INFLUENCE OF HEAT TREATMENT ON Al-Si COATING CHEMICAL COMPOSITION

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Abstract

This paper addresses structural changes of Al-Si coating depending on various heat treatment parameters. Al-Si coated martensitic steel is one of the most commonly used materials in automotive industry for structural parts. Describing transformation of Al-Si coating is necessary in order to understand the phenomena affecting the welding and adhesive bonding stability. Three various heat treatment cycles were used in order to prepare specimens which were later evaluated by scanning electron microscopy, X-ray diffraction and tensile testing. Changes of the phase composition of the coating and mechanical properties of the base material are discussed in the paper.

Keywords: Al-Si coating, 22MnB5, heat treatment, phases

1. INTRODUCTION

There is a persisting trend in automotive industry of decreasing weight of a vehicle in order to reduce fuel consumption and therefore emissions while maintaining or even improving safety of passengers. One way how to achieve these goals is by using materials with high tensile strength such as press hardened steels -PHS. These materials enable reducing the thickness of parts, decreasing the weight of the part and subsequently of a car as a whole. PHS is manufactured by a process called hot forming, which is a combination of heat treatment and plastic deformation [1]. The blank is heated at austenitization temperature, held at that temperature for certain time and then quenched in a die during forming. It is a complicated process with a large number of parameters that need to be taken into account in order to produce a quality part. One of these parameters is dwell time at the austenitization temperature. In order to fully austenitize the material, blank needs to undergo a heating for several minutes at temperatures rising up to 920°C. Uncoated material surface would deteriorate fast as a result of high temperature oxidation [1]. Considering small thickness of the blank, large percentage of the material would be affected this way. In order to prevent this phenomenon thin aluminum-silicon coating is deposited on the surface via hot dip galvanizing method. While Al-Si coating is necessary for successful manufacturing of the part, its presence is highly unpleasant for parts assembling. Deviances in coating properties are causing instability during welding and adhesive bonding [1]. Al-Si coating is not homogeneous coating but it consists of sublayers of various chemical composition [2] and physical and mechanical properties [3]. Development of these sublayers was examined in dependence on various austenitization temperatures, in order to better understand the phenomena occurring during welding and adhesive bonding.

2. EXPERIMENT

Steel sheets 1.2 mm thick of 22MnB5 steel coated with Al-Si were used in the experiment. Specimens were prepared in a shape and dimensions corresponding with DIN 50125. In the first step, chemical composition of the base material and coating prior to heat treatment was evaluated by Bruker G8 Galileo and Tescan scanning electron microscope respectively. Three sets of specimens were prepared in total and each set was heated at a different temperature. The first set dwelling temperature was 850°C just above austenitization temperature, the second at 885°C and the third at 920°C. The dwell time in the oven was the same for all specimens, 480 seconds. Specimens were taken out of the oven and quenched in steel die after an austenitization period. The transporting from oven into die took 2 seconds. Temperatures used for heat treatment were selected to be above a_{c3} temperature in order to monitor changes in the coating during autstenitization period. The third set of specimens which underwent heating at 920 °C was prepared in order to compare results to findings in literature [4]

Six specimens from each set were used for tensile testing, where mechanical properties were measured. Remaining specimens were used for X- ray diffraction analysis and SEM analysis. Both surface and coating in cross section were evaluated. Specimens for cross section analysis were prepared in accordance with standard metallographic methods using electrochemical etchant colloidal silica Struers OP-S on Struers Tegramin in the last step. SEM analysis was performed on FE-SEM Zeiss Ultra Plus with accelerating voltage of 10 kV. Measurement of diffusion layer thickness and coating total thickness was performed on light microscope Olympus GX71. X-ray diffraction was carried out by a Bruker AXS D8 diffractometer using CoK_{α} radiation (λ = 1.79021 Å) at room temperature.

3. RESULTS AND DISCUSSION

The chemical composition of a base material **Table 1** is corresponding to the typical chemical composition of 22MnB5 steel. Chemical composition of Al-Si coating measured by EDS is in **Table 2.**

Table 1 Chemical composition of base material 22MnB5 prior to the heat treatment

Element	C	Si	Mn	Cr	P	S	Al	Cu	Ti	B
22MnB5 (wt%)	0.22	0.24	1.17	0.19	0.010	0.002	0.044	0.006	0.026	0.0027

Table 2 Chemical composition of the coating prior to the heat treatment

Element	Al	Si	Fe
AlSi (wt%)	90.99	6.00	3.01

Overall structure of the coating as well as an average coating thickness of 39 μm and diffusion layer of 4 μm in a pre-treatment state is depicted in the **Figure 1**. Furthermore, coating structure of specimens after heat treatment process for each set are shown in **Figure 2**, **Figure 3** and **Figure 4**.

A sub-layered structure of the coating is also different for each variant. Formation of thin continuous sub-layer roughly 20 μm deep under the surface of the coating is observed for 850 °C. This layer moves closer to the surface and ceases to be continuous for temperatures 885 °C and 920 °C. Formation of second incoherent sub-layer deeper under the surface is apparent for specimens which underwent heating at 885 °C and 920 °C. Base material prior to the heat treating is ferrite - pearlite steel and turn into a martensitic after the heat treatment.

There is a noticeable increase in diffusion layer thickness with an increasing austenitization temperature **Figure 5** - a phenomenon previously described in literature [3]. Thickness gradually increases from 5 μm at 850 °C to 12 μm at 920 °C.

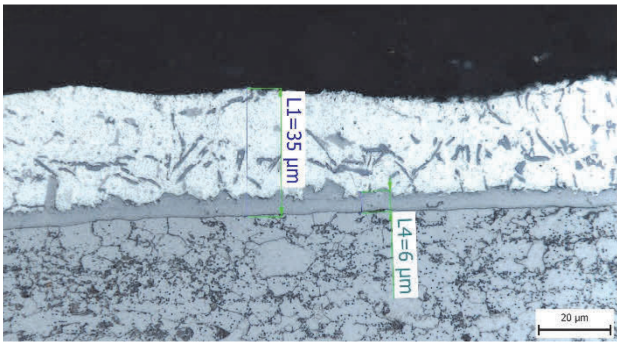

Figure 1 Al-Si coating in pre-treatment state

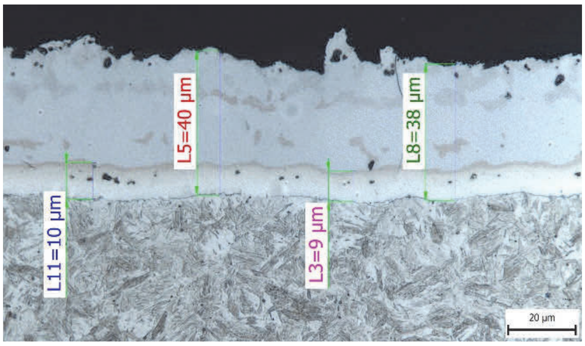

Figure 3 Al-Si coating after heating at 885°C

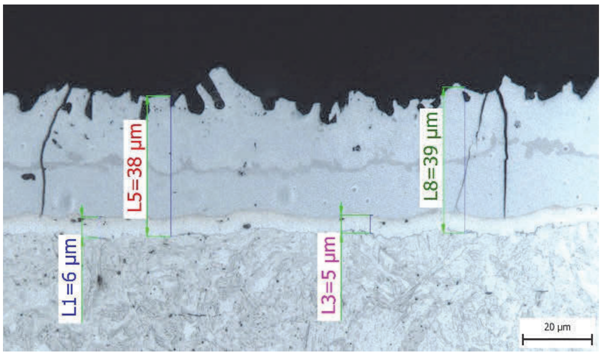

Figure 2 Al-Si coating after heating at 850°C

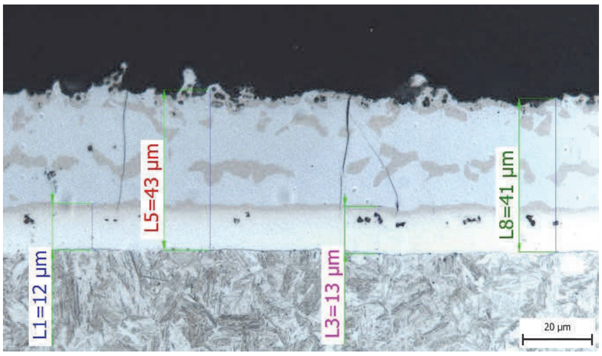

Figure 4 Al-Si coating after heating at 920°C

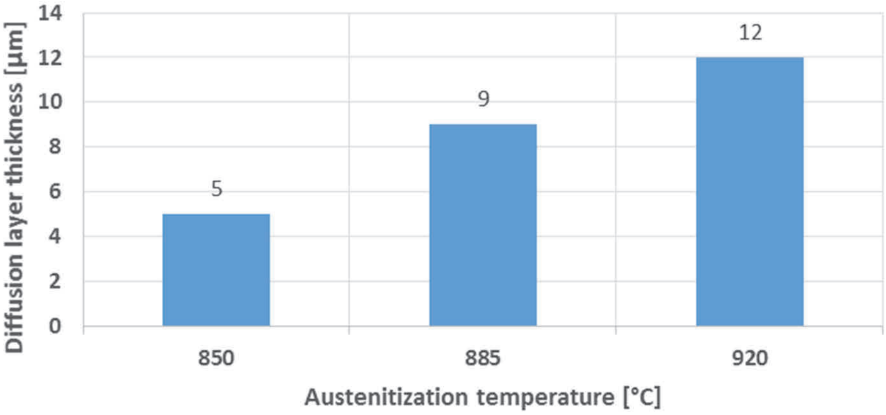

Figure 5 Dependence of diffusion layer thickness on austenitization temperature

Data obtained from SEM analysis were compared to [5]. Specimens from first set **Figure 6** showed that sublayer has increased content of Si and Fe while Al content is decreased. It was identified as AlFe. Coating body above and under this layer is mainly consisting of Al_5Fe_2.The body of the coating remains Al_5Fe_2 while sub-layer closer to the surface consists of Al_3Fe_2Si and sublayer closer to the base material composes of AlFe for second set **Figure 7**. Third set specimens **Figure 8** maintain chemical composition of the coating Al_5Fe_2 with sublayers of AlFe. These findings are in consensus with [6,7].

EDS surface analysis revealed visually similar texture for all specimens with oxidation level increasing with increasing temperature. XRD surface layer analysis showed presence of Al_5Fe_2 phase at all three sets **Figure 9**. In addition to this phase, $Fe_{1.7}Al_4Si$ was discovered on the surface of specimen heated at 850 °C.

For specimens heated at 885 °C Fe_2Al_3Si was present. However, because of the limited resolution and penetration depth of XRD, some phases were difficult to detect. Thus specimens were further studied by SEM-EDS analysis.

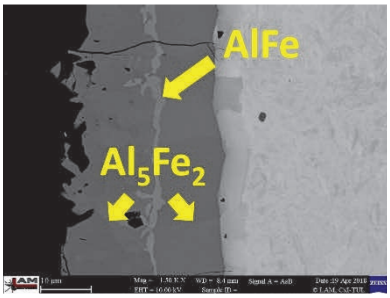

Figure 6 AS150 coating after heating at 850 °C

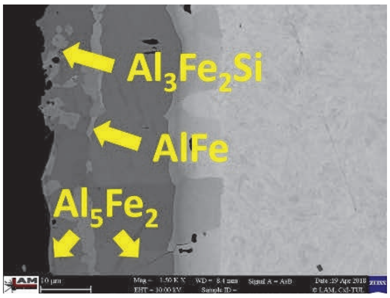

Figure 7 AS150 coating after heating at 885 °C

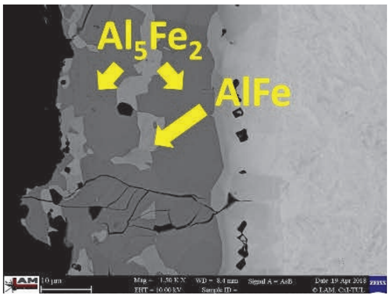

Figure 8 AS150 coating after heating at 920 °C

Tensile testing was performed in order to monitor effect of a different austenitization temperature on base material. No apparent change of mechanical properties between three sets occurred with average R_m = (1420 ± 35) MPa and R_e = (961 ± 32) MPa (**Figure 10**). Slightly lower values are probably caused by lack of deformation during quenching which was not present during tensile testing specimens' preparation.

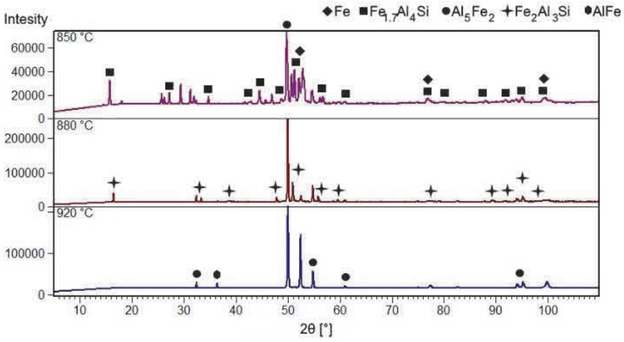

Figure 9 Diffraction patterns of Al-Si coating surface after heating at (850, 885 and 920) °C

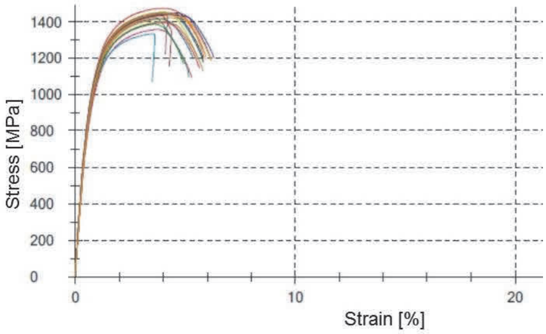

Figure 10 Tensile testing diagram for all sets

4. CONCLUSION

Chemical composition changes dependent on various heat treatment were examined in this paper. Three sets of specimens were prepared by heating at 850 °C 885°C and 920°C and then quenching in a steel die. Different distribution of sublayers in the coating was observed. While chemical composition of coating body was the same for all sets, Al_5Fe_2 phase was present on the surface of every specimen set. In addition to it $Fe_{1.7}Al_4Si$ was found on the surface of specimens heated at 850 °C and Fe_2Al_3Si on specimens heated at 885 °C. Results obtained for specimens heated at 920 °C are in consensus with findings in literature [4]. Change of the austenitization temperature had little if any effect on mechanical properties of the steel. This can be caused by absence of deformation during quenching which is present in case of production of serial parts.

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