Oleksii Sherepenko, Sven Jüttner, Veronika Zhuk

Resistance spot welding of ultra-high strength steels with production-related process influences

Abstract: Ultra-high and advanced high strength steels find their application in the production of vehicles, for the manufacturing of car body components, especially of those that are crash safety relevant. Production related influences may affect the process stability and cause the loss of quality that can be particularly critical for spot welds with high quality requirements. Despite the high accuracy of the manufactured components, process related variations of geometry may cause gaps between the welding partners. For welding, these gaps must be bridged prior to turning on the welding current. During the welding process of such elements with gap, the preload results in specific thermal and mechanical loading of the joint that can cause imperfections in the welded joint, e.g. cracks. This article gives a review on hot stamping process as well as on previous investigations in RSW of AHSS and UHSS with production related gaps. The present study shows the influence of production related gaps on process stability, and changes in microstructure and geometry of spot welds with gaps. Based on experimental investigation, an effect of welding time, coating and production related gaps on the quality and mechanical performance of RS-welded joints is discussed.

Keywords: ultra-high strength steels, resistance spot welding, welding properties

Introduction

Ultra-high and advanced high strength steels find their application in the production of vehicles, for car body components, especially of those that are crash safety relevant. Such components must fulfill high requirements, considering strength and crashworthiness. Thus welding of these components is a challenge, considering their martensitic structure and high stiffness, which in case of process related gaps may cause high stress in the welded joints and as a result promote cold cracking. Another known problem when joining these components refers to the coatings used for prevention of oxidation by thermo-mechanical strengthening of the parts. In this paper some of the mentioned aspects and their influence on the quality of welded joints, made of high strength steels shall be discussed.

Hot stamping

A sequence of thermo-mechanical manufacturing processes that is widely used to produce components from high-strength martensitic steels is commonly known as hot stamping. The materials, most commonly used for hot stamping are boron steels. The material used in the present study is the most widely used boron

O .Sherepenko, S. Jüttner,V. Zhuk - Institute of Material Science and Joining Technologies, Otto-von-Guericke University, Magdeburg, Germany

steel 22MnB5 [1]. The schema of hot stamping is shown in Figure 1, and a complete review of the process is given in [1]. The aim of the process is to gain optimal microstructure of the MS steel while forming. During the forming process, a specific cooling rate of 27K/s must be reached, to assure the resulting martensitic microstructure [2].

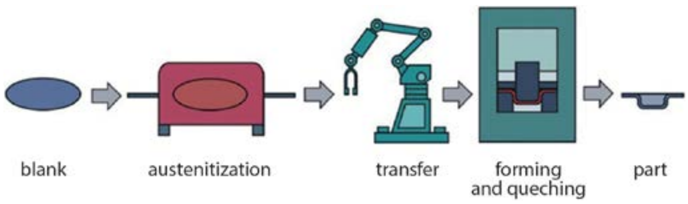

Fig. 1: Schema of direct hot stamping process [1]

Resistance spot welding with gap

Production related influences may affect the process stability and cause the loss of quality that can be particularly critical for spot welds with high quality requirements. Despite the use of modern forming techniques, a spring back of the hot formed details cannot be completely prevented. This may cause gaps between the components in the body-in-white process.

This problem of bridging gaps and their influence on the welding process and mechanical properties of the resistant spot welded joints has been intensively investigated over the past years. Hou, Kelly and Creteur [3, 4] proposed a classification of gaps for the automotive industry, depending on their geometry and a model for determining and comparing the stiffness of the gap that incorporates material properties and geometry.

Some studies [5] give an impact on the influence of gap on the process window, process stability and on the strength of resistance spot welded joints under static and dynamic loads. After [6–8] gaps have a significant effect on process stability and lead to a smaller process window. As a countermeasure against the gap, the authors recommend the usage of prolonged welding time in combination with a higher welding force, as well as welding with 2-3 pulses.

Moos and Vezetti [9] have shown the influence of the gap on mechanical stress after welding, that is induced when bridging the gap for DP-steels. The authors show that the stress has influence on contact between the sheets and as a consequence – on the formation of the nugget.

Considering high strength and stiffness of car body components, made from martensitic steels, this effect in combination with critical microstructure and production related hydrogen increases the risk of cold cracking. Despite these facts, no previous investigation of the influence of gap on cold cracking was found in the literature. This should be nearly discussed in present paper.

Experimental setup

Investigated material

In this study, welding of 2-sheet joints from 22MnB5 with Al-Si coating was investigated. The chemical composition of the material is shown in Table 1.

Table 1: Chemical composition of the investigated 22MnB-AS

22MnB5	C	Mn	Si	P	S	Al	Ti	Cr	B	Mo	Cu	Ni
	0,196	1,26	0,234	0,0257	0,0152	0,0247	0,0336	0,2	0,0050	0,016	0,009	0,02

Specimen geometry and experimental setup

Geometry of the specimens was designed with respect to the standard DIN EN ISO 14272:2002, thus the width of the specimen was chosen to be 45 mm to make the conditions of the bridging of gap comparable with the results of previous investigations of welding with gap.

When welding the gapped specimens, the tilting of the sample gap during the welding process must be excluded, in order to ensure reproducibility of results. When welding with a welding gun, it does not represent a major

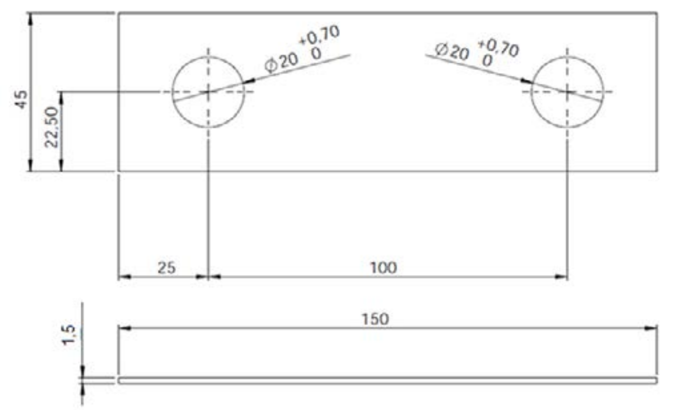

Fig. 2. Geometry of the specimens (all dimensions in mm)

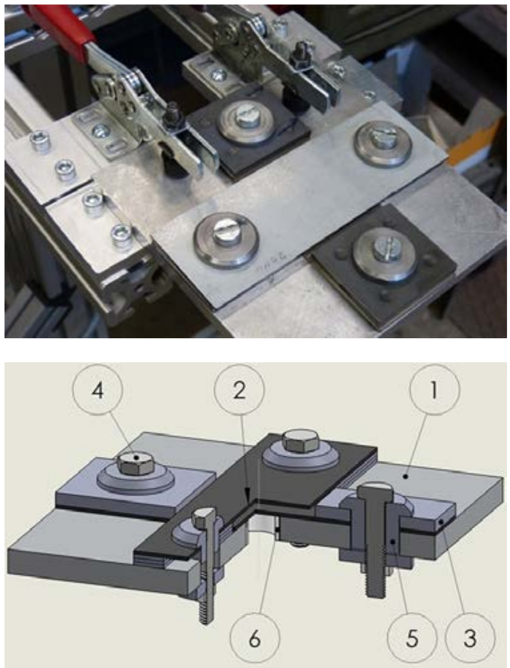

Fig. 3. Experimental setup for welding of the cross tensions specimens with gaps. a) assembled specimen before welding; b) cross-section of the clamping device

challenge, since simple fixation of samples is possible, which does not prevent the two-sided gap bridging. To simulate the conditions of two side gap bridging when welding with the stand point welding machine where only one electrode moves, a clamping device was developed as described in [10], which prevents the tilting and allows the movement of the specimen in vertical direction only. All other movements are excluded by the guides. This device consists of a movable frame on which the samples are clamped. Due to the low weight of the aluminum frame, and the guides (3.5 kg) with respect to the welding force (3.5 kN), the friction in the guides can be neglected. The frame was modified as shown in Figure 3. The device for welding of specimens for the cross-tension test consists of an aluminum frame (1), on which the specimens are fixed, using the bolts (4) pins (5). The pins have different length, as can be seen in Figure 3 (b) to assure easy removal of the specimen from the clamping device after welding. The gap width and height are set up with the distance plates (3). An isolating polymer ring (6) is used to prevent an electrical contact of the electrode with the aluminum plate and to ensure a precise positioning of the device on the electrode.

Such clamping device has several advantages in comparison to 4-point bending test, that was used for cold crack testing in the previous work [11]. The specimens for the 4-point bending test cannot be loaded directly after the welding, some time is needed to put the specimen into the clamping device and apply the load. In comparison to that, after the welding with gap, the load on the specimen is applied immediately after the release of welding force while the specimen and the HAZ are still warm after welding, which may influence the hydrogen diffusion and the stress in the loaded zone. Rapid loading after welding can also be beneficial in case of acoustic emission control of cold cracking, as the measurement can be started directly after welding.

External hydrogen addition

The addition of external hydrogen between the welded sheets was performed as described in [11]. Oil and water were used as production relevant hydrogen sources. Water was sprayed on the lower specimen prior to performing the assembly. Oil was distributed on the surface of the lower specimen, using a polymeric foam roll. In total three experimental series, each containing three specimens were performed respectively for 0h and 24h hold time after welding: 1) welding without a hydrogen addition, 2) welding with an addition of water and 3) welding with an addition of oil between the specimens. Separate samples were welded for metallographic investigations. During the loading time, the specimens stayed in the clamping device to simulate constructive loads that are caused by gap bridging. After the corresponding loading time, the cross tension test (DIN EN ISO 14272:2002) of the specimens was made. The change in the strength of the joints may indicate the degradation of the joint and may be used as an indicator for the cold cracking.

Welding Parameters

Welding parameters for resistance spot welding of 22MnB5, shown in Table 2 were found in [12] and the usage of these parameters for welding of 22MnB5 with gap height up to 3 mm and gap width 50 mm was shown in [10]. The electrode cap used was F1-16-20-50 EN ISO 5821:2004.

in strength can be indicated for the joints with oil after a 24 hour holding time. Fractographical investigations show evidence of brittle fracture at the points of high stress concentration for all joints with hydrogen addition (Figure 5), without correlation with the loading time. This may lead to the hypothesis that only cracking in the specimens with oil addition was severe enough to cause the loss of strengths.

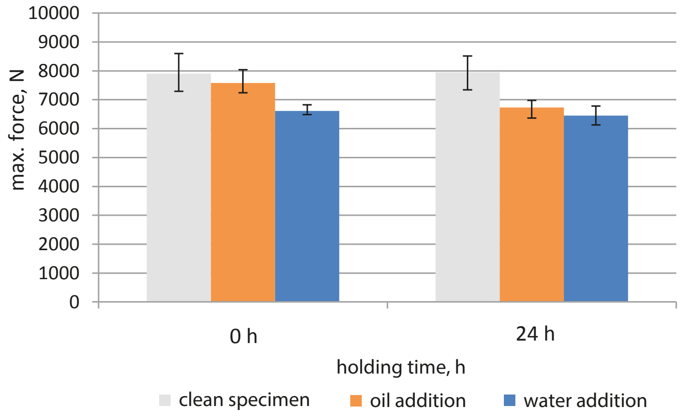

Fig. 4. Results of the cross tension test

Table 2: Welding Parameters for 22MnB5

Hold time [ms]	1st pulse current [kA]	1st pulse time [ms]	Pause [ms]	2nd pulse current [kA]	2nd pulse time [ms]	Post weld hold time [ms]
500	4.5	300	30	5.6	300	300

Results and discussion

Influence of gap and hydrogen addition on cold cracking of 22MnB5

As mentioned before, residual stress after bridging the gap in combination with process relevant hydrogen additions may cause cold cracking. Figure 4 shows the maximum force, obtained from the cross tension test with no holding time and 24 hours holding time, respectively with and without hydrogen additions.

Specimens welded without hydrogen addition have shown the highest strength and no significant change in strength after 24 h loading time. Specimens with the water addition show a decrease in strength where no significant between the 0 h and 24 h holding times can be seen. The metallographic investigations have shown the presence of cold cracks in joints with water for both loading times. A decrease

The fractographs, obtained with REM (Fig. 5) show the evidence of hydrogen induced cold cracks (separated triple point grain boundaries and dimples on the fractured surfaces) for the specimens, welded with oil addition that loaded for 24h.

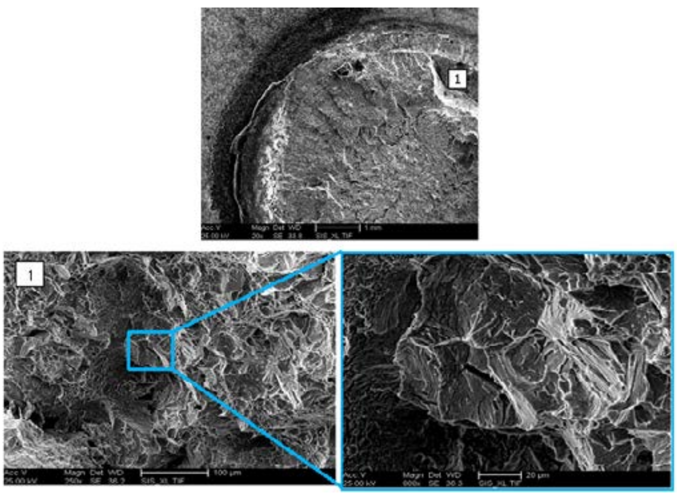

Fig. 5. Fractographs of the cold cracked regions in RS-welded joint (oil addition, loading time 24h)

Phenomenological microstructure observations

In addition, phenomenological hardness loss in the heat affected zone near the melting line of RS-welds of 22MnB5 steel with AlSi coating (Figure 6), complex microstructural inhomogeneities were indicated in the welds during present investigations.

They can be seen in Figure 7(a), where they are marked with the arrows. The phenomena can be respectively found in both welds with and without gaps; however, they exhibit variation in form (V-shape to round shape) and size, as it can be seen in figures 7 to 9.

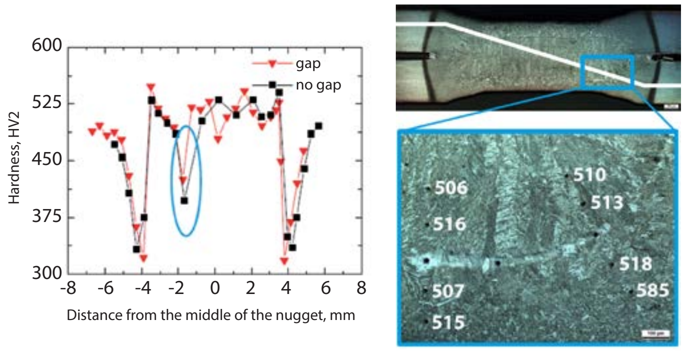

Fig. 6. Hardness profile in the cross section of the welded joints with 3 mm gap and without gap, material: 22MnB5 with AlSi coating (a); hardness loss along the melting line in the HAZ of the joint (b) [10].

They are situated in the HAZ at the both sides of the lens where the rests of the coating are most likely to be squeezed out during the welding process and therefore it may be assumed, that the microstructural inhomogeneities are caused with the segregation of the coating components -Al and Si as it is known from the laser welding of 22MnB5 AS. The EDX element mapping was employed to prove this hypothesis. However, the element maps of Al and Si have shown a homogenous distribution of these elements in the specimen.

Further investigations of the mentioned regions have shown, that they have a complex structure. As can be seen in Figure 9, they consist of the two zones, that exhibit different microstructure. The zone at the border of the observed inhomogen region exhibits fine grain martensitic microstructure, containing lath martensite with high hardness values (about 700-900 HV). In the middle of the region, a ferritic microstructure, sometimes with a fine grain martensite regions can be found with corresponding lower hardness of 370 to 600 HV with intra- and intergranular precipitations, assumable carbides, seen in Figure 8 b that may indicate a higher concentration of B and C in this region.

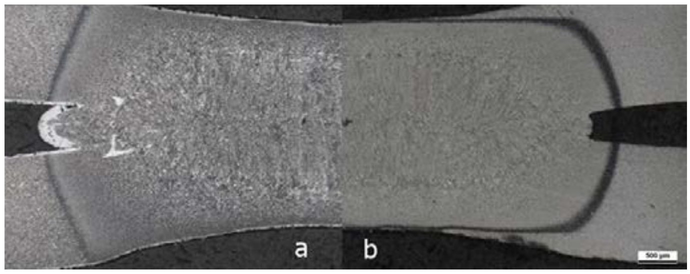

Fig. 7. Macrograph of a gaped RS-Welded joint of 22MnB5, welded with AS-coating (a) and a gapped joint, welded with the AS coating removed prior to welding (b)

CEN Images of the regions with changed microstructure Figure 8 (a) have shown the inhomogeneity of chemical composition that could not be seen on the EDX maps. Figure 8 a exhibits a false color CEN image that indicates the difference between the two regions.

A lighter zone at the outer border of microstructural inhomogeneity Figure 8 (a) appears to have a slightly higher Mn contents 1.9 wt.% in comparison with the base metal (1.4 wt.%). This zone refers to the zone with fine grain martensite. However, the fact of its lighter appearance on the CEN-image may indicate lower concentration of light elements in this region.

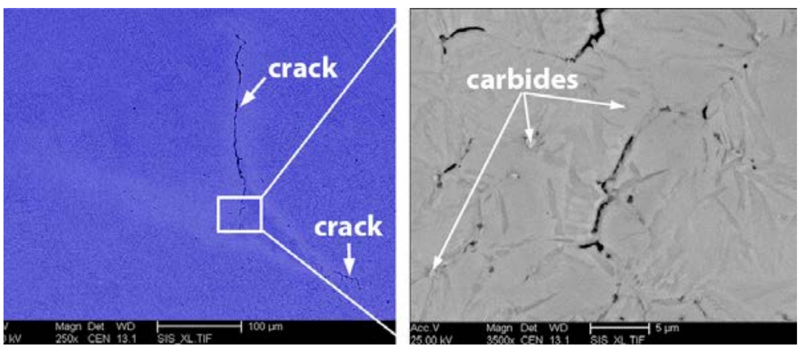

Fig. 8. CEN-image of the microstructural inhomogeneity in the HAZ of a specimen, welded with water addition (hold time of 24 h).

Fig. 9. An interference-contrast optical micrograph of the microstructural inhomogeneity.

The second zone in the middle of the inhomogeneity, appears darker on the CEN image (Figure 8a). This indicates a higher concentration of elements with low atom weight, e.g. Mn, B and C that are relevant for 22MnB5. The manganese content of the inner region is high, up to 3.7 wt%.

The cold cracks were found in the described microstructural inhomogeneities, as can be seen in Figure 8 a. The crack is situated in the martensitic zone of the inhomogeneity and the hypothetical blunting of the crack can be mentioned in the ferritic region in Figure 8 (a) and (b). Figure 7 (b) also indicate an intergranular path of the crack. This approves the hypothesis that the microstructural inhomogeneities act as metallurgical stress concentrators and may increase the cold cracking susceptibility.

Conclusion and summary

1. The microstructural changes in the HAZ of the RS-welded joint, made of 22MnB5 were found and described. They are present only in joints of 22MnB5 with Al-Si coating. The nature of these microstructural changes could not be clearly described; however, it can be assumed that they are caused with the redistribution of chemical elements such as C, Mn and B due to diffusion processes in the HAZ at elevated temperatures.
2. Cold cracks were detected in the specimens with hydrogen addition, using metallographic and fractographic investigations. Only the addition of oil led to a decrease in strength of the welded joints after 24 h loading time.

Further investigations, employing SIMS to observe the distribution of light elements, such as C and B inside the described regions shall be performed in the future works.

Modelling of the thermodynamic processes in the HAZ of the RS-welds should be performed to get a closer insight in reasons for the microstructural inhomogeneities in the HAZ.

Closer observation of cold cracking processes in the RS-welded joints shall be performed employing acoustic emission analysis for defining the time of crack and propagation during the loading time.

Current investigations were supported by the Graduate Scholarship Program of Saxony-Anhalt.

References

1. Karbasian, H.; Tekkaya, A. E.: A review on hot stamping. In: Journal of Materials Processing Technology 210 (2010) 15, pp. 2103–18.
2. Geiger, M.; Merklein, M.; Hoff, C.: Basic Investigations on the Hot Stamping Steel 22MnB5. In: Advanced Materials Research 6-8 (2005), pp. 795–804.
3. Hou, W.; Cretteur L.; Kelley S.C. Effect of Gap on AHSS RSW Weldability (2009).
4. Hou, W.; Kelley S.C.: Collapse force prediction for AHSS gapped RSW Joints, paper 1-2. In: N.N. (Hrsg.): Sheet Metal Welding Conference XIII. Detroit 2008.
5. Bestimmung des Einflusses von fertigungsbedingten Imperfektionen und bertriebsbedingten Eigenschaftsänderungen auf die Festigkeit von Punktschweißverbindungen unter Crashbelastung, AiF 15 295 N/4 2009.
6. Wesling, V.; Rekersdrees, T.; Keitel, S., et al.: Widerstandspunktschweißen moderner Mehrphasenstähle. In: TUC Forschung-Stähle 16 (2005), pp. 54–58.
7. Untersuchungen zum Widerstandspunktschweißen von Feinblechen aus neuentwickelten höher- und höchstfesten Stahlwerkstoffen: Abschlussbericht zum AiF 12.618 N.

8. Meyer, R.: Erhöhung der Prozesssicherheit durch Beherrschung der Bauteilabweichung beim Fügen im Karosseriebau. Dresden 2012.
9. Moos, S.; Vezzetti, E.: Compliant assembly tolerance analysis: guidelines to formalize the resistance spot welding plasticity effects. In: The International Journal of Advanced Manufacturing Technology 61 (2012) 5-8, pp. 503–18.
10. Sherepenko, O.; Jüttner, S.: Schweißtechnische Verarbeitung höchstfester Stähle. Widerstandspunktschweißen unter Berücksichtigung fertigungs-bedingter Spalte: 34. Assistentenseminar Füge- und Schweißtechnik. Vorträge der gleichnamigen Veranstaltung in Lichtenwealdevom 26. bis 28. September 2013. Düsseldorf 2014.
11. Schwedler, O.; Zinke, M.; Jüttner, S.: Untersuchungen zum Kaltrissverhalten von Widerstandspunktschweißverbindungen an Feinblechen aus pressgehärtetem 22MnB5: Produktionssysteme und -methoden für den Leichtbau. Wegbereiter zur E-Mobilität. Tagungsband des 33. EFB-Kolloquiums Blechverarbeitung 2013. Hannover 2013, S. 209–18.
12. Wink, H.-J.; Krätschmer M.: Charakterisierung und Modellierung des Bruchverhaltens von Punktschweißverbindungen in pressgehärteten Stählen. Teil II - Simulation des Schweißens. Ulm 2012.