# STRENGTH OF THE ADHESIVE JOINTS AT THE CAR-BODY PARTS FROM THE AHSS WITH AL-SI COATING

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**DOI: 10.17973/MMSJ.2017_11_201750**

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The paper deals with the monitoring the utility properties of the Al-Si coating which is applied by means of the hot dip coating on the ultra-high strength sheet 22MnB5 (martensite steel alloyed by boron). These sheets are used at the car-body design as the safety elements (bumpers, reinforcement posts). Individual parts are jointed also by the adhesive bonding methods. Evaluation of the material surface protection layers is carried out in dependence on the time of material heating in the furnace during thermal treatment and subsequent influence of this layer on the adhesive joint strength and failure pattern. To compare adhesive joint strength is used epoxy adhesive from two producers. Results provide information about behavior of the ultra-high strength sheets adhesive joints strength properties as a criterion for suitability to apply coatings AlSi in the series production of cars.

**KEYWORDS**

Adhesive, Car Body, AlSi Coating, 22MnB5, AHSS Steel

## 1 INTRODUCTION

During these days of developed automotive production are still finding new methods hot to improve driving properties as well as properties of the individual car-body components. And there are also still stronger demands arising from customers e.g. on reliability, safety, attractive design, economic engines and last but not least of course cost.

Corrosion resistance represents quite very important property of the car-body metal parts. That is why sheets producers are still improving the anticorrosive protection of material and trying to protect surface by organic or inorganic coatings.

Nowadays exist a lot of different types of steel sheets surface protection – from the classical zing coatings up to coatings that are based on alloys (e.g. aluminium and magnesium alloys). By using alloys is created the resistant protective layers having a lot of advantages compared to common zinc coatings.

The crucial influence on the safety of passengers has design and car-body material. In many new car models are in the critical areas used high-strength steel sheets.

As a presumption to provide the quality integrity of car-body, there is utilization of different jointing methods. It can be done by classical methods (screws, rivets) in combination with welding or adhesive bonding. Determination of used materials utility properties for car-body design is a very important part of research and development of these materials and methods.

## 2 MATERIALS FOR CAR-BODY PARTS

Variety of materials that are used for the car-body production is huge and doesn´t have any similarity in the mass production of parts in the engineering industry. Nowadays, majority of the car-bodies is produced from steel. Classification of steels can be made acc. to different characteristics and utilization depends on the type of stamping. Beside the conventional deep-drawing sheets are used also low-strength steels (LSS), high-strength steels (HSS) and during last years are still more and more also used advanced high-strength steels (AHSS). These parts are produced by technology ULSAB (Ultra Light Steel Auto Body), where car-body in mostly produced from AHSS. It means that car-body is lighter and more resistance against any loading.

Difference between LSS and HSS materials is given mainly by the ultimate strength (see fig. 1). Moreover, they differ in structure and production method [Petrucha 2015.]

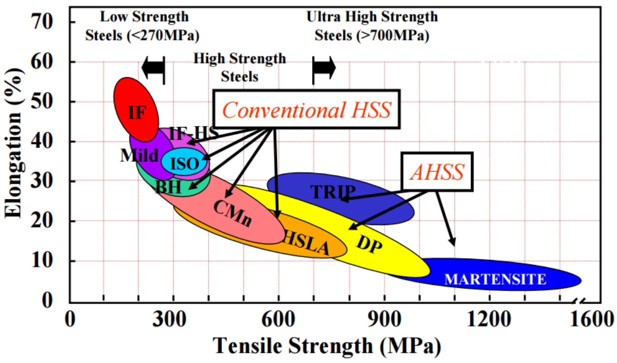


**Figure 1.** Classification of AHSS [Petrucha 2015]

### 2.1 *Advanced High-strength steel - Steel 22MnB5*

As one of the advanced high-strength steels there´s martensitic steel 22MnB5 – martensitic structure is given by alloying boron. It is cold roll steel suitable for the hardening and tempering, having high ultimate strength and good formability. It is used mainly for parts that require good formability during their processing and high strength for final part. Required strength and hardness of this steels is achieved by simultaneous forming and heat treatment (hardening is performed in the forming tool). These materials are called as press hardened steels (PHS).

Process of the PHS production technology depends on the presence of surface coating. As a two basic methods there is direct method (for steels without surface coating) and indirect method (steels with surface coating). Indirect method differs from direct method only by adding pre-stamping of part before its own heating. In fig. 2 and 3 are shown both technologies that are used for processing steel 22MnB5.

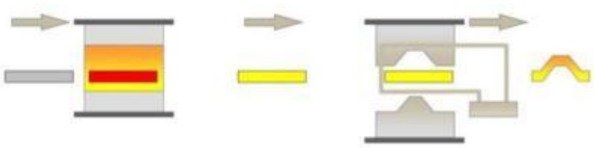

**Figure 2.** Direct method of press hardened steel [Arcelor Mittal 2015]

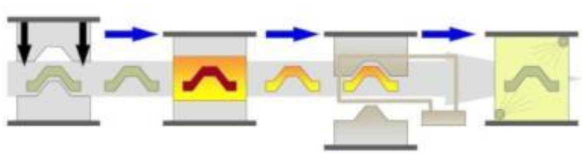

**Figure 3.** Indirect method of press hardened steel [Arcelor Mittal 2015]

Due to the martensitic internal structure of this steel can be assemblies of parts substituted by just one complex part which has the same or higher strength and also the lower weight then e.g. welded part.

This type of steel is in the automotive industry used mainly for the safety parts of car-body as can be e.g. reinforcements in the critical areas of car during impact. As an example there is part of B-pillars, reinforcement of bumpers or different supporting frames (Fig. 4) [Arcelor Mittal 2015].

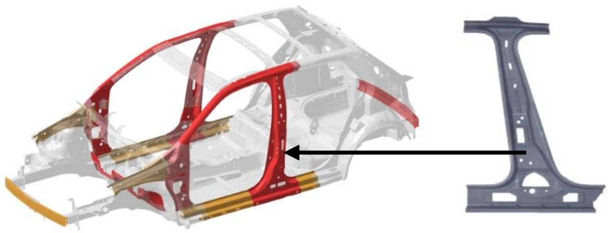

**Figure 4.** Utilization of AHSS in car-body design (B-pillar)

### 2.2 *Protective layer Al-Si*

On the surface of sheets is created Al-Si coating which serves as protective layer of sheets against oxidation and decarburization during the hot forming process – namely during heating in the furnace and during manipulation with sheet into forming tool as well as during subsequent forming and hardening in the mould. Such coatings are applied by hot dip coating method.

Coating is not homogenous through the whole cross-section (see fig. 5). It consists of several layers in dependence on the technological conditions during its production – its thickness is about 30 up to 40 µm.

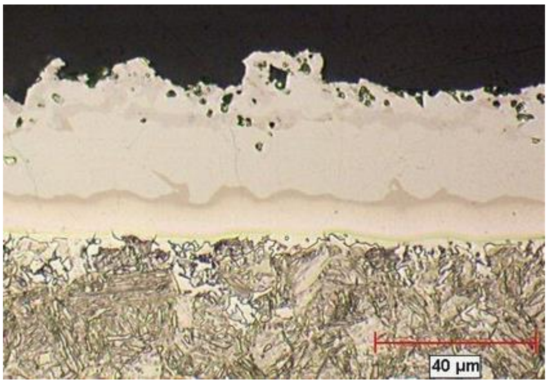


**Figure 5.** Appearance of the coating after hot stamping (optical microscopy) [Arcelor Mittal ,2015]

## 3 EVALUATION OF Al-Si COATING

Sheets with Al-Si coating were measured to evaluate possibility to utilize bonding technology as one of the jointing technology for car-body parts. Tests were performed acc. to the concern standard [PV 12.35, 2006], shape of samples is shown in fig. 6. For testing was used synthetic adhesive on the epoxy basis, thickness of adhesive was 0,2 mm (it was determined by distance wires). For own evaluation were chosen two adhesives from different producers – their basic properties are briefly summarized in tab. 3.

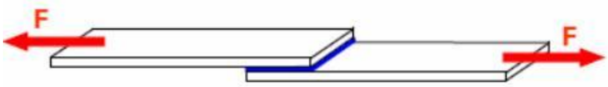


**Figure 6.** Shape of sample acc. to PV 12.35

### 3.1 *Conditions of experiment [Bašus 2017]*

- Substrate: 22MnB5, thickness 1,2 [mm]
- Coating : Al-Si, thickness 79 [g/m$^2$]
- Heat treatment : 6,12 and 18 min/900°C
- Epoxy adhesives: 2 producers - A, B
- Curing: without ageing
  (temperature +180°C /time 20 min)
- PV 12.35 test under temperature RT (+23°C)

Chemical composition of substrate is shown in tab. 1.

| Chemical composition of substrate 22MnB5 [%] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | Si | Mn | P | S | Al | B | Cr | Cu | Mo | Nb | Ti |
| 0,201 | 0,226 | 1,13 | 0,01 | 0,0005 | 0,033 | 0,002 | 0,187 | 0,011 | 0,001 | 0,001 | 0,034 |

**Table 1.** Chemical composition of substrate for 22MnB5

Samples were heated in the furnace on temperature 900°C, holding time 8, 12 and 16 min and subsequently hardened.

Chemical composition of Al-Si surface coating was as following: 87,73 % aluminium, 10,31 % silicon and 1,96 % of ferrum.

Because of non-homogenous chemical composition of coating and simultaneous increase of oxides thickness on the coating surface, there is change of the surface color due to different interference of these oxides (higher amount of Al in the surface layer). That is why it´s possible to evaluate quality and coating composition from its color (see fig. 7).

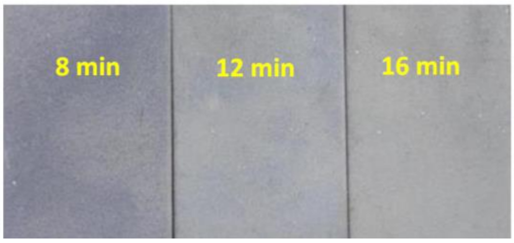


**Figure 7.** Colors of coating after heat treatment

Tab. 2 summarizes mechanical properties of substrate before and after the heat treatment. It is evident, that there´s increase of yield and ultimate strength and decrease of ductility.

| AHSS - 22MnB5 | $R_{p0,2}$ [MPa] | $R_m$ [MPa] | $A_{80mm}$ [%] |
|---|---|---|---|
| Before heat treatment | 397 | 553 | 23 |
| After heat treatment | 977 | 1379 | 4,6 |

**Table 2**. Mechanical properties of substrate

| Properties of adhesives | Adhesive A | Adhesive B |
|---|---|---|
| Density [kg/m$^3$] | 1300 | 1240 |
| Viscosity [Pas] | ca 1000 | ca 46 |
| Shear strength [MPa] | 30 | 29,6 |

**Table 3.** Properties of epoxy adhesives [Adhesives - A, B]

In tab. 4 are summarized results from the shear test (shear strengths) of 2 tested adhesives from different producers in dependence on time of heat treatment (6, 12 and 18 min).

| PV 12.35 - under temperature RT | | |
|---|---|---|
| Shear strength [MPa] | | |
| **Time of heat treatment [min]** | **Adhesive A** | **Adhesive B** |
| **8** | 35,49 | 33,27 |
| **12** | 31,72 | 33,72 |
| **16** | 28,93 | 34,78 |

**Table 4.** Shear strength of tested adhesives [Bašus 2017]

As another criterion for evaluation the bonded joint quality there is evaluation of failure patterns acc. to [ČSN ISO 10365, 1995]. Basic failure patterns are as following: CF - cohesion failure, SCF – special cohesion failure, DF – delamination failure, AF – adhesive failure. Failure patterns for individual thermal treatments times are summarized in tab. 5. In Fig. 8 up to 13 are shown samples after tests.

| **Adhesive** | | **Adhesive A** | | | **Adhesive B** | | |
|---|---|---|---|---|---|---|---|
| **Time of heat treatment [min]** | | **8** | **12** | **16** | **8** | **12** | **16** |
| **Failure pattern [%]** | **CF** | 15 | 10 | 20 | 5 | 0 | 0 |
| | **SCF** | 45 | 50 | 30 | 15 | 10 | 5 |
| | **DF** | 40 | 40 | 50 | 80 | 90 | 95 |

**Table 5.** Failure patterns under RT [Bašus 2017]

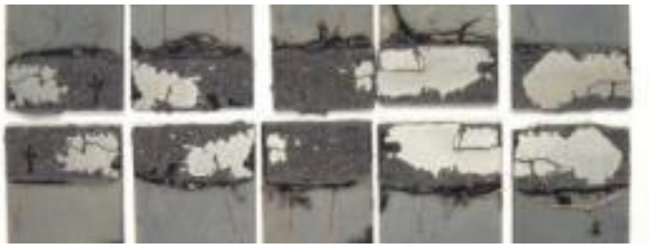

**Figure 8.** Failure patterns of samples for adhesive A, RT time of heat treatment 8 minutes

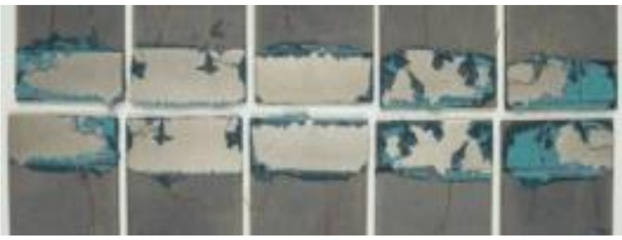

**Figure 9.** Failure patterns of samples for adhesive B, RT time of heat treatment 8 minutes

**Figure 10.** Failure patterns of samples for adhesive A, RT time of heat treatment 12 minutes

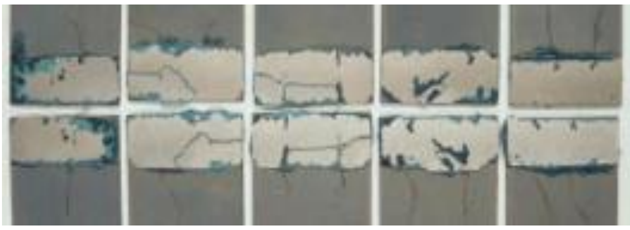

**Figure 11.** Failure patterns of samples for adhesive B, RT time of heat treatment 12 minutes

**Figure 12.** Failure patterns of samples for adhesive A, RT time of heat treatment 16 minutes

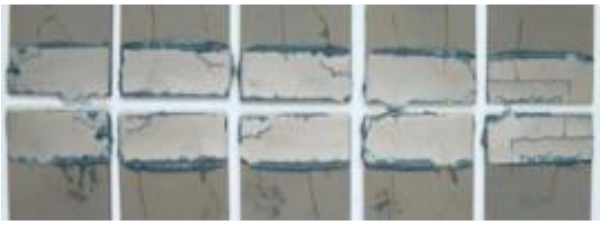

**Figure 13.** Failure patterns of samples for adhesive A, RT time of heat treatment 16 minutes

### *3.2 Results of experiment [Basus 2017]*

Evaluation of bonded joint strength properties for ultra-high strength steel Mn22B5 with protective coating Al-Si was experimentally carried out by shear test acc. to PV 12.35 under the testing temperature RT (+23°C).

Performed analysis of coating chemical analysis revealed that time of heat treatment didn´t have any important influence on the final chemical composition of protective coating – for every time interval was such composition very similar.

With the time of heat treatment is also connected the color dye of sheet surface. At shorter time of heat treatment (8 min) there is dark blue, after 12 min in the furnace has sheet griseous color and after 16 min it has grey color. All of these colors after heat treatment are shown in fig. 7.

During the shear strength test of bonded joints was obvious minimal difference in magnitudes of adhesive B strength in dependence on time for heat treatment. Shear strength of adhesive A decreased with the increasing heat time. Such fact is graphically illustrated by graph in fig. 14. Results of samples tested under temperature +23 °C revealed that adhesive A achieved the highest magnitude of shear strength at sheets with time of heat treatment 8 min. Its strengths vary with the time of heat treatment and reveal the decreasing tendency. For 12 min is strength lower by 10,6% and for 16 min by 18%.

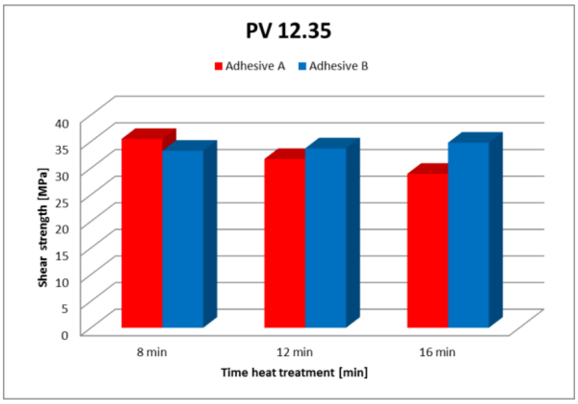


**Figure 14.** Comparison of shear strength for tested adhesives

Failure pattern for both used adhesives is different (see tab. 5). For adhesive A prevails, without influence on the time of heat treatment, delamination failure (DF) with special cohesion failure (SCF), where distribution of these failure patterns was uniform on the bonded surface. In the case of adhesive B there is obvious the certain relation between failure pattern and time of heat treatment (time of substrate in the furnace). Here at time of heat treatment 8 min was observed delamination failure (DF) together with special cohesion failure (SCF) and cohesion failure (CF). For substrates which were in furnace for time 12 and 16 min prevailed mainly delamination failure (DF).

## 4 CONCLUSIONS

From the results of bonded joint strength experimental testing for material 22MnB5 and epoxy adhesives can be deduce interesting results both in light of mechanical properties and regarding failure pattern of bonded joint. At most of samples were measured higher values of shear strength then is specified on the technical documentation of used adhesives – see tab. 3.

Also occurrence of different failure patterns for bonded joint revealed interesting results. There was observed delamination failure which is related to the used substrate and not with used adhesive. Failure of bond always occured on the transition of intermetallic and diffusion layer of substrate. Thus there can be stated that cohesion forces in the tested adhesive are higher than cohesion of these layers.

From the final results is obvious that strength of bonded joint depends mainly on the used Al-Si coating and not on the type of used epoxy adhesive.

Utilization and importance of ultra-high strength steels is still increasing (see fig. 15) and there can be assumed that such type of materials will be used in the car-body design in still higher size. Adhesive bonding is interesting and perspective method to joint materials and such issue of bonding ultra-high strength steels is objet of current research.

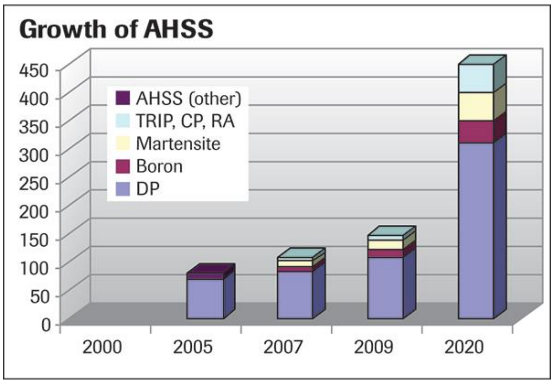


**Figure 15.** Increase of high-strength steels utilization [Krupitzer 2013]

## ACKNOWLEDGMENTS

This publication was written at the Technical University of Liberec as part of the Student Grant Contest "SGS 21122" with the support of the Specific University Research Grant, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2017 and with the cooperation of SKODA AUTO a.s. Mlada Boleslav, Czech Republic.

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