Published: International Conference on Steels in Cars and Trucks, June 15-19, 2014, Braunschweig; © 2019 Steel Institute VDEh

Performance of a ZM-coating with 1.6% Mg and 1.6% Al in the autobody process chain

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Abstract: Stroncoat® belongs to a new family of zinc magnesium coatings developed in Europe with comparable phase composition and properties. Their range in composition goes from 1wt% for Mg and Al, respectively, to 3wt% Mg and 3,7wt% Al, the remainder being zinc, whereas Stroncoat® as a typical member contains 1,6wt% Mg and Al, respectively. All of these coatings have been proven to yield high corrosion protection, especially under salt rich lab test conditions. This has put the question, whether the possible advantages can be saved throughout the process chain of building the body-in-white. Several key aspects of forming and joining properties of Stroncoat® were benchmarked with established zinc coatings in state-of-the-art lab tests. Particular interest was put on resistance spot weldability, adhesive joint strength in aged and unaged condition as well as on zinc abrasion and galling during deep drawing. Stroncoat® was found to be compatible with standard processes, bringing additional benefit to car manufacturing. Many properties can be characterized in the lab, while some may only be understood during a production trial. Very often there is a relevant interdependency between the coated sheet steel and the individual manufacturing process.

Key words: ZM coatings, application properties, car production, adhesive joining, resistance spot welding, forming, zinc abrasion, tool pollution

1. *Introduction*

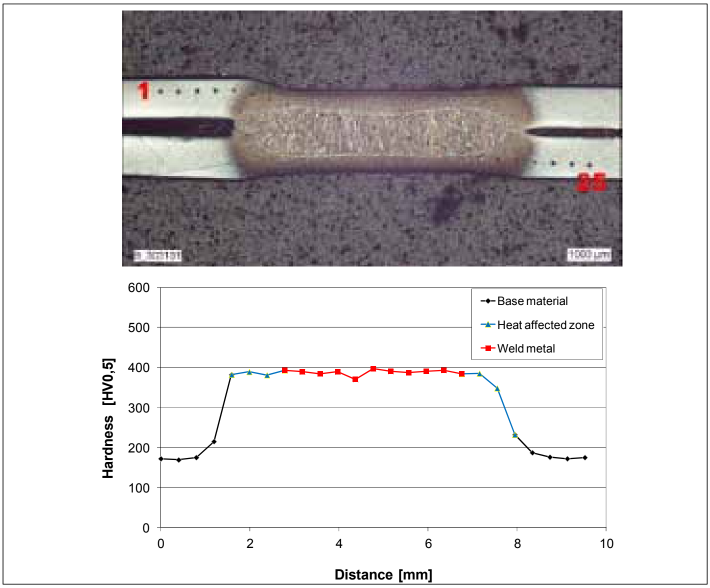
Salzgitter Flachstahl runs two hot dip galvanizing lines, where galvanized strip and ZM-coated material can be produced. Since the original development of Stroncoat® was focussed on improved corrosion properties, the current main area of application is the construction industry with colour coated ZM material [1]. The enhanced processing properties compared to standard zinc coatings are proposing to use ZM in the automotive industry, too [2-4].

2. Joining

2.1 Resistance Spot Welding

Resistance spot-welding is examined for integration of formed-steel-parts into the body-in-white (BIW). The influence of the ZM-coating on the welding behaviour and the joint properties is of particular interest especially for resistance spot welding due to the surface sensitivity of this process. A micro alloyed fine-grained steel, HC420LAD+ZM70 having a thickness of t = 1.5 mm, was available for the investigation. The portrayed investigations were conducted on a pedestal-type spot welding machine with medium-frequency direct-current technology (1000 Hz). Welding parameters are stipulated according to SEP1220-2 on the basis of the work piece thicknesses and the surface conditions of the test material [5]. The presented results for resistance spot welding encompass the determination of the quality limits, the microstructure and the load-bearing behaviour of the joint.

For H420LAD+ZM70, a welding range of 1.2 kA can be determined. At the same time a number of 1100 welds was achieved using one pair of electrode caps. A ferritic structure with small proportions of pearlite exists in the base material, Fig. 1. Due to the welding, a mixed structure consisting of ferrite and martensite occurs in the heat-affected zone (HAZ). Bainite and martensite are present in the molten metal. Starting from the base material (170 HV0.5) and via HAZ and weld nugget (397 HV0.5) the hardness traverse exhibits a rise. No influence due to the coating can be found in joints of the material, also no pores were detected.



Material

HC420LAD + ZM70

Sheet thickness

1,5 mm

Joining process

Resistance spot welding
1000Hz / MF

Test scope

Metallography

Parameter

Magnification : 500:1
Caustic : HNO_3

Electrode type: F1-16-20-5,5
Electrode force: 4,5 kN
Welding current: 8,7 kA (I_{max})
Weld time: 260 ms

Specimen

SEP1220-2

Fig. 1: Cross section of weld with hardness measurement

With the HC420LAD + ZM70 mean values of pull-off forces for shear tension between 8.6 kN for lower quality limit I_{min} and 9.7 kN for maximum welding current I_{max} were achieved. In quasi-static cross tensile testing mean values of pull-off forces between 4.6 kN for lower quality limit I_{min} and 7.1 kN for maximum welding current I_{max} were achieved. Pull-off forces show, as expected, lower values in cross tensile strength due to the notch sensitivity of this high strength steel. Concerning fracture behaviour for both, tension shear and cross tensile testing, plug failure could be achieved. The strengths of the joints subjected to cyclic stresses were investigated on component-like H-shear lap specimens. Spot welds of HC420LAD+ZM70 show comparable values of fatigue life to spot welds of GI coated material.

ZM coatings are comparable to GI concerning parameters like welding range or electrode life time for resistance spot welding carried out in mid frequency.

2.2 Adhesive Joining

Compatibility with structural adhesives is mandatory to all metallic surfaces used in car bodies. This applies to both the initial strength and its change due to environmental influences. To evaluate the compatibility of adhesives on metallic surfaces, the use of single overlap shear specimens that are tested in quasistatic tensile tests, is quite common. Tensile shear strength and appearance of fracture, represented by the description of the ratio of cohesive / adhesive fracture patterns, are used to qualify adhesive joints. Adhesive compatibility of ZM coatings was tested with different structural adhesives of epoxy (EP) and rubber (RUB) type regarding lap shear strength, fracture mode and impact peel resistance before and after accelerated ageing in a cyclic corrosion test (CCT) according to Volkswagen's PV1210 with at least 5 identical samples. The corrosion test includes salt spraying according to DIN EN ISO 9227 NSS, constant humidity acc. to DIN EN ISO 6270-2 CH and normalized room climate (23°C; 50% r.H.). Samples for shear tests were prepared according to VW PV 1235; samples for Impact peel according to DIN EN ISO 11343. Testing was performed after 24h or ageing for 90/60 days in CCT (normal climate at weekends was skipped). Evaluations were done regarding lap shear strength F_s max, ratio of surface near cohesive failure SCF, and impact peel resistance F_{peel}, respectively. Results derived from single overlap shear specimen are influenced by substrate properties and therefore hardly comparable, if different steel grades and sheet thicknesses are used. Therefore tests on 3 identically prepared wedge shaped specimen were performed. In addition, shear loads are not as suitable as peel loads to obtain information about the adhesion of adhesives to substrates as peel loads are a far more unfavourable load case for adhesive joints. If the results after ageing are of interest, it has to be noticed that in the field specimens are often loaded both by climate and mechanical loads. In climate chambers, only ageing influences the bond strength.

2.2.1 Lap Shear Strength

In the unaged state all epoxy based adhesives revealed slightly more than 20 MPa lap shear strength on GI and ZM substrates. With respect to the steel grade (DX54) and substrate gauge ~ 1mm this indicates excellent adhesion properties. This is also true for the rubber based adhesive, which yielded approx. 10 MPa lap shear strength on both substrates. After CCT, no sample revealed corrosive undercreep of the joint. Significant decreases of the lap shear strength from its initial value were measured for all samples. While ZM with epoxy adhesives retained approx. 80-90 % of its initial value, GI could only

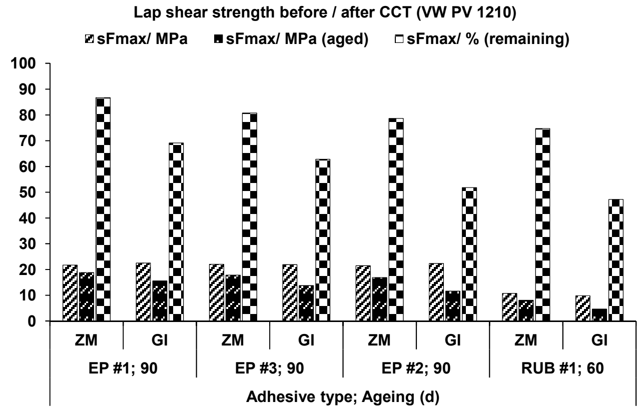


Fig. 2: Lap shear strength before and after ageing

keep 50-70 % of the initially measured strength. With well above 75% (ZM) vs. almost 50% (GI) this was even more correct for the rubber adhesive. Figure 2 gives a brief comparison of the lap shear strengths before and after ageing. Evaluations of the fracture mode underline the above findings. While the shares of cohesive failure decreased markedly for all epoxy adhesives on GI after ageing, ZM could retain more cohesive failure. Similar behaviour was found for the rubber based adhesive

2.2.2 Impact Peel Resistance

Impact Peel was performed to find out about the resistance of the metal/polymer interface against high speed peeling and its susceptibility to corrosion.

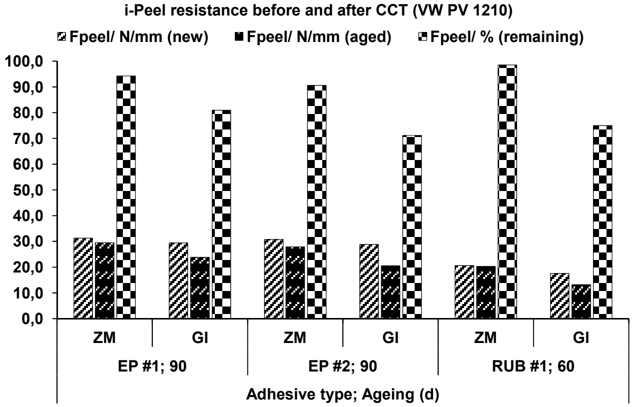


Fig. 3: i-Peel resistance before and after ageing

After accelerated ageing, none of the joints revealed corrosive attack. All samples failed 100% (S)CF. Figure 3 shows a comparison of the peeling resistance measured before and after ageing. It clearly shows less decrease for ZM based samples with all adhesives, indicating a higher resistance against degradation of the interface by environmental attack.

2.2.3 Wedge Test

The influence of ageing with superimposed mechanical loads on adhesive bonds can be determined with the so called modified wedge specimen. This test was developed at University of Paderborn [6] and allows applying the same mechanical loads on an adhesive layer whatever substrate is used and whatever the properties of the substrate may be. This is realised by bonding two sheets of steel, where adhesive is applied only on the last third of the specimen. After bonding the specimens, peeling loads are applied to the adhesive by driving a wedge of a fixed height between the bonding mates with a defined distance to the adhesive. With the wedge parameters height and distance, one can calculate the deformation of the adhesive, which is characterised by a differential equation, which describes the deflection curve of the bonding mates when they are spread by the wedge. From the resulting deflection at the beginning of the bondline, one can calculate the applied loads. To understand the principle of this test, the following figure may be helpful (Fig 4, left).

The specimens are put into a climate chamber and are investigated regarding cracking and crack growth every week. As a result you will get a diagram, where crack propagation is plotted over time. To compare the adhesion of common structural epoxy-based adhesives to zinc-magnesium coatings and to common metallic coatings, wedge tests were performed with two different epoxy-based adhesives on zinc-magnesium coatings, hot-dip galvanised and electro-galvanised coatings.

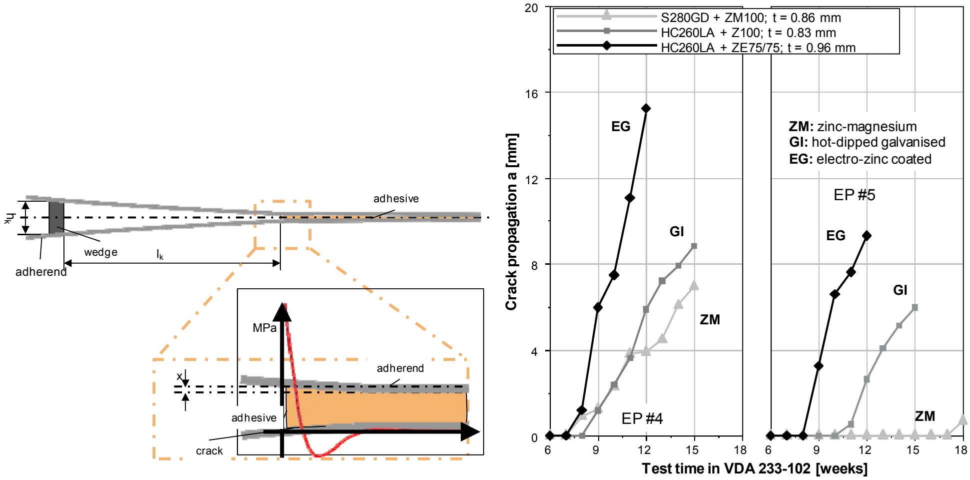


Fig. 4: Results of wedge tests performed on metallic-coatings

The wedge specimens were aged using VDA233-102 ageing test. The results are shown in Fig. 4. One can see that in the case of EP #4 cracking of the bond starts nearly at the same time, whereas crack propagation on ZM coatings is slower as on conventional steel coatings. Using EP #5, one can see that crack propagation is again slower using ZM than when using EG and GI. In addition, cracking starts at a point much later in time using ZM coatings.

The tests performed on different metallic coatings with different epoxy-based adhesives show, that using ZM is beneficial in concerns of combined mechanical and corrosive loads compared to standard zinc coatings.

3. Forming

In deep drawing processes the friction between blank holder, die, and blank can have a great influence on the forming result. If the coefficient of friction (CoF) is too high, sheet thinning and cracks in critical forming areas could appear. In previous studies, the good tribological behaviour of ZM-coatings in sheet metal forming was exposed [3]. Stroncoat® shows advantages in multiple forming steps and exhibits a low temperature sensitivity, which has been tested with the Strip-Drawing-Test (SDT). To determine the behaviour of Stroncoat® for higher degrees of deformation, laboratory tests with the Draw-Bead-Test (DBT) were performed on one hand and a trial with a deep drawing part at a car manufacturer was realised on the other hand. Low coating abrasion is an important factor in sheet metal forming. Otherwise it may lead to tool pollution in form of galling and powdering. Therefore pilot-line experiments were performed to compare zinc abrasion of Stroncoat® to GI and EG. All tests were done with similar mechanical properties and roughness parameters of the materials.

3.1 Multiple forming steps

Strip drawing tests conducted with Stroncoat® and GI coatings show a comparable CoF for the first pass [3]. To reproduce the tribology condition of a deep drawing process, the Draw-Bead-Test was used. The radii were varied (2 mm and 5 mm) to cause different degrees of deformation. The surfaces of the ZM- and Z-coatings changed during the DBT, see figure 5, left. On the SEM-image a significantly higher smoothing of the GI-coating can be seen than in case of Stroncoat®.

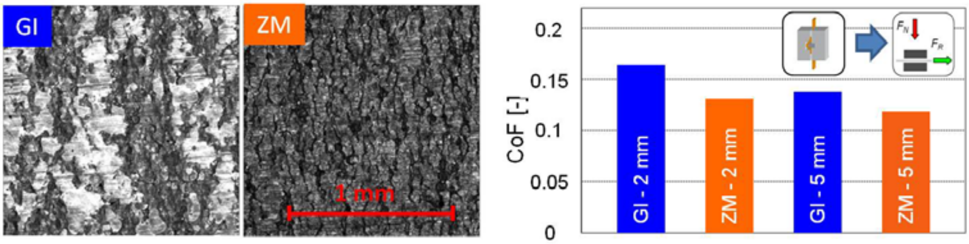


Fig. 5, left: surface after DBT; right: comparison of CoF after DBT between ZM and GI.

The new tribology performances of the changed surfaces after the DBT are then determined with a subsequent Strip-Drawing-Test. The resulting friction coefficient displays a much lower value for Stroncoat® than for GI, see figure 5, right. The same ratio can be observed for a lower degree of deformation (radius = 5 mm). This corresponds to former findings that Stroncoat®-coatings have distinct advantages, if formed areas experience re-contact to the tool, such as in multi-stage processes [3].

3.2 Single forming step

In addition to the lab test, a trial with a door inner part was realised at a car manufacturer, see figure 6, left. The standard material was coated with GI and the experimental coating was Stroncoat®.

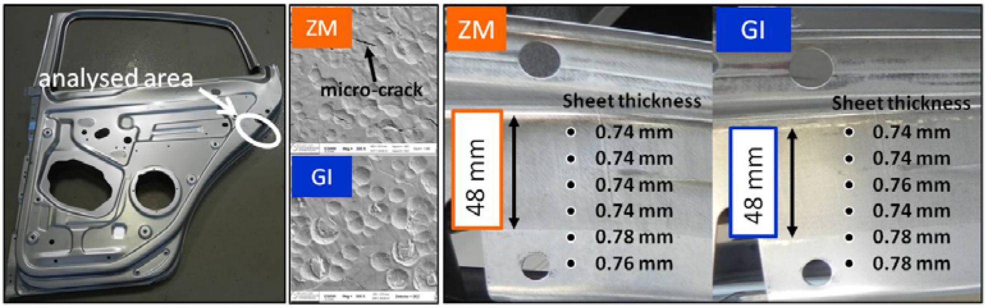


Fig. 6, left: door inner trial part; mid: SEM image of ZM and GI coating; right: sheet thickness thinning and contact length.

The part quality, evaluated by visual assessment was equal for Stroncoat® and the GI-coating. The surfaces of both material were captured with a SEM (figure 6, mid) for detailed analysis. Furthermore sheet thinning at the contact area of punch and die and flow behaviour at the main forming area were measured (figure 6, right).

During forming of ZM-coatings micro-cracks may occur in the coating, see figure 6, mid. These micro-cracks in the ZM-coating do not impart the formability in deep drawing processes, since the thinning of the GI- and ZM-materials were measured as nearly equal. The same holds for the contact length at the deep drawing area. According to this, the friction conditions of GI and Stroncoat® are not influenced by the observed micro-cracks and showed a similar forming behaviour in this single pass forming step.

3.3 Coating Abrasion

The coating abrasion of Stroncoat® has been tested with a pilot line trial at PtU, TU Darmstadt, see figure 7, right [7]. The reference coatings were GI and EG. The three test materials were cut from one mother coil and accordingly show comparable mechanical properties and roughness parameters. Each material experienced 6000 DBT strokes of 100 mm.

Figure 7, left: zinc abrasion appearance and amount between 3001st and 6000th stroke; right: pollution test with the DBT at PtU via FILZEK-TRIBOtech.

GI coated material left the most debris in form of powder and many big flakes. For EG, the measured amount of material was already reduced by half, showing powder and fewer small flakes. For Stroncoat® the debris was even reduced down to a third of GI, leaving mainly fine powder. Cold shuts could be experienced explicitly for GI and to a lesser extent for EG, but none for Stroncoat®.

With the use of Stroncoat® abrasion can be significantly decreased and lower galling and powdering ensure high process stability. So, Stroncoat® has a positive impact on the tribological lubricating effect.

3.4 Coating Hardness

The consistency of a surface in a tribological system is influenced by its hardness. To understand the hardness of ZM coatings, the different phases were identified in SEM cross sections (cf. fig. 8): I) zinc primary crystals, II) fine lamellar ZnMgAl eutectic and III) coarse lamellar ZnMg phase. These different regions were measured with a nano-indenter and the resulting Vickers Hardness was calculated to I) 100 Hv, II) 150 Hv and III) 180 Hv, whereas the hardness of a reference GI coating yielded 90 Hv. This gives a possible explanation, why ZM coatings are doing so well during deep drawing and other forming processes: The imprinted deterministic surface roughness of a steel sheet offers lubrication pockets for the tribo-system. Under high contact pressures, these lubrication pockets may level out and an increasing metal-metal contact may lead to cold shuts, which then raise friction resistance. A harder coating may maintain lubrication pockets for a longer time, avoiding metal-metal contact and resulting cold shuts. Besides that the harder ZM coating seems to better withstand the shear stresses applied by the relative movement of tool surface and steel sheet, staying more consistent without losing much material during the forming step.

Fig. 8, a) cross section **b) Mg-rich phases** **c) Al-rich phases**

4. Summary

The good resistance spot weldability and excellent forming properties of Stroncoat ® facilitate processing during the manufacturing of the body-in-white. The comparison of Stroncoat® to standard coatings like GI or EG shows that the already known good corrosion protection of ZM coatings also favors properties of adhesive joints, especially after corrosive attack. This opens the path for a new type of coating in the automotive sector. The manufacture of automobile parts with ZM-coated sheets has started and will grow strongly in the future. Stroncoat® is now being developed to fulfill quality standards also for exposed parts.

5. Literature

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