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INVESTIGATIONS OF MICROSTRUCTURE OF RESISTANCE SPOT-WELDED JOINTS MADE OF HSLA340 AND DP600 STEELS

BADANIE MIKROSTRUKTURY ZŁĄCZY ZGRZEWANYCH PUNKTOWO ZE STALI HSLA340 I DP600

The paper presents results of metallographic investigations of spot welds made of high-strength steel HSLA340 and dual-phase DP600 steel. Low-carbon martensite microstructure was found in the weld nugget of HSLA steel. The DP600 steel shows martensite and bainite microstructure. For both steels, no carbides of microadditives were found because they dissolved in liquid nugget and could not precipitate again because of rapid heat abstraction. Moreover, no transcrystallisation was found in both steels, which proves good mixing of the materials within the weld.

Keywords: resistance spot welding, high-strength steel, metallographic examination

W artykule opisano wyniki badań metalograficznych zgrzein punktowych wykonanych ze stali o podwyższonej wytrzymałości HSLA340 i dwufazowej stali DP600. Badania wykazały, że jądro zgrzeiny dla stali HSLA ma mikrostrukturę martenzytu niskowęglowego, a dla stali DP600 martenzytu i bainitu. Dla obu gatunków stali w zgrzeinie nie obserwowano węglików mikrododatków stopowych, gdyż w czasie tworzenia ciekłego jądra zostały one rozpuszczone, a w wyniku szybkiego odprowadzania ciepła do elektrod nie zdołały się ponownie wydzielić. Ponadto dla obu gatunków stali zaobserwowano brak transkrystalizacji, co świadczy o dobrym wymieszaniu się materiałów w obrębie zgrzeiny.

1. Introduction

Resistance spot welding is a basic method of bonding the structure and supporting components in automotive vehicles. Because the process is quick and can be easily automated, this situation will last for the next decades [1].

Modern constructional steels applied in present-day manufacturing systems in automotive industry offer their users low weight and high safety level. Application of high-strength steels of the HSLA and DP groups together with properly selected welding parameters permit making correct joints with desired microstructure [2]. Appearing in the market the high-strength dual-phase steels created problems related to selection of welding [3] and resistance-welding parameters [4], thus implying worse strength properties of welded and resistance-welded joints. Analysis of microstructure of spot welds of HSLA340 and DP600 steels gives information on possible drop of strength of resistance-welded joints.

Depending on destination of individual parts of a vehicle structure, they are made of different grades of steels. The steels used in automotive industry can be divided into three groups [5]:

- Low-Strength Steels (LSS),
- Traditional High-Strength Steels (HSS),
- Advanced High-Strength Steels (AHSS).

Figure 1 shows grouping of steels used in automotive industry, classified acc. to the relationship between elongation and tensile strength.

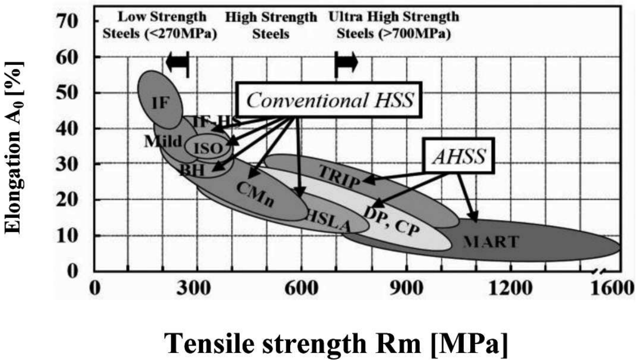

Fig. 1. Relationship between elongation and tensile strength of various steels used in automotive industry [6]

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The group of low-strength steels (LSS) includes [5]:

- Mild steels,
- Deep-drawing, Interstitial-Free steels (IF).

Among traditional high-strength steels (HSS), the following can be distinguished:

- Deep-drawing, Isotropic Steels (IS),
- Precipitation-hardened, Bake-Hardenable steels (BH),
- Carbon-Manganese steels (CMn),
- High-Strength Low-Alloy steels (HSLA).

The family of advanced high-strength steels (AHSS) includes:

- Ferritic-martensitic, Dual-Phase steels (DP),
- Complex Phase steels (CP),
- Transformation-Induced Plasticity steels (TRIP),
- Martensitic steels (Mart).

2. Characteristics of HSLA and DP (Dual Phase) steels

The HSLA steels belong to the group of traditional steels with higher strength (HSS) and are designed for cold working. It originates from weldable, unalloyed constructional steels C-Mn with ca. 0.2% C and ca. 1.5% Mn. Further examinations lead to developing high strength microalloyed constructional steels C-Mn of HSLA type, including microadditives having high affinity to carbon and nitrogen, i.e. Nb, Ti and V up to ca. 0.1%. On Fig. 2 the influence of microadditives (Nb, Ti and V) has been presented.

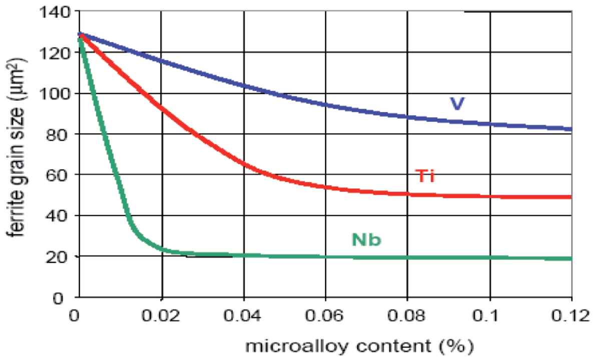

Fig. 2. Influence of microadditives on grain refining [7]

In comparison to unalloyed, low-carbon steels (with identical C content), these steels demonstrate almost twice as high yield point and tensile strength. Fig. 3 describes tensile stress-strain curves of various HSLA steels compared with mild steel.

The DP steels belong to an advanced group of steels with high and ultra-high strength (AHSS) of the first generation [8]. The steels are hardened by a phase transformation that occurs during the material preparation stage. Microstructure of a DP steel is composed of a matrix (fine-grained polygonal or acicular ferrite, carbide-free) with "islands" of martensite in the amount of 5 to 30% (depending on needs, this percentage can be slightly increased). Because of hard martensite islands present in the microstructure, cold-formed products of these steels, e.g. stamped truck wheel disks, intensively harden and demonstrate high fatigue strength [9,10]. Tensile strength of DP steels can be even higher than 1000 MPa, maintaining good elongation of a dozen percent [8].

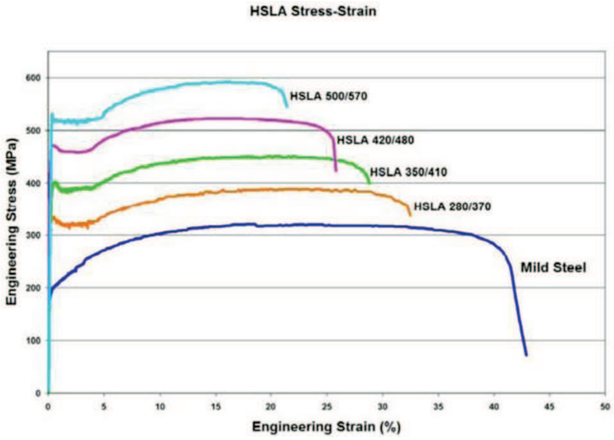

Fig. 3. Tensile stress-strain curves of various HSLA steels compared with mild steel

3. Materials, welding parameters and methodology

For testing, specimens 25×80 mm were prepared of sheets HSLA340 and DP600 1.2 mm thick. Chemical compositions of the materials determined by spectral analysis are given in Table 1.

TABLE 1

Chemical compositions of tested materials

ITEM	ELEMENT [wt%]	TESTED MATERIAL	
		HSLA340	DP600
1	**C**	0.04	0.07
3	**Mn**	0.79	0.85
4	**Si**	0.02	0.20
5	**P**	0.007	0.006
6	**S**	0.006	0.003
7	**Cr**	0.04	0.03
8	**Ni**	0.02	0.02
9	**Al**	0.04	0.05
10	**V**	0.003	0.01
11	**Ti**	0.001	0.001
12	**Nb**	0.05	0.014
13	**Fe**	Balance	

The resistance-welded joints were made using a spot-welding machine ZPa-80 equipped with contact points of copper alloy MHY, with working surface dia. 6 mm. The welding parameters were selected experimentally, so that the pressure weld diameter was 5 to 6 mm. For both materials, i.e. HSLA340 and DP600 steels, a simple, single-impulse welding program with initial pressure time 30 ms, welding time 16 ms and final pressure time 40 ms was applied. The welding current was 6.5 kA and pressure force was 3 kN.

The welded specimens were cut-out with a spark-erosion cutter and metallographic sections were prepared. Metallographic examinations were carried out on a light microscope Neophot 32 and an electron scanning microscope JEOL 5800LV.

4. Examinations of welded joints of HSLA 340

Figure 4 shows microstructure of base material of HSLA 340 steel. For analysis, a specimen of not-welded base material was selected. It was found that microstructure of base material consisted of very fine-grained ferrite with precipitates of cementite inside grains and on grain boundaries, see Fig. 5.

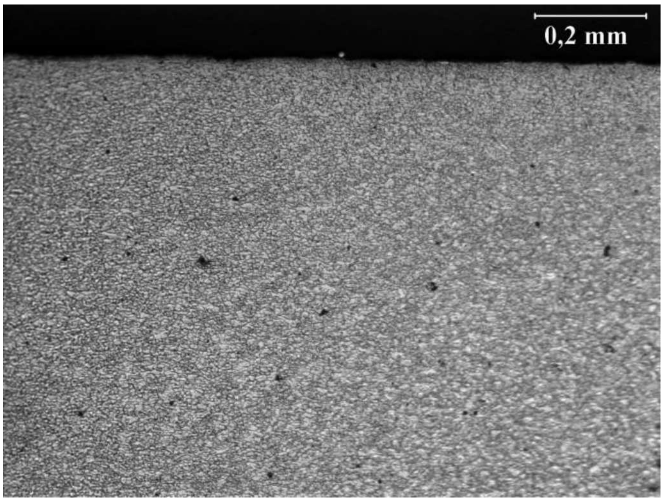

Fig. 4. Microstructure of HSLA340 base material, etched with 5-% nital, light microscope

In Fig. 6, the boundary between base material from the electrode side, heat-affected zone and weld nugget are clearly visible. The surface layer retained ferritic microstructure (Fig. 7) because the material was not overheated and its microstructure was unchanged thanks to rapid heat abstraction to the electrode. Microstructure of the heat-affected zone consists of fine-acicular, low-carbon martensite in the areas of former austenite, which gradually changes to ferritic microstructure. Elongated shape of grains in the weld nugget corresponds with the direction of heat abstraction, i.e. radially to the electrodes and the welded material.

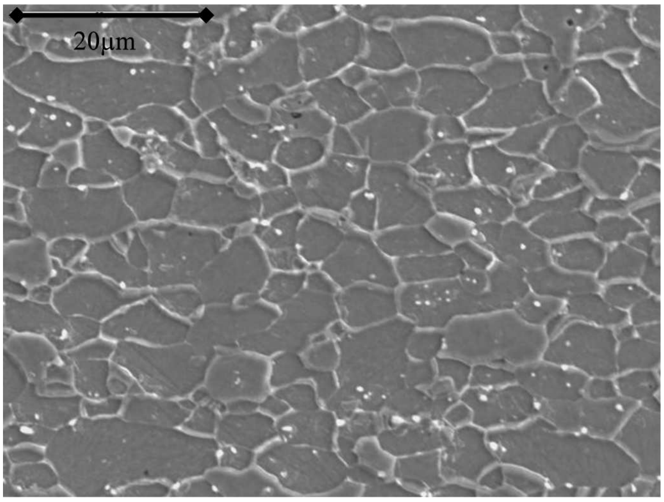

Fig. 5. Microstructure of HSLA340 base material, etched with 5-% nital, SEM

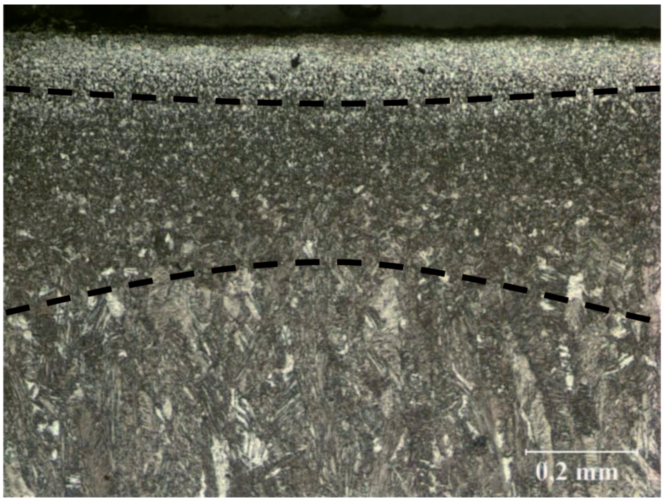

Fig. 6. Microstructure of HSLA340 weld: base material, heat-affected zone and weld nugget, etched with 5-% nital, light microscope

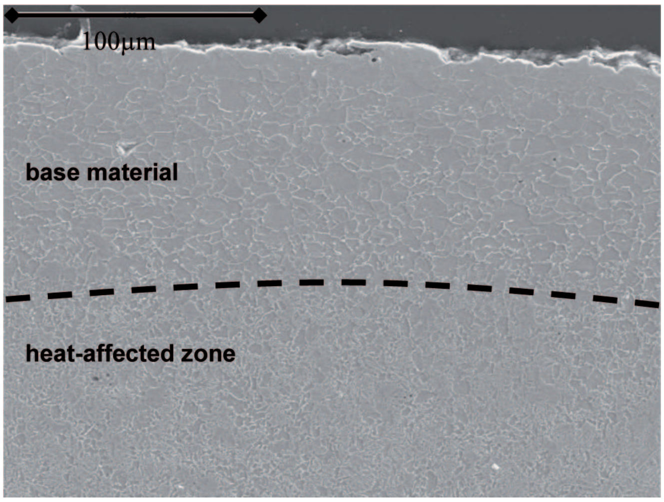

Fig. 7. Microstructure of HSLA340 weld: base material and heat-affected zone on the electrode side, etched with 5-% nital, SEM

Microstructure of weld nugget (Figs. 8 and 9) is similar to that of a cast ingot in the columnar crystals zone. Microscopic examinations of the weld nugget zone reveal microstructure of low-carbon martensite which hardness reaches 450 HV0,2 [11]. No carbides are present in the weld, because they were dissolved during heating and could not precipitate during rapid cooling. No transcrystallisation was found, which proves that the materials within the weld were well mixed.

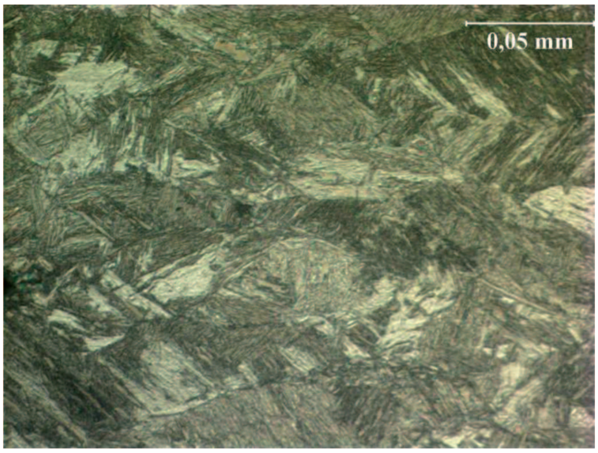

Fig. 8. Microstructure of HSLA340 weld: weld nugget material, etched with 5-% nital, light microscope

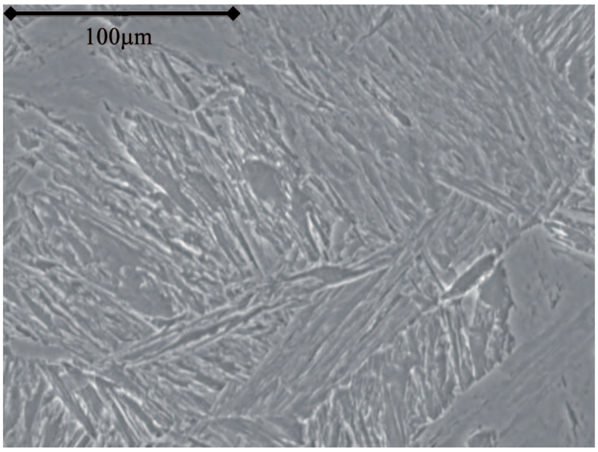

Fig. 9. Microstructure of HSLA340 weld: spot-weld nugget, etched with 5-% nital, SEM

5. Examinations of welded joints of DP600

Like in the case of HSLA340, the specimens of the dual-phase DP600 steel after resistance welding were subject to metallographic examinations on a light microscope and an scanning electron microscope (SEM). Structure of base material of DP600 (Figs. 10 and 11) consists of soft ferrite matrix with martensite ”islands”.

Like it was observed in HSLA340, also in DP600 a boundary between base material, heat-affected zone and weld nugget was clearly visible, see Figs. 12 and 13. Microstructure of HAZ consists of fine-acicular martensite that gradually changes to ferritic-martensitic structure characteristic for the base material. No carbides were observed in the weld and the base material, probably because of their significant dispersion.

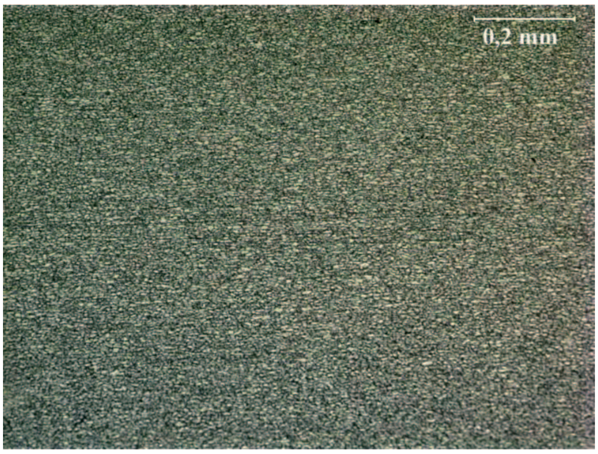

Fig. 10. Microstructure of DP600 base material; magn. 100x, etched with 5-% nital, light microscope

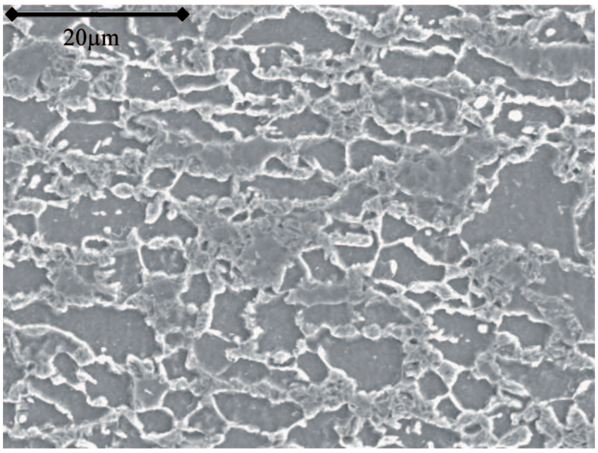

Fig. 11. Microstructure of DP600 base material, etched with 5-% nital, SEM

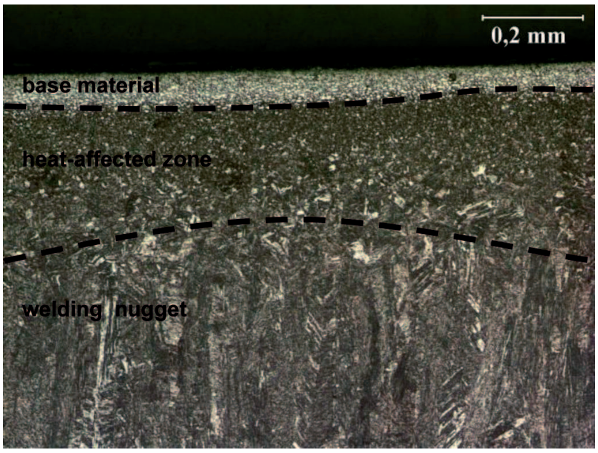

Fig. 12. Microstructure of DP600 weld: base material, heat-affected zone and weld nugget, etched with 5-% nital, light microscope

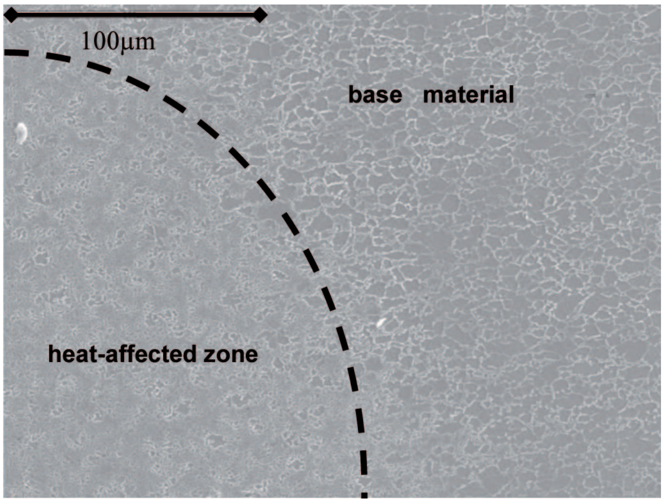

Fig. 13. Microstructure of DP600 weld: base material and heat-affected zone on the electrode side, etched with 5-% nital, SEM

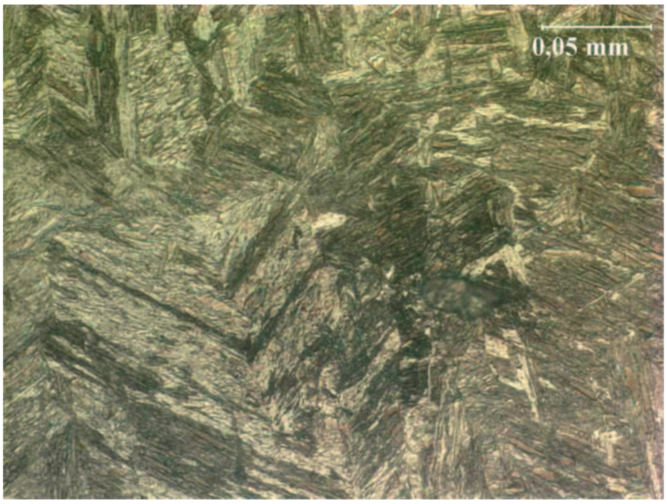

Fig. 14. Microstructure of DP600 weld: weld nugget, etched with 5-% nital, light microscope

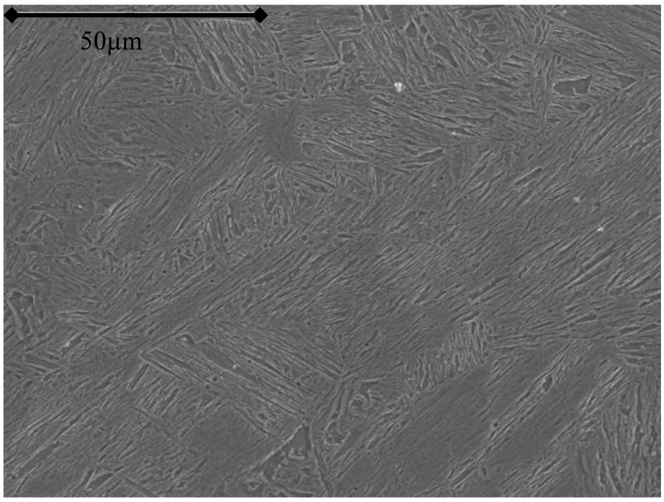

Fig. 15. Microstructure of DP600 weld: weld nugget, etched with 5-% nital, SEM

In the weld nugget of DP600 (Figs. 14 and 15), structure of low-carbon, coarse-acicular martensite and bainite was found. Based on [12] microhardness in welding nugget oscillates around 450HV0,2.

6. Conclusions

The performed examinations of spot-resistance welded joints showed that microstructure of the weld nugget consists of low-carbon martensite in the HSLA steel and martensite, bainite in the DP600 steel. No carbides were observed in both steels, because they dissolved during creation of the liquid nugget and could not precipitate again because of rapid heat abstraction to the electrodes. Moreover, no transcrystallisation was found in both steels, which proves good mixing of the materials within the weld.

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