Computation of residual stress development in boron steels and experimental assessment with X-ray and neutron diffraction.

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Abstract

The hot stamping process has been deployed in the automotive industry to improve the lightweight design and security of body in whites, as detailed in the review of Karbasian and Tekkaya (2010). The latest generations of boron steels have a higher carbon content, resulting in improved mechanical properties, useful for crash-components such as B-pillars (see Merklein et al. (2016)). However, increasing carbon contents favour the potential risk of detrimental residual stresses. Two competing mechanisms are involved: the martensitic transformation, which redistributes stresses within the martensitic steel, as highlighted by Bok et al. (2015) and Neumann et al. (2019), and the coating-substrate interaction, as stated by Morel (2023). Boron steels are usually protected with an aluminised coating, which contributes to the development of residual stresses due to the difference of mechanical properties, by enhancing strain incompatibilities within the blank.
Harnessing residual stresses is thus of prime importance and can be achieved through both modelling and experimental characterisation. A micromechanical model has been developed by Morel (2023), which encompasses both martensitic substrate and Al-Si coating descriptions from the end of the austenitising step to the complete cooling of the blank. The substrate phase transformation from austenite to martensite is central to the model, as it is pivotal into the stress development during the hot stamping process. Finite element simulations have been performed on a representative layer of the omega-shaped parts to reduce the required computation time. At the end of the simulation, the stress tensor has been compared to experimentally determined residual stresses in both planar directions.

Two different ways have been considered to determine residual stresses: laboratory X-ray

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diffraction (XRD) and neutron diffraction (ND), performed on the top and on the fillet of an omega-shaped hot-stamped part. Having a lower energy, XRD is unable to diffract through the coating and requires successive matter layer removal to frame a stress profile within the substrate. This has been performed with electrolytical etching by successive 50 μm removed layers. However, ND experiments, performed on the SALSA beamline at the Institut Laue-Langevin, access the martensitic substrate through the coating and offers an in-depth complete stress profile without any matter removal. Both XRD and ND experiments are in line and yield similar levels of residual stresses within the substrate. Within the near-coating zone, stresses are in compression around -200 MPa and slowly decrease further away in the substrate. A comparison between numerical and experimental stress profiles displays satisfying results in both planar directions through the whole thickness of the part.

To conclude, ND experiments validate that the electrolytical etching required for XRD measurements do not distort residual stress profiles. It also furthers the comparison between XRD and finite element simulations as many part geometries have exiguous areas inaccessible to XRD measurements. Besides, these results tend to confirm the leading role of the coating into the development of residual stresses during the hot stamping process of boron steels.

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