

MICROSTRUCTURE OF FIBRE LASER WELDED BUTT JOINTS

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Microstructures and microhardness profiles of butt joints welded by fibre laser were evaluated. Dual phase steel HCT980X and bake hardening steel HX220BD sheets with thickness of 1.2 mm were welded at five different welding parameters. The joints showed microstructural changes from ferrite and martensite in dual phase steels or ferrite in bake hardening steels to acicular ferrite, bainite and martensite in the fusion zones and heat affected zones. The welding resulted in a significant microhardness increases in the fusion zones and even more in the heat affected zones near dual phase steel HCT980X. The microstructures observed in particular weld zones corresponded well with microhardness profiles measured across the joints.

KEYWORDS

dual phase steel, bake hardening steel, fibre laser welding, microstructure, microhardness.

1 INTRODUCTION

Advanced high strength steels have been widely used in automotive industry to reduce greenhouse gas emissions and fuel consumption. Dual phase (DP) steels comprise important part of advanced high strength steels because of their advantages compared to standard steels. DP steels have superior mechanical properties, moderate price and excellent technological properties [Gong 2016, Mei 2009]. The excellent mechanical properties are the consequence of their multiphase structure, which consists of 30-70 % martensite in the fine grained, spherical ferrite matrix and 1-10 % of metastable retained austenite. As a result, the steel is characterised by high tensile strength up to 1180 MPa with unit elongation up to 27 % [Bandyopanday 2016, Farabi 2011, Krajewski 2014, Mazaheri 2015].

DP steels can be used in automotive industry to produce tailor welded blanks. Tailor welded blanks are semi-finished parts that consist of at least two single sheets with different mechanical properties, thickness or coatings. Bake hardening (BH) steels with ferritic structure and excellent formability are suitable materials for joining with DP steel in tailor welded blank. Tailor welded blanks made of DP and BH steels enable adaptation to locally different loading conditions or other requirements in the parts [Merklein 2014, Rossini 2015, Wang 2016].

Fibre laser welding has been widely used to create tailor welded blanks due to their small fusion zone (FZ), heat affected zone (HAZ) and the lower cost and greater flexibility compared to other welding methods. Although the laser welding process produces less impact on the material properties than other welding methods the formability is worsened by material

properties resulting from microstructure changes accompanying the laser welding. The microstructure is affected mainly by chemical composition of base materials, sheets thickness and welding parameters. The studying of the welding parameters effects on microstructure of weld joints in tailor welded blanks is important to optimize the laser welding process [Broggiato 2015, Cui 2016, Mesko 2014, Saha 2014, Vinas 2014].

2 EXPERIMENTAL MATERIALS AND USED METHODS

Two different steels, dual phase steel HCT980X and bake hardening steel HX220BD with thickness of 1.2 mm and zinc coating of 100 g.m⁻², were chosen for laser welding of butt joints. The chemical compositions and mechanical properties of experimental steels are given in Table 1, 2 and 3.

Table 1. Chemical composition of dual phase steel HCT980X

Element	C	Mn	Si	P	S
C _{max} (wt. %)	0.23	2.5	0.8	0.08	0.015
Element	V	Al	B	Cr+Mo	Nb+Ti
C _{max} (wt. %)	0.2	2.0	0.005	1.0	0.15

Table 2 Chemical composition of bake hardening steel HX220BD

Element	C	Mn	Si	P
C _{max} [wt. %]	0.1	0.7	0.5	0.08
Element	S	Nb	Ti	Al
C _{max} [wt. %]	0.025	0.09	0.12	0.1

Table 3. Mechanical properties of experimental steels

Steel	HCT980X	HX220BD
Tensile strength [MPa]	980	320-400
Proof strength [MPa]	600-750	220-280
Min. elongation at Lo = 80 mm [%]	10	32

The experimental steels have different maximal allowed concentrations (C_{max}) of both carbon and alloying elements. DP steel has higher concentration of these elements, which results in higher strength but lower plasticity compared to BH steel. The maximal concentration of Al (2.0 %) given in standards for DP steel is quite high, but the typical concentration is about 0.04 % Al. The blanks of experimental steels were welded by Nd:YAG YLS 5000 fibre laser with a maximum beam power of 5 kW and with a wavelength of 1.06 μm. Diameter of fibre was 0.1 mm and the distance of focus head 250 mm. Welding experiments were conducted on sheets with length of 200 mm and width of 100 mm along the longitudinal edge. Welding surfaces were cleaned with steel wire brush and acetone before laser welding. The microstructures of joints were studied on samples cut off the welding joints using Axiovert 40MAT light microscope and JEOL IT300 scanning electron microscope. Microhardness profiles were measured on transverse sections of weld bead centres parallel to the surfaces of sheets using Vickers indentation method. Microhardness profiles were measured at two different loads 50 g and 100 g, indentation distances of 0.05 and 0.1 mm, and dwell time of 15 s.

3 RESULTS

Butt weld joints prepared at five different beam powers (P), welding speeds (v) and heat inputs (P/v) calculated in a simplified way are summarized in Table 4.

Table 4. Welding parameters of laser joints

Weld No.	Beam power [kW]	Welding speed [$\text{cm}\cdot\text{s}^{-1}$]	Heat input [$\text{J}\cdot\text{cm}^{-1}$]
1	0.9	1	900
2	1.5	3	500
3	2.2	5	440
4	2.8	7	400
5	4.0	10	400

An example of cross section of the butt joint No. 1 with DP steel left and BH steel right is documented in Fig. 1. The weld is formed well and free of porosity or cracks in the FZ or both HAZs. The joint is characterised with the slight concavity of the face and root sagging.

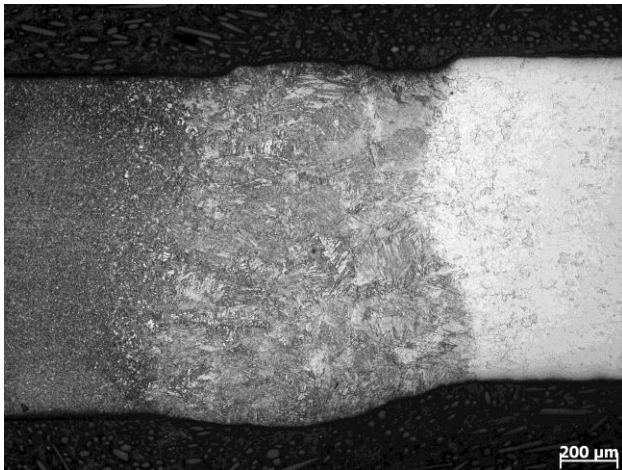


Figure 1. Cross section of the butt joint No. 1

Joints welded at different parameters are similar and without macroscopical defects. The widths of welds decrease with increasing of beam power and welding speed, which is the consequence of smaller amount of the heat input and larger cooling speed.

3.1 Microstructure of joints

The microstructures of the base metals (BM), fusion zones (FZ) and heat affected zones (HAZ) were observed at joints welded at different parameters according to Table 4. The microstructure of DP steel is documented in Fig. 2. It consists of martensitic island in ferrite matrix with equal portion of these phases and with average grain sizes under $1\ \mu\text{m}$. The BH steel in Fig. 3 has ferritic microstructure with the average grain size above $10\ \mu\text{m}$.

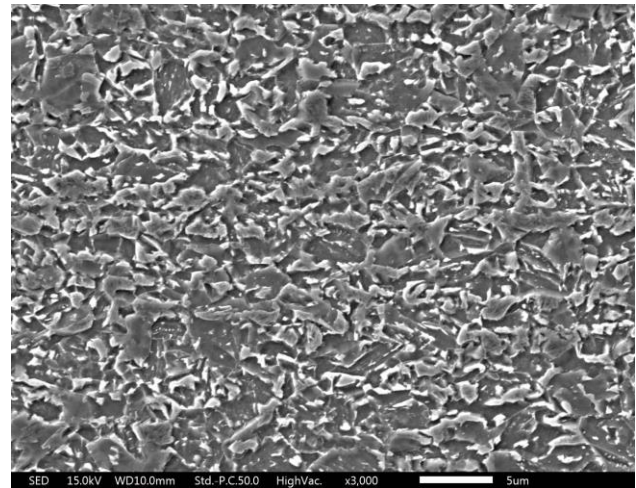


Figure 2. Microstructure of DP steel HCT980X

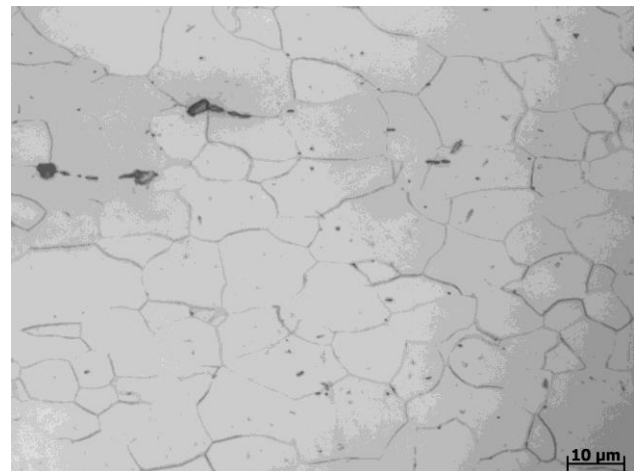


Figure 3. Microstructure of BH steel HX220BD

The microstructures of both steels change during laser welding from ferrite and martensite (DP steel) or ferrite (BH steel) to ferrite, bainite and martensite in FZ and HAZ. The FZ contains large amount of acicular ferrite and small areas of martensite and bainite. The formation of these non-equilibrium microconstituents in the FZ is the result of the rapid cooling of the weld pool containing relatively higher contents of carbon and alloying elements in DP steel (see Tab. 1). More martensite and bainite is observed in joints prepared at higher beam powers and welding speeds (joint No. 5) compared to lower values of these welding parameters (joint No. 1), but the difference is small. The typical microstructures of FZ can be seen in Fig. 4 and 5 which document FZ of joints No. 3 and No. 5. The FZ of laser joint No. 3 with dominant creation of acicular ferrite is in Fig. 4. The FZ of laser joint No. 5 with lath microconstituents is in Fig. 5.

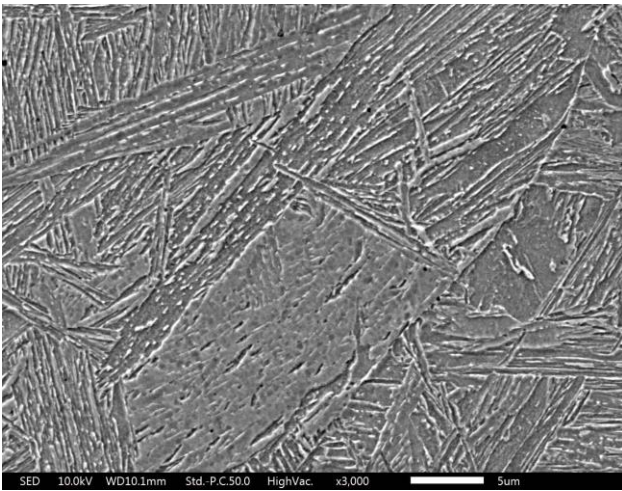


Figure 4. Fusion zone of laser joint No. 3

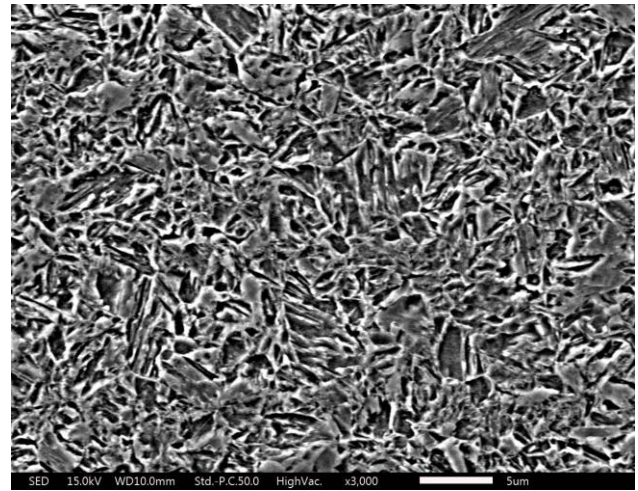


Figure 7. Microstructure of fine grained region of HAZ near DP steel

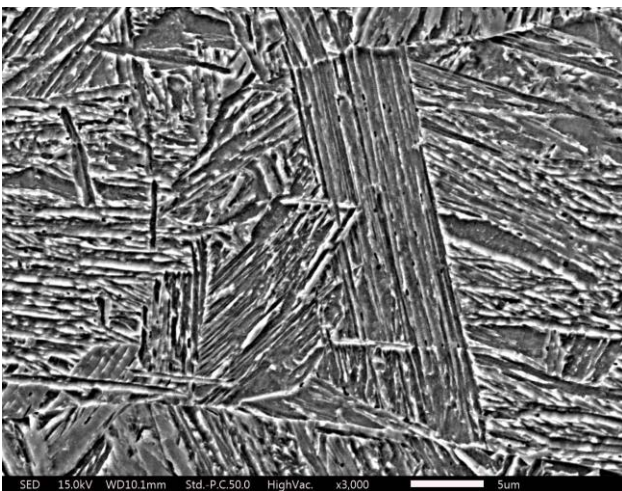


Figure 5. Fusion zone of laser joint No. 5

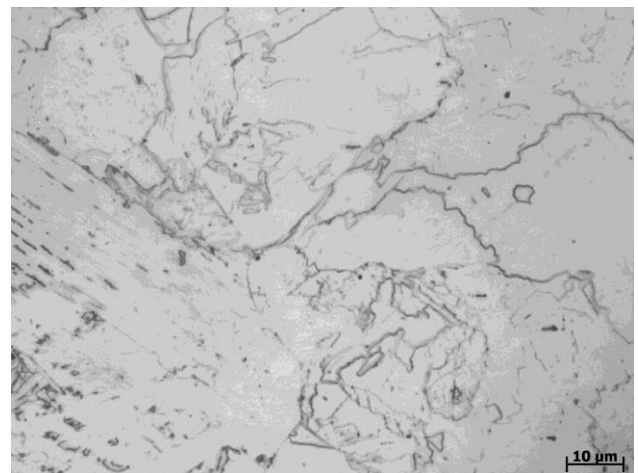


Figure 8. Microstructure of HAZ near BH steel

A similar tendency was found when comparing HAZs prepared at different welding parameters. The microstructures of both HAZs near DP steel and near BH steel are for joint No. 5 documented in Fig. 6, 7 and 8.

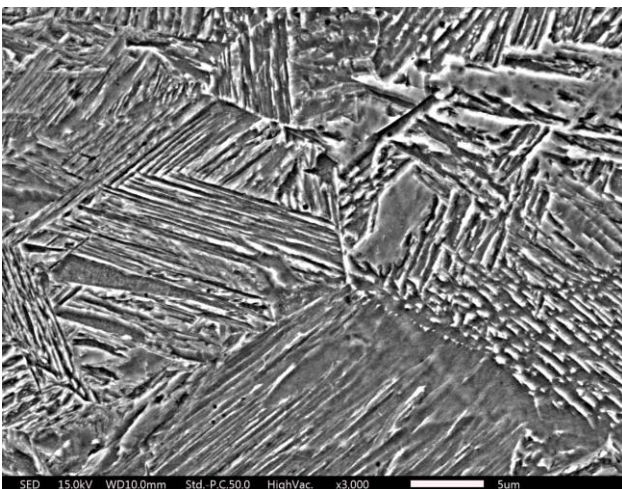


Figure 6. Microstructure in high tempered region of HAZ near DP steel

As DP steel HCT980X contains a larger amount of alloying elements compared to BH steel HX220BD, the HAZ microstructure near DP steel consists mainly of lath microconstituents build in packets. These packets can be martensite or bainite and they are presented in Fig. 6 and 7. Fig 6 represents high tempered region of HAZ near DP steel and Fig. 7 the fine grained region of HAZ near DP steel. The HAZ microstructure near BH steel in Fig. 8 consists mainly of ferrite and acicular ferrite with large grain size.

3.2 Microhardness of joints

The microhardness profiles of joints welded at different parameters show an increase in measured values with heat input. This effect can be seen by comparing Fig. 9 and 10 and Table 5. Higher microhardness is measured at the lowest heat input of 400 J.cm^{-1} compared to the highest heat input of 900 J.cm^{-1} .

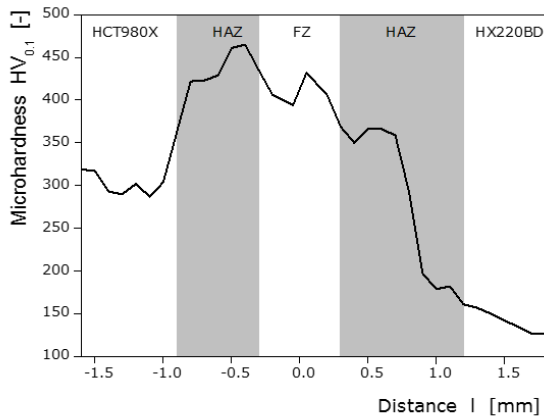


Figure 9. Microhardness profile of laser joint No. 1

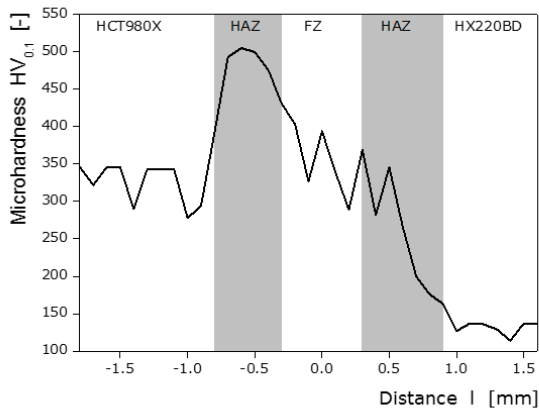


Figure 10. Microhardness profile of laser joint No. 5

Microhardness profiles in Fig 9 and 10 are characterized by similar unsymmetrical shape and slightly different maximal measured values in particular zones of joints. The microhardness values in particular zones correspond to the microstructures in these zones. The maximal measured microhardness values are measured in joints welded at minimal heat inputs which represent maximal cooling speeds. The widths of both FZ and HAZ decrease with decreasing heat input. The HAZ near BH steel HX220HD is wider than the HAZ near DP steel HCT980X. The BH steel HX220HD has microhardness under 150 HV_{0.1} and this value represents ferritic structure of this steel (Fig. 3). The microhardness of DP steel HCT980X is in the interval from 280 to 340 HV_{0.1} and it is in a good agreement with dual phase ferrite and martensite microstructure (Fig. 2). The microhardness from 300 to 450 HV_{0.1} measured in FZ confirms creation of bainite and martensite in the FZ. The large difference in the microhardness in both HAZs is in good agreement with their microstructure. The HAZ near DP steel contains the largest amount of hard lath microconstituents (Fig. 6 and 7) and reaches the highest microhardness of 500 HV_{0.1}. The microhardness in HAZ near BH steel is from 180 to 370 HV_{0.1} and its value decreases with the distance from the weld as can be seen in Fig. 9 and 10. Lower values confirm creation of softer microconstituents (Fig. 8) compared to HAZ near DP steel.

Table 5. Microhardness HV_{0.1} in particular zones of laser joints

Weld No.	HAZ near DP steel	FZ	HAZ near BH steel
1	363-465	369-432	197-369
2	360-487	302-452	181-355
3	371-487	297-353	198-369
4	412-492	306-396	192-321
5	391-505	298-403	182-369

4 CONCLUSIONS

Dual phase steel HCT980X with thickness of 1.2 mm was fibre laser welded with bake hardening steel HX220BD with the same thickness. The beam power was in the interval from 0.9 to 4.0 kW and the welding speed from 1 to 10 cm.s⁻¹. The effects of welding parameters on both microstructure and microhardness of butt joints were studied. The microstructures of experimental steels change during laser welding from ferrite and martensite (DP steel) or ferrite (BH steel) to ferrite, bainite and martensite in FZ and HAZ. The FZ contains large amount of acicular ferrite and small areas of martensite and bainite. The formation of these non-equilibrium microconstituents is a result of the rapid cooling of the weld pool containing relatively higher concentration of alloying elements. The HAZ microstructure near DP steel HCT980X consists mainly of lath microconstituents build in packets and the HAZ microstructure near BH steel HX220BD consists mainly of ferrite and acicular ferrite. The microhardness profiles of all samples correspond well with observed microstructures. The highest microhardness of 500 HV_{0.1} is measured in HAZ near DP steel HCT980X with the highest portion of hard lath microconstituents in the joint welded at the highest beam power and welding speed.

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REFERENCES

- [Bandyopandyay 2016] Bandyopandyay, K. et al. Microstructure and failure analyses of DP980 laser welded blanks in formability context. *Materials Science and Engineering A*, 2016, Vol.A652, pp 250-253.
- [Brogiato 2015] Brogiato, G. B. et al. Full field strain measurement of dissimilar laser welded joints. *Procedia Engineering*, 2015, Vol.109, pp 356-363.
- [Cui 2016] Cui, Q. L., et al. Effect of coating on fiber laser welded jointe of DP980 steels. *Materials and Design*, 2016, Vol.90, pp 516-523.
- [Farabi 2011] Farabi, N. et al. Microstructure and mechanical properties of laser welded dissimilar DP600/DP980 dual-phase steel joints. *Journal of Alloys and Compounds*, 2011, Vol.509, pp 982-989.
- [Gong 2016] Gong, H. et al. Experimental investigation of the mechanical response of laser welded dissimilar blanks from advanced- and ultra-high-strength steels. *Materials and Design*, 2016, Vol.90, pp 1115-1123.
- [Krajewski 2014] Krajewski, S. and Nowacki, J. Dual-phase steels microstructure and properties consideration based on artificial intelligence techniques. *Archives of civil and mechanical engineering*, 2014, Vol.14, No.2, pp 278-286.

[Mazaheri 2015] Mazaheri, Y. et al. Nanoindentation study of ferrite-martensite dual phase steels developed by a new thermomechanical processing. *Materials Science & Engineering A*, 2015, Vol.639, pp 8-14.

[Mei 2009] Mei, L. et al. Research on laser welding of high-strength galvanized automobile steel sheets. *Optics Laser Technology*, 2009, Vol.47, No.11, pp 1117-1124.

[Merklein 2014] Merklein, M. et al. A review on tailored blanks – Production, applications and evaluation. *Journal of Materials Processing Technology*, 2014, Vol.214, No.2, pp 151-164.

[Mesko 2014] Mesko, J. et al. Microstructure analysis of welded joints after laser welding, *Manufacturing Technology*, 2014, Vol.14, No.3, pp 355-359.

[Rossini 2015] Rossini, M. et al. Investigation on dissimilar laser welding of advanced high strength steel sheets for the automotive industry. *Materials Science & Engineering A*, 2015, Vol. 628, pp 288-296.

[Saha 2014] Saha, D. C. et al. Microstructure-properties correlation in fiber laser welding of dual-phase and HSLA steels. *Materials Science and Engineering A*, 2014, Vol. A607, pp 445-453.

[Vinas 2015] Vinas, J. and Abel, M. Analysis of Laser Welds on Automotive Steel Sheets. *Materials Science Forum*, 2015, Vol. 818, pp 239-242.

[Wang 2016] Wang, J. et al. Effect of energy input on the microstructure and properties of butt joints in DP steel laser welding. *Materials and Design*, 2016, Vol. 90, pp 642-649.

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