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Laser Beam Welding of Press Hardened Ultra-High Strength 22MnB5 Steel

Benjamin Gerhards[a], Oliver Engels[a], Simon Olschok[a], Uwe Reisgen[a]

[a] *ISF - Welding and Joining Institute RWTH - Aachen University, Pontstraße 49, Aachen 52062, Germany*

Abstract

Lightweight design is the most challenging topic for OEMs worldwide of this and the following decades. Thus ultra-high strength steels like the press hardenable 22MnB5 Boron steel gain further importance as construction materials.
Through the press hardening process where the parts are heated up to 900 °C and then quenched in a die, the 22MnB5 steel gains a fully martensitic structure with an ultimate strength of 1500 MPa. To prevent scaling, the steel sheets are usually protected by an aluminum-silicon layer which remains on the parts after the press hardening process.
As good as the press hardened 22MnB5 steel is as construction material, there are some issues when it comes to joining. Each heat input into the material harms the costly adjusted material properties. Thus, each welding process reduces the strength in the heat affected zone considerably. Furthermore, each fusion welding process brings the aluminum-silicon layer into the weld pool.
The effect is a primary problem of laser beam welding. Due to the high welding speed and the missing filler material there is only little weld pool movement. Especially in the case of welding overlap joints this leads to precipitation of aluminum at the fusion line, causing a strong metallurgical notch.
This means there are two weaknesses of laser welded 22MnB5 seams: the heat affected zone where the strength is reduced and the precipitation of aluminum at the fusion line. The latter usually bears the failure during lap shear tests. Removing the aluminum-silicon layer can shift the crack from the fusion line to the heat affected zone.

Keywords: Laser; 22MnB5; sheet metal; uhss

1. Introduction

Lightweight design with constant crash properties is the most important and challenging issue for OEMs worldwide. A common method for decreasing the Body in White weight is using a combination of lightweight materials and advanced high strength steels.

22MnB5 for example is a fully martensitic steel with an ultimate yield strength of about 1500 MPa. It is usually used for safety relevant automotive body parts such as A-Pillar, B-Pillar, roof rails, door-beams etc. and the market keeps growing. The advantages of 22MnB5 are numerous, excellent quenchability, good formability at high temperature while the springback is minor, high impact stability and as formerly mentioned tensile strength up to 1500 MPa. [ABD 10] [WIN 13]

The described mechanical properties are gained through a process called press hardening. Therefore parts are heated for 5 – 10 min. in a furnace until reaching temperatures of about 900 – 950 °C, the steel is then fully austenitized. In this state the parts are transferred into a die where they are simultaneously formed and quenched. The forming process takes advantage of the good formability at high temperatures. To gain the fully martensitic structure the die keeps closed for about 20 s while the sheet is cooled down with a velocity of about 27 °C/s. [FEI 11] [FAN 10] [ABD 10]

New developments promise the possibility of gaining strength up to 1900 MPa. Therefore the amount of alloying elements such as carbon and boron is increased. [AUR 08]

To prevent scaling during austenitization in the press hardening process 22MnB5 sheets usually are hot dip aluminized. Therefore, an aluminum-silicon coating was developed. It does not melt because of building intermetallic phases with the steel substrate. Furthermore it provides a basic corrosion protection. [FEI 11]

In order to apply the aluminum-silicon coating the sheets are hot-dipped into molten aluminum. The result is an intermetallic layer between steel substrate and coating which is usually about 10 µm thick. During the heating phase the aluminum-silicon coating does not liquefy although the temperature is above melting temperature of aluminum. Steel diffuses into the coating and different intermetallic phases are built. Duration and temperature of the heating process as well as the silicon content and coating thickness have influence on which phases occur. Silicon slows down the diffusion and therefore effects the thickness of the intermetallic layer. [BAE 11] [WIN 13] [ALL 14]

As good as the press hardened 22MnB5 may be as construction material, there are several issues when it comes to joining. Each heat input induced by a joining process harms the costly adjusted material properties. The result is a loss of hardness and strength in the heat affected zone which can be quantified to ca. 200 HV 1. This applies especially for fusion welding processes such as laser beam welding. Although its advantages are high energy density and therefore high welding speeds and low energy input the effect still occurs. The temperature field where the loss takes place lies between approx. 450 °C and 780 °C. [WIN 12]

The point of maximum hardness loss in the HAZ is theoretical 723 °C because the material is not austenitizated anymore. [RIE 10]

Furthermore the aluminum-silicon coating, which is applied to prevent scaling and decarburization, has to be considered. Some experiments show only few differences between laser welded 22MnB5 sheets with and without AlSi coating. The difference in tensile tests is nearly not existent. [SCH 09]

Other results show a distinct gap, the coated specimen fails at the fusion line. Uncoated samples on the other hand fail throughout shearing of the weld seam. [KIM 11]

2. Motivation

The given facts show an irreversible change of the material properties of press hardened 22MnB5 caused by fusion welding processes. Some effects, like the loss of hardness and strength, are well documented. Others, like the precipitation of aluminum at the fusion line, are controversial.

It is the objective to describe and verify the failure mechanisms of laser welded aluminum-silicon coated and press hardened 22MnB5 and to postulate solutions.

3. Experimental Setup

The experiments are performed according to the SEP 1220-3. Therefore the sheets are adjusted with an 16 mm overlap, length and width were 300 x 100 mm with a thickness of 1 mm. Laser power was configured to 4 kW and the welding speed was determined as the maximum velocity where the sheets are fully welded through. A TruDisk 16002 with a focal diameter of 0,6 mm was used as beam source, no process gases were utilized. To determine the difference between coated and uncoated samples the aluminum-silicon surface coating was removed by sandblasting.

4. Results and Discussion

There are three main weaknesses in laser beam welded, press hardened 22MnB5 sheets with aluminum-silicon coating which are responsible for failure in lap shear tests:

1. Stress concentration in the virtual weld width
2. Loss of strength and hardness in the HAZ
3. Precipitation of aluminum at the fusion line

The first weakness is the most obvious in the field of laser beam welding sheets thicker than 1 mm without beam oscillation. Reasons are different loads in the weld seam compared to the sheet and an insufficient virtual weld width, Fig. 1.

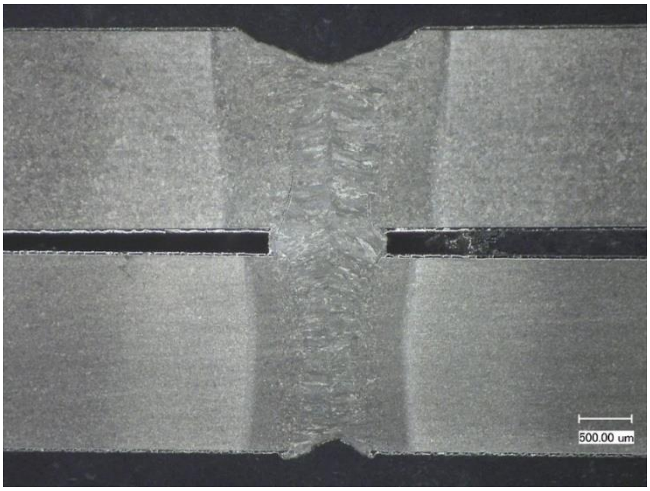

Fig. 1. Virtual weld width of the joint 2 mm on 2 mm 22MnB5 Al 150 Ph

Therefore the weld seams are not capable of enduring the same amount of stress as the sheets in lap shear tests, the result is a shearing of the seam, Fig. 2.

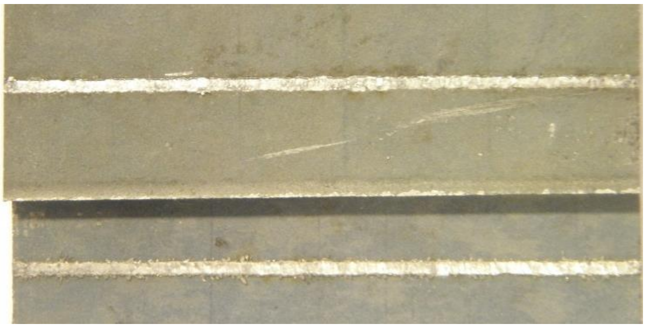

Fig. 2. Shearing of weld seam of the joint 2 mm on 2 mm 22MnB5 Al 150 Ph

Some guidelines demand a virtual weld width of at least $A_{min} = 0,9 \bullet tmin$ to prevent shearing and achieve a sufficient loading capacity.

The second weakness is caused in the HAZ. It is a common phenomenon with ultrahigh strength steels because the strengthening properties are strongly influenced by each heat input. As described in chapter 1, the press hardened 22MnB5 consists of a fully martensitic structure. The weld seam itself and the close range HAZ are heated above austenitization temperature. Combined with a high cooling rate common in beam welding processes the structure remains martensitic. With increasing distance to the weld seam strength and hardness decrease until reaching the maximum loss of hardness. Afterwards they increase again until reaching the level of base metal. Theoretical considerations of Riedel et. al. and Wink et. al. suggest that the maximum loss of hardness is reached when the temperature is slightly below austenitization temperature. Thus no hardening mechanisms can be achieved and the structure is mainly ferrite and bainite instead of martensite.

Those effects are increased by little head dissipation and high energy input per unit length. Hardness measurements of the joint 0,5 mm on 1 mm 22MnB5 Al150 Ph show that the loss of hardness can be quantified to nearly 200 HV1, Fig. 3.

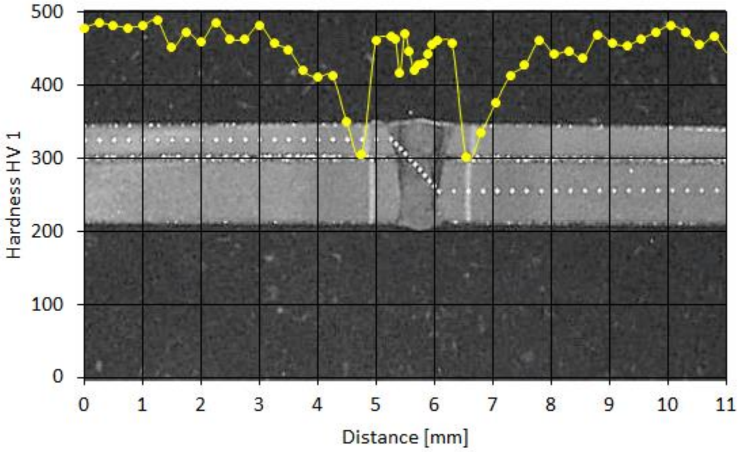

Fig. 3. Hardness measurements of the joint 0,5 mm on 1 mm 22MnB5 Al150 Ph

So far these problems were solved constructively. It is common to increase material thickness to compensate the occurring stress.

The third weakness of laser beam weld seams is the contribution of surface coating into the weld pool. While zinc-based surface coatings evaporate throughout the welding process, aluminum coatings are inserted into the weld pool. SEM examinations of the joint 0,5 mm on 1 mm 22MnB5 Al150 Ph show consequences of laser beam welding on the percentage of aluminum in the weld seam. Whereas the concentration of aluminum in base metal is about 0,07 % it is approx. 2,4 % within the weld pool. Furthermore, parts of the aluminum surface coating precipitate at the fusion line where concentrations up to 15,3 % aluminum can be found, Fig. 4.

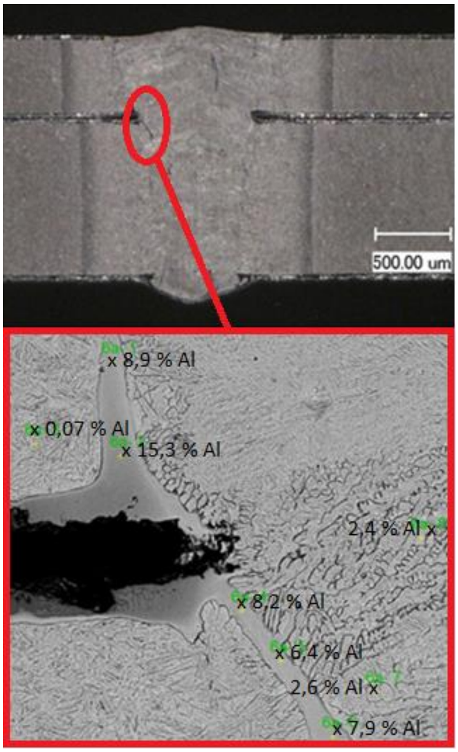

Fig. 4. SEM examinations of the joint 0,5 mm on 1 mm 22MnB5 Al150 Ph

The aluminum-silicon coating is dissolved in the weld seam as well as precipitated as intermetallic phases at the fusion line. The latter leads to a strong metallurgical notch which forms the most severe weakness.

The weakening effect becomes clear in lap shear tests. The examined joints with aluminum-silicon coating fail brittle at a force of ca. 19 kN.

Comparing test of sheets without aluminum-silicon coating with same welding parameters show a maximum force of 31 kN which is 150 % above the level of coated specimens, Fig. 5.

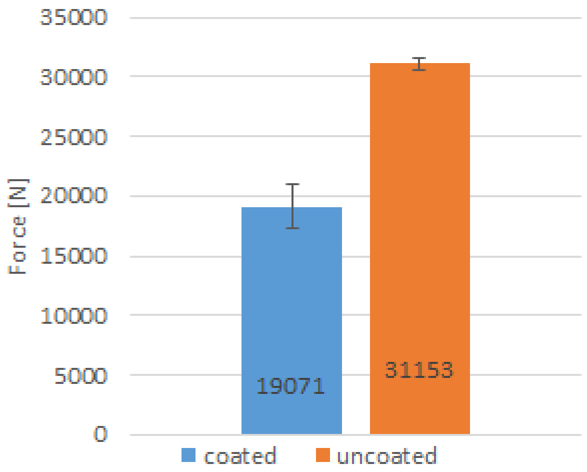

Fig. 5. Comparing results of lap shear tests with and without coating

Viewing the fractured surface the difference between coated and uncoated specimens can turn out. While the coated samples fail because of precipitation of aluminum at the fusion line, the uncoated samples fail in the HAZ. The difference can be seen in Fig. 6.

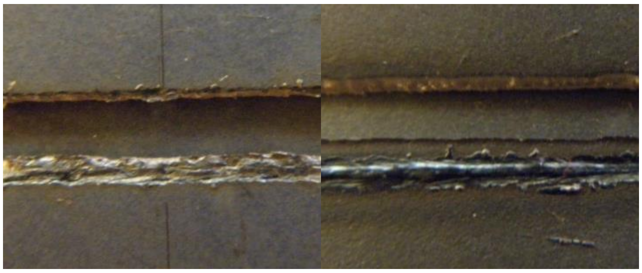

Fig. 6. Fracture surfaces of lap shear tests with (l) and without (r) coating

The examinations show that the contribution of aluminum at the fusion line represents the joints' greatest weakness. With constant coating thickness the effect increases because of rising percentage of aluminum in the weld seam. This results in local higher concentrations of aluminum precipitation at the fusion line.

5. Conclusion

Examinations of aluminum-silicon coated, press hardened 22MnBt show three different weaknesses of laser welded overlap joints.

The first weakness is the concentration of stress in minor virtual weld width. It can be avoided by using beam oscillation to create a minimum virtual weld width of $A_{min} = 0{,}9 \bullet t_{min}$.

Loss of hardness and strength in the heat affected zone forms the second weakness. Each heat input into base material causes irreversible change of material properties. The effect is enhanced by poor heat dissipation out of the work piece, as well as high energy input per unit length. Usually this effect is encountered by locally increased material thickness.

The third weakness is caused by the contribution of aluminum into the weld pool. This leads to a strong metallurgical notch and at least in the case of lap shear test to failure at the fusion line. In some cases manufacturers tend to remove the coating before laser welding to increase the joint strength significantly.

To decrease the weakening effects there are the following working hypotheses:

1. There is a connection between heat dissipation and size of the HAZ
2. There is a connection between heat dissipation and size as well as type of intermetallic phases caused by contribution of aluminum in the weld seam
3. The welding speed takes influence on the distribution of aluminum in the weld seam
4. Multiple welding causes evaporation and oxidation of aluminum
5. An increase of weld pool movement causes dilution of aluminum at the fusion line which reduces the metallurgical notch

To improve heat dissipation out of the work piece and reduce negative effects caused by multiple welding, low welding speed and similar techniques an active cooling device will be designed.

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