Development of Innovative Nanoparticle-Based Protective Coatings for the Production of High-Strength Steel Components by Press-Hardening

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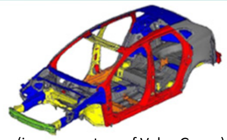
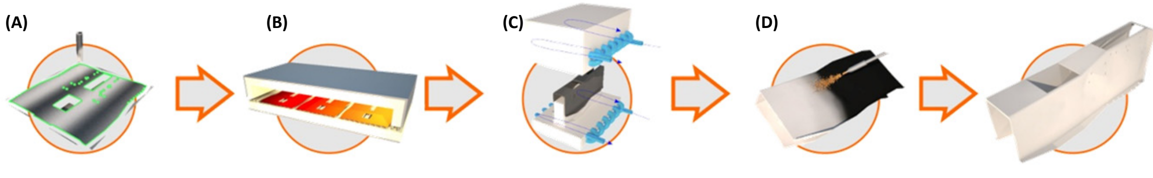
Introduction & Project Goal

Production of advanced high strength steel (AHSS) components in automotive industry aims at the drastic reduction of the vehicle weight. The highest strength with complex geometry is achievable only in the direct press-hardening process, where heating up to 950°C and quenching in press takes place. One further step includes typically a sandblasting cleaning of the final component in order to make it weldable and paintable because used steels, like 22MnB5, are prone to severe corrosion unless adequately coated. Initial attempts to fabricate a protective coating by the classical sol-gel process have delivered decent protective ability at temperatures up to 800 °C. Instead the multilayer coatings based on particulate Sols have demonstrated necessary corrosion and thermal shock resistance, as well as a flexibility upon deformation in press.



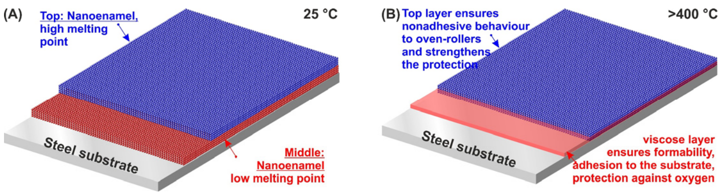
(image courtesy of Volvo Group)



Above: **Body-in-white, where press-hardened components are represented in red color**

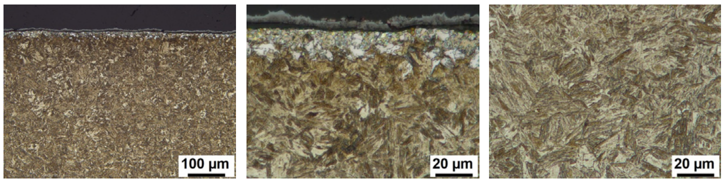
Left: **Typical process flow for the production of press-hardened steel components for OEM producers. A steel sheet is cut (A), heated (B), then (C) reshaped and cooled simultaneously, and finally (D) cleaned by means of sandblasting**

Our Approach – Multilayer Ceramic Coating (MLCC)



In the revised approach aqueous dispersions of inorganic nanoparticles, for example, made of SiO_2, accompanied with additives for accelerated sintering process, improved adhesion, and rheological properties among others have been applied via sol-gel process (dip-coating). That has allowed to improve the solid content in the initial coating and, therefore, to achieve the low porosity and much thicker coatings in one coating step.

The coated samples were heated at 950°C followed by austenitisation between steel blocks at room temperature. The morphology of the substrate and the layers has been characterized by bright field microscopy, SEM and ESMA, while the oxidation rates have been investigated by thermogravimetry (TG).

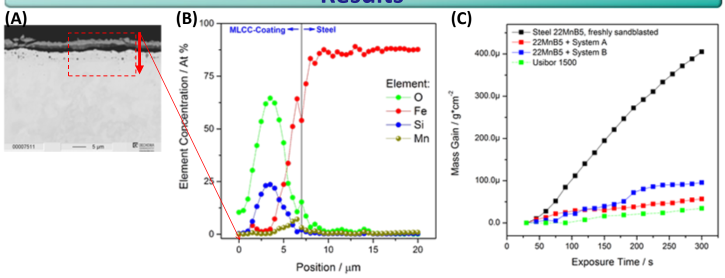


Overview | **Coating-substrate interface** | **Middle of the substrate**

Martensitic microstructure in 22MnB5´(1.5mm)-MLCC after the austenitisation for ≥3 min @950°C and quenching down to room temperature

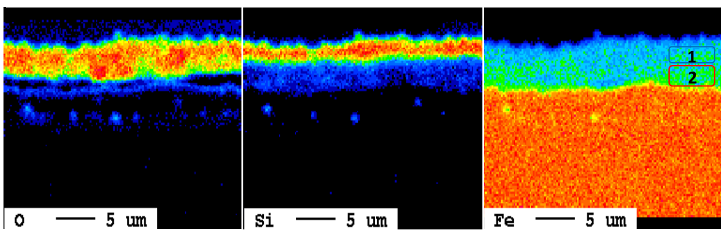
- With MLCC accelerated austenitisation is possible (100% martensite is achievable upon quenching after 3 min @ 950°C for 1.5mm steel substrate)
- Some decarbonisation of the steel at the coating-substrate interface prevents martensite formation.

Results



(A) Cross-section of the system 22MnB5-MLCC after firing @ 950°C and quenching at room temperature, (B) Element distribution along the indicated region, (C) TG curves for 22MnB5 samples with different coatings in air @ 950°C

- MLCC protects the steel from scaling, but only partly from internal oxidation
- The propagation of scale (Fe_xO_y) is limited by the thickness of the coating
- In comparison with industrial standard Usibor 1500 (22MnB5 with AlSi-coating) the MLCC systems provide decent protection from high-temperature oxidation as confirmed by TG



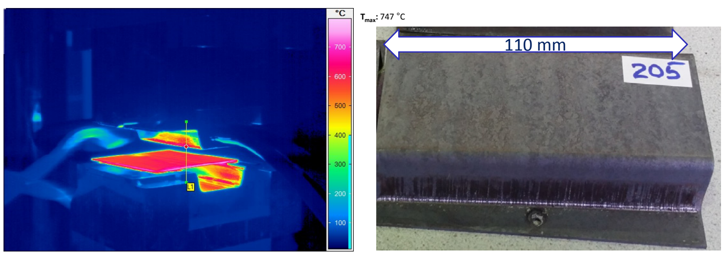
Elemental maps for the system 22MnB5-MLCC after firing @ 950°C and quenching at room temperature

- After quenching the MLCC consists mainly of oxides as could be seen from O-map
- The preservation of the Si- and Fe-content gradient confirms the limited diffusivity between the top and the middle nanoenamels, which play various functions

Application Trials

MLCC application trials @ press-hardening facilities of Steel Institute (RWTH Aachen)

- Austenitisation (continuous heating) has been accomplished in an oven with a flow of N_2 to reduce the oxidative effect of the atmosphere
- Sample transfer from the oven into press takes less than 6 seconds, so conditions comparable to industrial ones have been re-created



IR image of the sample before and optical image after quenching in the press

- After the austenitisation and the transfer to press the sample maintains temperature above the bainite transition (ca. 650°C)
- Low glass-transition temperature of the middle nanoenamel allows the flexibility of the coating upon deformation of the steel blank

Conclusions & Outlook

- **With the multilayer ceramic coating (MLCC) 100%-martensitic microstructure could be obtained within 3 min @ 950 °C without considerable scale formation**
- **Oxidation resistance of MLCC-coated 22MnB5 is comparable to Usibor 1500 (AlSi-coated 22MnB5)**
- **Initial trials for press-hardening with MLCC went successfully, industrial implementation is envisaged**

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