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CHARACTERISTIC OF Nd:YAG LASER WELDED JOINTS OF HDT580X GRADE AUTOMOTIVE DUAL PHASE STEEL

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Summary

Results of investigation of laser HDT580X steel welds have been presented. The main goal of these research was to verify whether the Nd:YAG laser welding can be used for welding of Dual Phase steel, without filler metal. To this end, the influence of welding parameters on mechanical properties and microstructural characterisation of joint 2.4 mm in thickness have been presented. The tensile strength of welded joints are at the same level as that of the base material and the maximum hardness in the heat affected zone (HAZ) and weld does not exceed 300 HV. The microstructure of the weld is mainly composed of lath martensite. In the HAZ ferrite, bainite and lath martensite is present. The fatigue strength of welded joints is lower than that of base material. The fatigue class FAT was calculated as 284 and 150 MPa for base material and welded joint, respectively. The results of technological welding trials and destructive examination of welds indicate that the Nd:YAG laser welding is a useful technology to join HDT580X sheet steel.

Keywords: Dual Phase steel, laser welding, fatigue test

Charakterystyka złączy stali HDT580X spawanych laserem Nd:YAG dla przemysłu motoryzacyjnego

Streszczenie

W pracy przedstawiono wyniki badań połączeń spawanych wiązką laserową, wykonanych ze stali dwufazowej HDT580X. Opracowano i wykonano złącza spawane za pomocą lasera typu Nd:YAG bez materiału dodatkowego. Określono wpływ parametrów spawania na właściwości mechaniczne i mikrostruktury złączy wykonanych z blachy o grubości 2.4 mm. Uzyskano wytrzymałość na rozciąganie badanych złączy spawanych na poziomie materiału podstawowego. Natomiast twardość maksymalna nie przekroczyła 300 HV. W badaniu mikrostruktury stwierdzono obecność w spoinie martenzytu listwowego. W strefie wpływu ciepła mikrostruktura składa się z ferrytu, bainitu i martenzytu listwowego. Wytrzymałość zmęczeniowa złącza spawanego jest mniejsza niż materiału rodzimego. Określono kategorię zmęczeniową FAT dla materiału rodzimego i złącza spawanego, odpowiednio 284 i 150. Wyniki prób technologicznych oraz badań niszczących pozwalają stwierdzić, że spawanie laserem Nd:YAG jest w pełni przydatne do spawania blach dwufazowych stali HDT580X.

Słowa kluczowe: stal dwufazowa, spawanie laserowe, badania zmęczeniowe

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1. Introduction

Nowadays, the most popular grades of automotive steels are DP (Dual Phase) grades [1-3]. Dual Phase steels, so called because they consist essential of a dispersion of martensite in a ferrite matrix, are produced by intercritical annealing and cooling at such a rate, as to give the desired structure. In theory, there are no gage or strength limitation on these steels; a higher strength is obtained by having a higher percentage of martensite in the structure [4]. The characteristic high work-hardening rate results from the generation and piling up of dislocations around the martensite fraction on straining. The combination of the high strength developed, associated with relatively high elongation values, enlarges the area under the stress/strain curve resulting in improved energy absorption compared with other steels of similar strength [5].

Apart from the chemical composition, the microstructure and mechanical properties from the practical point of view the most important factor is 'join ability' of automotive steels. Traditionally, resistance welding and fusion welding have been used in the automotive industry, with spot welding being the main welding process also for DP steels [3, 6-8]. Another process which was introduced at the beginning of the 1990s and which may have some impact on joining of thin plates is Friction Stir Welding (FSW) [3, 9]. However, the main application for this process today is welding of aluminium, FSW welding of steels is still in a development phase, where some interesting results have been reported for dual phase steels [10, 11]. The fourth main joining method in the automotive industry is laser welding. Some available results indicate that the laser welding technology is a promising method for joining the DP steel sheet [11-15]. The main advantages of laser welding are small distortions of the sheets, due to restricted size of the melt and the high welding speeds attainable. Laser welding as a seam welding method was introduced in the automotive industry in the beginning of the 1990s and has been used for many applications [3]. The researchers [11] have shown results of laser welding of DP 600 steel 1.4 mm in thickness. On the basis of hardness, mechanical properties and formability tests as well as microstructure examination they have proved that the DP steel is characterized by good laser weldability. However, the results have shown that the maximum hardness in the HAZ exceeds 350 HV. That hardness was the result mainly of bainite, ferrite and small amounts of martensite phase. In another studies [12], High Strength Low Alloy (HSLA) and DP980 (980 MPa) sheet steels 1.2 mm in thickness were welded with a 4 kW diode laser. For the DP steel, weld formability was much lower than that of corresponding base metal, which appeared to be due to the formation of soft zones in the outer region of the HAZ of the welds. Results of DP 600 steel grade welding by CO_2 laser are also available [13]. That results show the influence of bake hardening on the mechanical properties of laser welded DP steel. A remarkable increase of hardness in the zone influenced by laser welding was observed. The weld zone had a low carbon lath martensite microstructure. The laser welded region was characterized by a higher interstitial carbon content than the base material [13].

Although laser welding has been used for a relatively long time, there are rapid developments in the automotive industry in the last 10 years. The two most interesting developments are: remote laser welding and hybrid welding, combining MIG welding and laser welding [3]. The new laser techniques can be also use for welding of dual phase steel sheet. The correct selection of adequate filler metal and heat input has provided proper quality of laser joints of DP steel [14]. Researchers [14] have compared the results of microstructure and mechanical properties, obtained by the application of hybrid laser welding, classical laser welding and MAG welding. The experiments have been carried out on DP steel sheet 1.4 mm in thickness. These steel sheet was subjected to both CO_2 – laser/MAG and diode pumped Nd:YAG – laser/MAG hybrid welding. It was found that a hardness drop might occur in the HAZ due to tempering of the martensite in the base material microstructure, leading to strength decrease and localized deformation during tensile testing. The other hand, use of improper filler material in combination with low heat input might lead to excessive weld metal hardness.

Although, some results of laser welding of DP steel sheet are available, there exists an urgent need of developments of these new techniques. Automotive industry uses many different grades of DP steel in a wide range of thickness. Most of the available results apply to laser welding of steel with a maximum thickness of 1.5 mm. In the presented study the thickness of DP steel sheet is 2.4 mm. The obtained results can be useful for the automotive industry.

2. Experimental procedures

2.1. Material

The chemical composition and mechanical properties of the DP600 steel HDT580X (acc. to PN-EN ISO 10336:2007) 2.4 mm in thickness are given in Table 1 and 2 respectively. The HDT 580 X automotive steel consists of ferrite (light regions) and martensite – austenite islands (dark regions) (Fig. 2).

Table 1. Chemical composition of HDT580X steel, % [15]

C	**Mn**	**Si**	**P**	**S**	**Cu**	**Cr**	**Ni**
0.07	0.90	0.09	0.028	0.001	0.04	0.40	0.04
Mo	**V**	**Al**	**N**	**Nb**	**Ti**	**B**	**Sn**
0.01	0.004	0.039	0.0058	0.002	0.022	0.0003	0.003

Table 2. Results of transverse tensile tests of welded joints [15]
(Mean values from three specimens)

Trial No	**1**	**2**	**3**	**Base material**
Tensile strength R_m, MPa	627	618	**631**	630

2.2. Welding equipment

The experiments were carried out on a robotic welding stand (Fig. 1) which was composed of the solid state laser Nd:YAG TRUMPH HL 2000D (maximum power 2 kW), the focusing head TRUMPF D70, the robot KUKA – KR 30/2 HA and the clamping system used to hold the welded plates during laser welding.

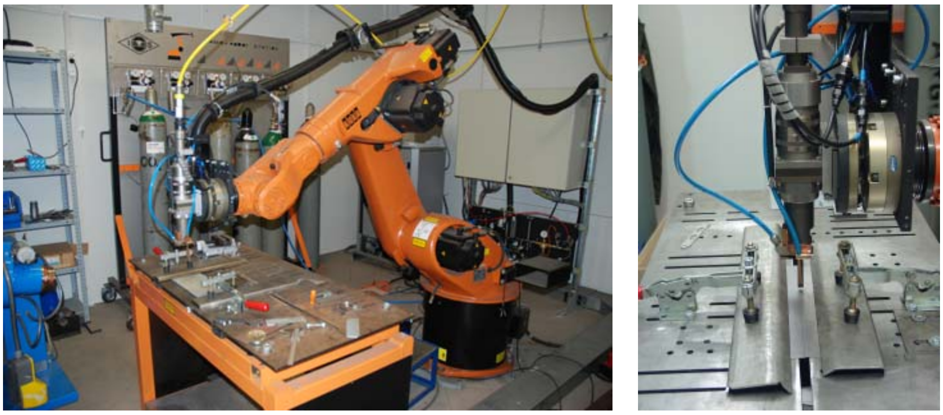

Fig. 1. The robotic welding stand with clamping system

2.3. Test equipment

Tensile testing transverse to the weld was executed on a 600 kN mechanical universal testing machine Instron 4210 at room temperature, in acc. with PN-EN 895. All presented test data are mean values of three tensile sample results.

The microstructure of the base material and welded joints was observed by optical microscope (OM) Leica MEF4M and Scanning Electron Microscope (SEM) Hitachi S-3500 N. The samples were etched by the Nital reagent. Vickers hardness measurement of the welded sheet was performed along the centreline of the material under the load of 4.903 N (HV0.5) acc. to PN-EN 1043-2:2000 using the Zwick hardness tester.

Fatigue testing of the base material and welded joint was accomplished on a 1000 kN fatigue machine MTS type 311.31 at a frequency in the range of 15 to 20 Hz. Specimens were tested at stresses that gave fatigue lives of about 10^7 cycles. Tests were conducted at the room temperature at a load ratio R = 0.2

(where R = $\sigma_{min}/\sigma_{max}$). The analysis of data was conducted acc. to IIW Document XIII-2151-07 / XV-1254-07 [16].

3. Results and discussion

The main purpose of these investigation was to verify whether the Nd:YAG laser welding can be used for welding of HDT580X steel, without filler metal. To this end, the technological trials, metallographic examination and mechanical tests were carried out.

As the first step of the presented investigation technological trials of laser welding on HDT580X steel sheet have been carried out. The tests were performed on the experimental stand at the following welding parameters: laser power 1.5 kW and 2.0 kW, welding speed in the range from 0.8 m/min to 2.4 m/min, shielding gas – 100% Ar, flow rate 16 l/min, working distance – 223 mm. The achieved results indicate, that only for few of the welding parameters welded joints with good properties can be obtained. The best results were gained for the combination of the following welding parameters: laser power 2.0 kW – welding speed 2.1 m/min; laser power 2.0 kW – welding speed 1.5 m/min, laser power 1.5 kW – welding speed 1.2 m/min. Taking into consideration that for the automotive industry the best results should be those achieved at the maximum welding speed (efficiency of the welding processes), for the next examination joints welded at laser power 2.0 kW and welding speed 2.1 m/min were chosen. Figure 2 presents the results of metallographic OM and SEM examination of the welded joint, which was chosen as the best. The weld in this welded joint is composed of lath martensite. The HAZ consists of ferrite, bainite and martensite. The maximum hardness does not exceed the 300 HV. Hence, it can be estimated that the volume of martensite in the weld and HAZ has not deteriorated mechanical properties of the welded joint (Table 2). In the tensile test all samples fractured in the base metal away from the weld. This indicates that the tensile strength of the weld is not lower then that for the base material. The results of microstructure examination for other trials have indicated, that at the lower welding speed the volume of martensite becomes lower in the HAZ and weld [15]. Based on the results of tensile tests and metallographic examination, the joint performed at the laser power of 2.0 kW and 2.1 m/min welding speed was chosen as the best one.

One of the most important factors estimating the quality of welded joints for the automotive industry is the fatigue strength of joints. Taking into consideration the previous results [17], the fatigue testing was performed only for the base material and the welded joint produced at the highest welding speed.

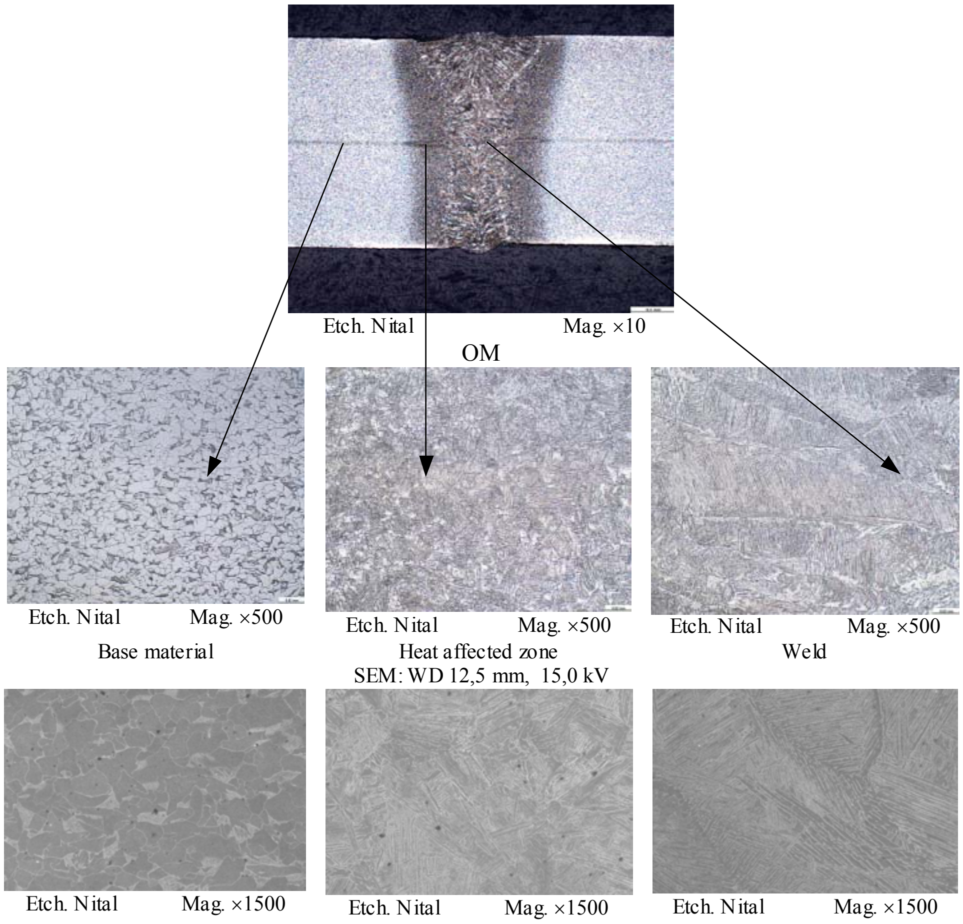

Fig. 2. Macro- and microstructures (OM and SEM) of the welded joint. Laser power 2.0 kW, welding speed 2.1 m/min. Other parameters as given in the text

Figure 3 shows the geometry and dimensions of fatigue test specimens for the base material and welded joint. The authors of the publication [17] have indicated that a higher volume fraction of martensite causes increase of a the fatigue strength. So, on the basis of mentioned above results of microstructure examination in the HAZ and weld, the authors estimate, that at lower welding speeds the fatigue strength will be lower. The fatigue class FAT was calculated on the basis of International Institute of Welding (IIW) procedure [16]. Figure 4 shows the results of fatigue tests for the base material and welded joint completed at the highest welding speed. The results have indicated that the fatigue resistance of the welded joint is lower then that for base material.

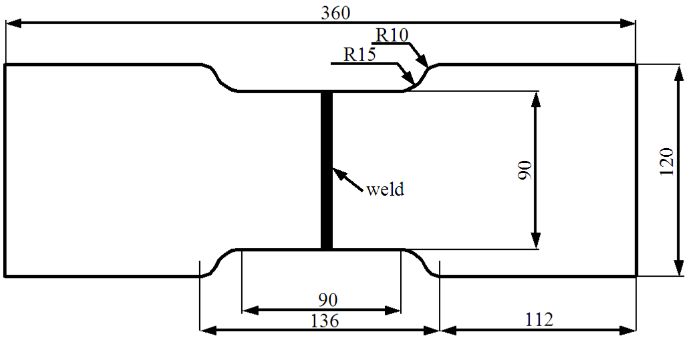

Fig. 3. Geometry and dimensions of fatigue test specimen of the laser welded butt joint [15]

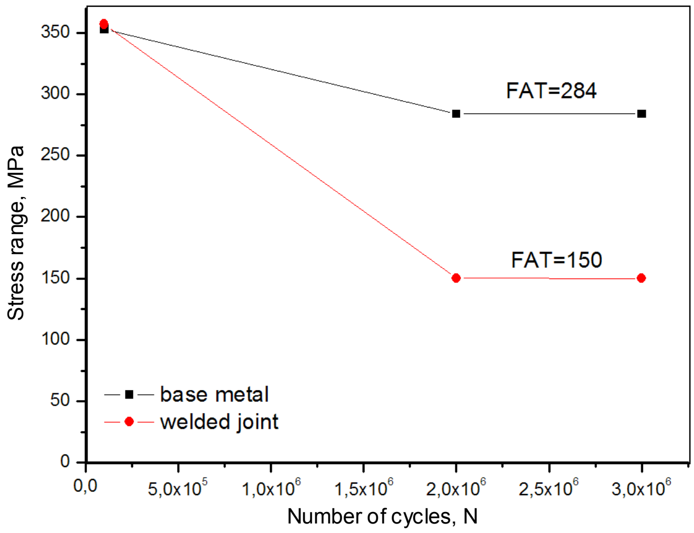

Fig. 4. Results of fatigue testing of base metal and welded joint with given FAT classes [15]

4. Conclusions

The properties of Nd:YAG laser welded 600 MPa grade DP steel joints were investigated in respect of hardness, microstructure, mechanical properties and fatigue strength and the following results were found:

- the microstructure of the welded joint, estimated as the best one, consisted of lath martensite in the weld metal and a mixture of ferrite, bainite and martensite in the HAZ,
- the maximum hardness does not exceed the 300 HV,

- the tensile strength R_m of the welded joint is at the same level (631 MPa) as that of the base material,
- the fatigue strength of the welded joint is lower than that of the base material. The fatigue class FAT was determined as 284 and 150 MPa for the base material and welded joint, respectively (Fig. 4).

The results of technological welding tests and destructive examination of welds indicate that the Nd:YAG laser welding is a useful technology to join HDT580X sheet steel.

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