PROPERTIES OF INTERFACE BETWEEN MANGANESE-BORON STEEL 22MnB5 AND COATING Al-Si

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Abstract

Resistive weldability of high-strength steel 22MnB5 is very important for automotive industry. Coated steel is galvanized. Al-Si coating protects the steel against oxidation during forming. At the interface of Al-Si coating and basic material the diffusion layer is created. The layer thickness depends on temperature and holding time of heat treatment. The contribution deals with chemical composition of coating (including diffusion layer) and its mechanical properties (indentation hardness H and elastic modulus E).

Keywords: Resistive weldability, 22MnB5, Al-Si coating, diffusion layer

1. INTRODUCTION

Protective coating Al-Si has eutectic temperature 575 °C [1]. It means, the coating melts during the forming process. The diffusion of iron from steel into the molten Al-Si layer runs also. This diffusion forms Al-Si-Fe intermetallic phases. These phases have a high melting temperature [2]. The melting points of $FeAl_3$ is 1157°C, for FeAl it is 1255 °C and for Al_5Fe_2 it is 1090 °C, which is higher than the austenitization temperature of basic material [3, 4]. Diffusion layer (DL) between coating and base material is very sensitive to temperature and temperature holding during heat treatment. A small range of thermal modes strongly influenced especially the thickness of the diffusion layer. The thickness of the diffusion layer increases considerably with increasing temperature and temperature holding [5]. A thickness maximum of all coating is generally recommended to 40 µm to preserve the weldability while providing good corrosion resistance [6].

It has been suggested in the literature that a sufficiently slow heating rate may allow the iron adequate time to diffuse from the 22MnB5 basic material into the Al-Si coating and form the Al-Fe phases. These phases avoid liquefaction of the coating [7, 8]. The diffusion of the iron into the Al-Si coating prior to reaching the eutectic temperature allows create intermetallic phases that prevent melting [9, 10].

Changing the thickness of the diffusion layer is related to the layout of other sub-layers of the coating. In case of the thinnest diffusion layer the heterogeneities were found as isolated units. When diffusion layer is growing, heterogeneities are combined to form a compact sublayer (see **Figures 2** and **3**). Sheets with thin diffusion layer have well resistance weldability (resistance weldability is ability of materials to create weld joint with required properties, using a resistive heat and pressure). At a thickness of 16 µm, the material shows resistant against welding [5]. The reason is creating of difficulty melting intermetallic phases (10 - 12 µm thick AlSi - rich in α-Fe, AlFe, Al_5Fe_2) [11]. The weldability is affected by chemical composition and mechanical properties.

2. MATERIALS

As basic material (BM) was used steel 22MnB5 (Arcelor Mittal) with coating on base Al-Si (AS150 - 90 % Al + 10 % Si). It is manganese-boron steel with martensitic structure (**Figure 1** left). Thickness of plate was 1.2 mm. Thickness of Al-Si coating is about 40 µm. Microstructure of coating in etched state with designations of particular phases is in **Figure 1** - right. Based on previous research report [5] samples with the thin, medium and thick diffusion layer were chosen.

Heat treatment is described in **Table 1.** The range of parameters is so small that it does not affect the structure of the basic material.

Table 1 Heat treatment of samples

Heat treatment	Sample 1	Sample 2	Sample 3	Sample 4
heating temperature	0 °C	880 °C	900 °C	920 °C
heating time	0 min	5.5 min	8 min	10 min
Thickness of DL	8 µm	5 µm	12 µm	25 µm

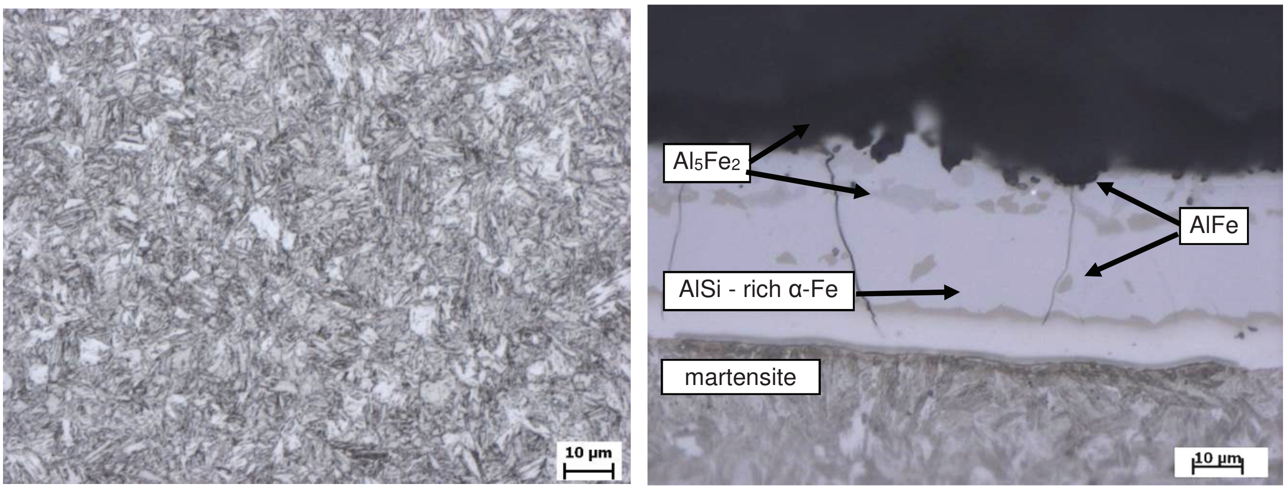

Figure 1 Microstructure of base material - etched (left), microstructure of coating - etched [11] (right)

3. EXPERIMENT

Microstructures of all samples were investigated by optical microscopy, electron microscopy (EDS) and a Hysitron system. Results of optical microscopy of particular samples in etched state are in **Figures 2** and **3**. .

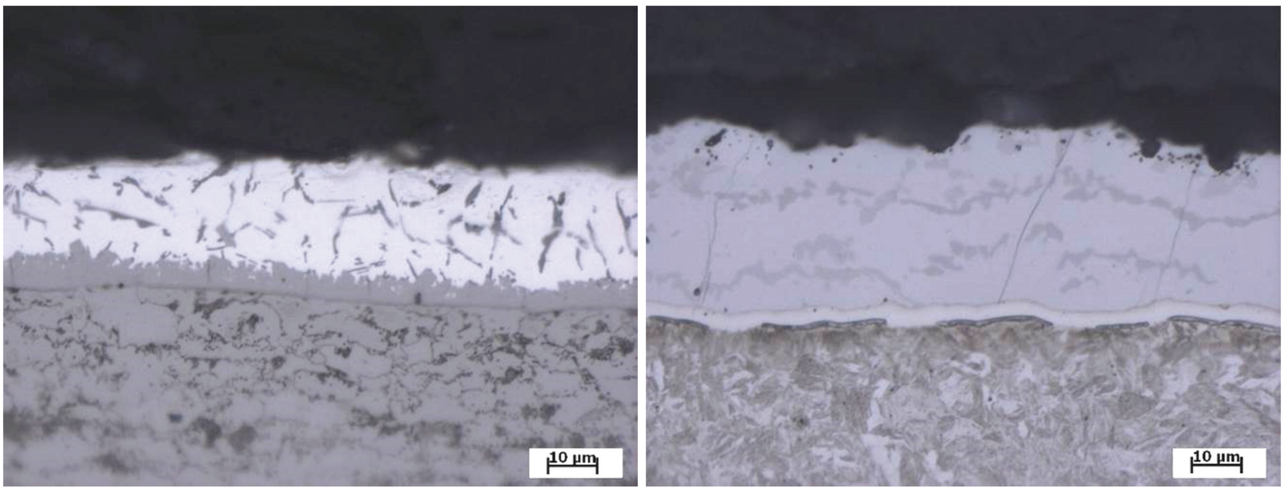

Figure 2 Microstructure of coating - etched: Sample 1 (left), Sample 2 (right), magnification 500x

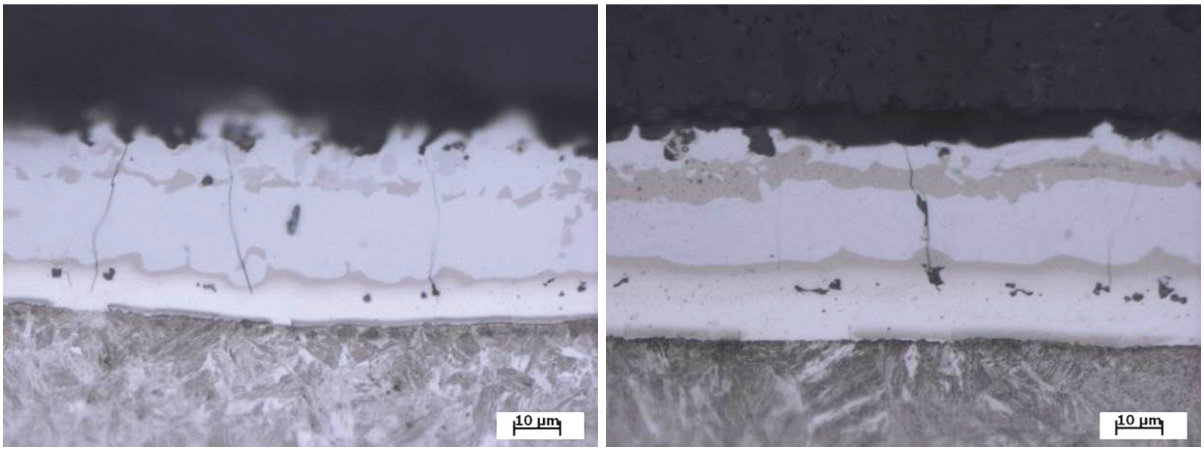

Figure 3 Microstructure of coating - etched: Sample 3 (left), Sample 4 (right)

The chemical composition from the surface to the base material was found by spot SEM analysis. Results are shown in **Figures 4-7**. The thicknesses of diffusion layers are: 8 µm (Sample 1), 5 µm (Sample 2), 12 µm (Sample 3) and 25 µm (Sample 4), see **Figures 4-7**. There are clearly seen areas of heterogeneities. Results of SEM correspond with results of optical microscopy.

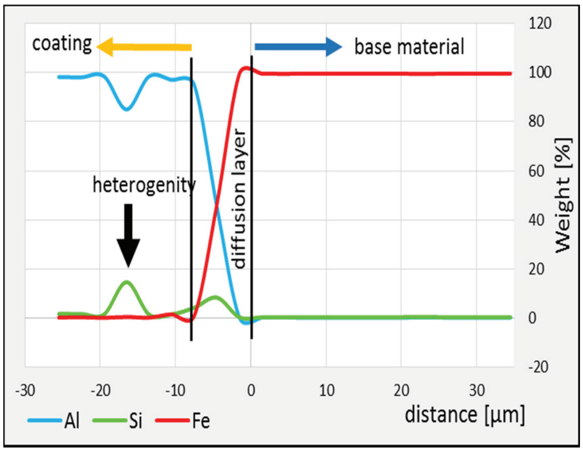

Figure 4 Sample 1 (thickness of DL is 8 µm)

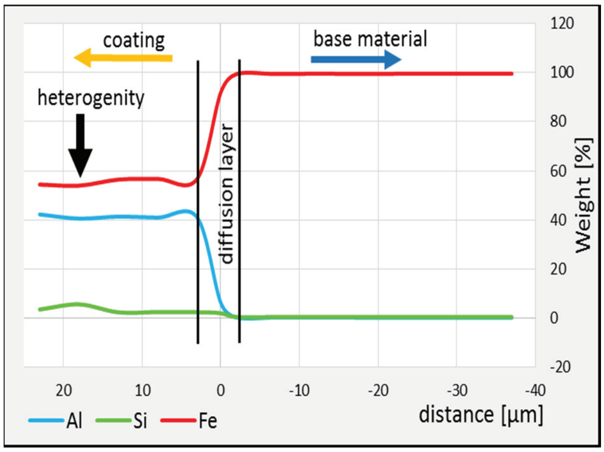

Figure 5 Sample 2 (thickness of DL is 5 µm)

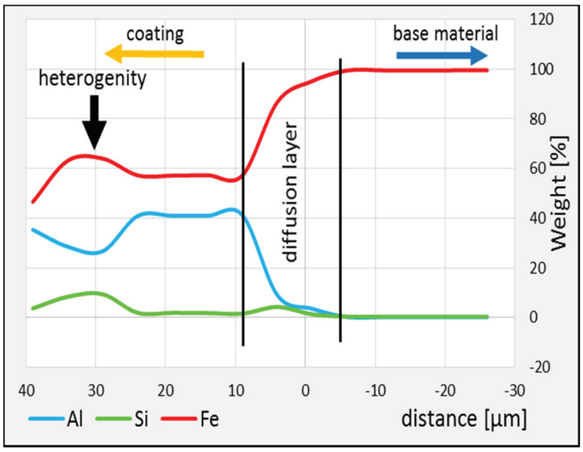

Figure 6 Sample 3 (thickness of DL is 12 µm)

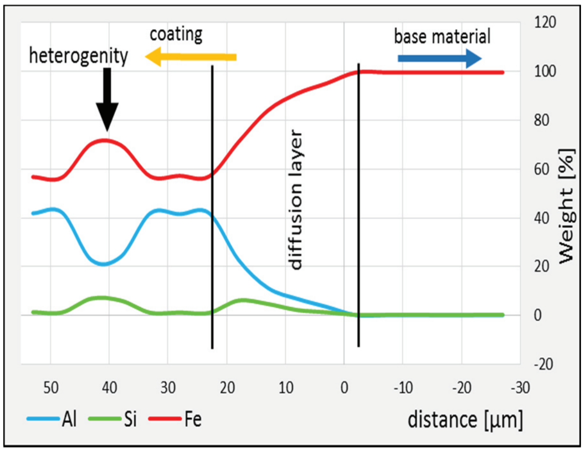

Figure 7 Sample 4 (thickness of DL is 25 µm)

Nano-indentation system Hysitron TI 950 TriboIndenter™ was used for analysis of mechanical properties on interface of steel and coating where creates diffusion layer. Results are in **Figures 8** and **9**.

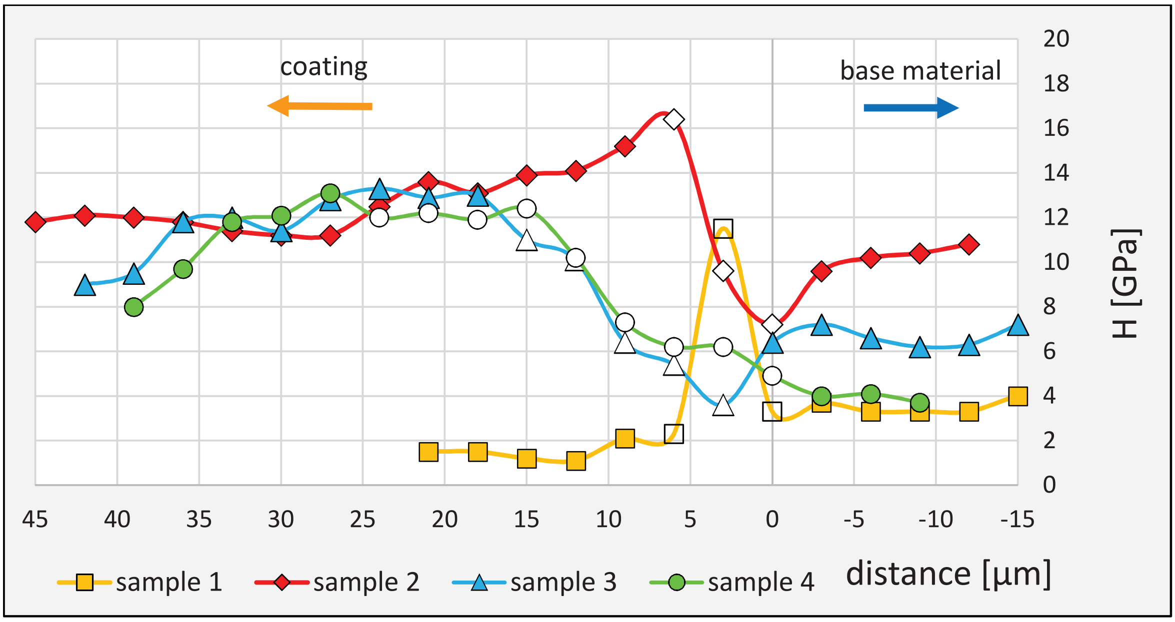

Figure 8 The hardness dependence on distance from the interface BM-coating (empty mark means diffusion layer)

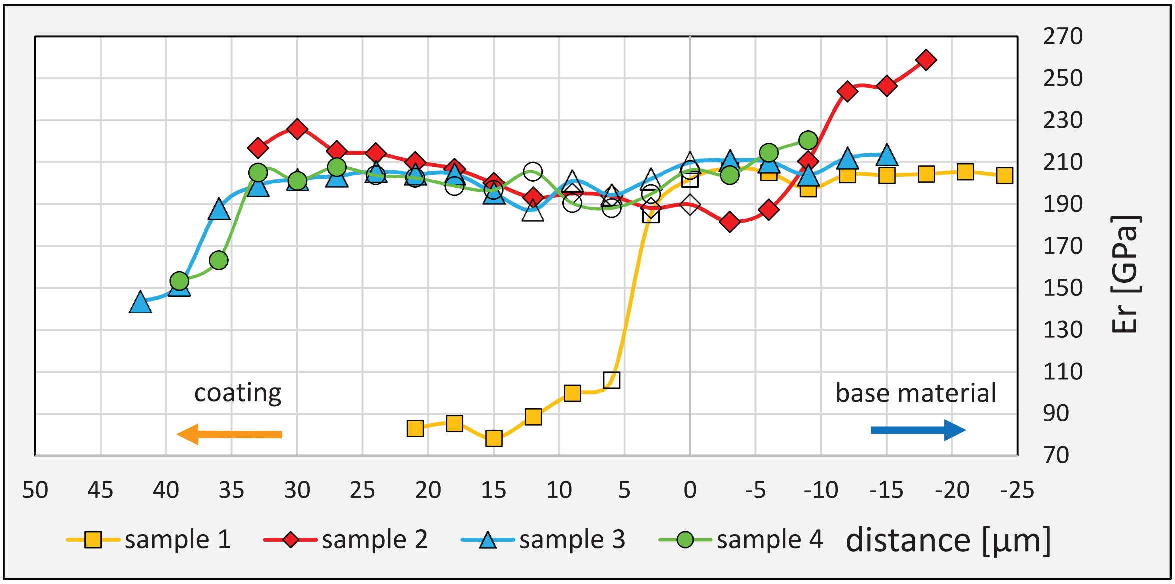

Figure 9 The reduced modulus dependence on distance from the interface BM-coating (empty mark means diffusion layer)

For mechanical analysis was chosen two quasi-static loading functions shift to depth 25 nm and 100 nm. The reason was the fragility of diffusion layer. Dislocations in material were occurred, which were manifested in form of numerous pop-in phenomena. When presence of pop-in, the ultimate strength is exceed and it is not possible to accurately evaluate the elastic properties of the material of relieving curve with model Oliver and Pharr [12-14]. Therefore, the load function was elected to a depth of 25 nm, where the pop-in occurred rarely. Nano-indentation to a depth of 100 nm was performed in order to obtain information about the indentation hardness, which is possible to evaluate in contact depth h_c up to 30 nm (when Berkovich tip is used - tip radius > 150 nm).

Setting of indentation function: maximal indentation depth h_{max} = 25 nm resp 100 nm. Loading function had 3 segments: 1) loading to h_{max} = 25 nm resp 100 nm (5 seconds), 2) holding with constant h_{max} (2 seconds), 3) unloading - ejecting the tip from the sample (5 seconds).

4. DISCUSSION

From the results it is seen that the major effect on the resistance weldability has the chemical composition of the coating.

From graphs of chemical composition (**Figures 4 - 7**) is seen, that content of silicon increases in areas of heterogeneities. The coating without heat treatment does not contain iron. It consists of Al and Si phases. Thickness of diffusion layer is about 8µm. This layer is Fe-rich. Basic material has ferrite-pearlite structure. When longer time of heat treatment (diffusion layer is 12 microns and more), heterogeneities are combined to form a compact sublayer. The thicker is diffusion layer, the higher the silicon content in it. Resistivity of Al is 0.0267 $\Omega \cdot mm^2 / m$, for Fe is 0.0996 $\Omega \cdot mm^2 / m$ and for Si is $2.5 \cdot 10^9$ $\Omega \cdot mm^2 / m$ (silicon is insulant and increases the contact resistance). A long time of heat treatment = thick diffusion layer a continuous sublayer of heterogeneities (both high silicon content - up to 10 %). Because of the high content of silicon (insulant), contact resistance significantly increases on the surface (in coating) of sheet. Also during heat treatment intermetallic phases AlFe and Al_5Fe_2 with high melting point are created in coating. Material is heated from surfaces. This is undesirably [15]. In the place of the weld the remaining resistance is insufficient to heat the material to melting temperature and sheets are not welded. In the case of thinner sublayers of heterogeneities and diffusion layer it leads to defects in weld joints, such as excessive spatter, and to instability of the welding process.

Course of hardness (**Figure 8**) shows decrease of values in diffusion layer at samples 2 and 3 (shorter times and lower temperatures of heat treatment). Then the course increase to values of coating Al-Si. Sample 4 has not initial decrease. It can be because of low hardness of basic material. For sample 1 (without heat treatment) the hardness course in diffusion layer steeply increases, then steeply decrease to coating. Hardness values of the AlSi coating are lower than hardness of basic material. Different hardness of base materials is given by different heat treatment (annealing rate). Values of hardness correlate with data from graphs in **Figures 1 - 4.**

The courses of reduced modulus (**Figure 9**) are similar for every sample and they are relatively flat. Reduces modulus of coatings are almost the same as pro basic material. Only coating without heat treatment (sample 1) has values significantly lower.

5. CONCLUSION

The weldability of materials is significantly affected by its chemical composition [16]. Composition of coating and thickness of diffusion layer (silicon content), formed on interface of basic material (22MnB5) and coating (Al-Si) during heat treatment, have serious effect upon weldability. The reason, why the sheets with a longer heat treatment (in order of minutes) are not resistant against welding, are a few sublayers in a coating with high silicon content and presence of difficulty melted intermetallic phases AlFe and Al_5Fe_2. One layer is a diffusion layer. Next (one or more depending on coating thickness) are strips of heterogeneities.

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