properties (adhesion) to the substrate roughness. The 3D cohesive zone element is extended to incorporate these effects of substrate roughening. The interfacial model has been integrated in the simulation of a sheet metal forming process, whereby critical areas for delamination are identified. Within this context, several additional aspects related to the formability of polymer-coated metal sheets will be discussed:

- The role of the external loading conditions
- Roughening of the metal substrate and its relation with crystal plasticity
- Influence of the intrinsic time-dependency of the coating