SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
19 (2014)

THE WELD TOE IMPROVED BY A LASER REMELTING PROCESS IN COMPARISON WITH A CLASSIC TIG-DRESSING TECHNOLOGY

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1.Introduction

A Domex® is the SSAB company trademark for advanced high strength steels. Thanks to a low carbon equivalent, these steels are very suitable for welded constructions, which is the main field of application for this steel. The high strength of Domex® steels is ensured via the extra fine grain structure. Thanks to this structure this SSAB steel grade has got higher yield strength compared to conventional steels. The welded Domex® steels are widely used in automotive industry, lifting equipment, trains etc. The main purpose of these steels usage is to saving the weight of construction (up to 40%), with keeping the same durability [1].

.Because the Domex® steels are widely used for welded constructions it is important to predict the weld fatigue life. A weld joint is one of the most dangerous parts of a construction. A weld in construction is a local cross-section change. It is also the location of highly inhomogeneous structure. It means that the weld is the place with the greatest probability for the initiation and propagation of the fatigue crack.

The area where the crack initiation is expected is defined as a weld toe. The greatest concentration of stress is in the weld toe. It is also the location of the weld fusion zone [2, 3]. Due to these facts weld causes decrease of the fatigue life of a construction. There are several possibilities for the weld toe improvement for increasing the weld joint fatigue life. The first category uses impose beneficial compressive stresses at the weld hot spot (shot peening, needle peening, initial overloading etc.). The second category, improve the shape of weld toe (TIG dressing, plasma dressing, burr grinding, etc.), with aim to increasing the corner radius [4, 5].

The work focused on the weld toe shape after the remelting process. It has been found that weld toe radius is one of primary geometrical feature that control the fatigue life. By increasing the weld toe radius the fatigue strength will increase due to a decrease in stress concentration at the weld toe [6]. The work compares the conclusions from the other works based on TIG dressing [4-6 and7] which focusses on the weld toe geometry. The hardness state of the incurred structure is compared with work [10] conclusions. The weld toe radius geometry, metallographic analyses and the hardness state has been carried out on the metallographic crosscut of the weld, after the remelting process.

2.Experimental material

The Domex® cold forming steels are thermo-mechanically rolled in modern plants where the heating, rolling and cooling processes are carefully controlled. The chemical analysis, consisting of low levels of carbon and manganese has precise addition of grain refiners such as niobium, titanium or vanadium. This together with an inclusion free structure makes Domex® Steels the most competitive alternative for cold formed and welded products [10]. The Domex® 700 was used as an experimental material. Chemical composition according the SAAB manufacturer standard are provided in Tab.1

Tab. 1 *Chemical composition of Domex® 700 (wt. %)*

C max	Si max	Mn max	P max	S max	Al min	Nb[1)] max	V[1)] max	Ti max
0.12	0.10	2.10	0.025	0.010	0.015	0.09	0.20	0.15

[1)] Sum of Nb, V and Ti = 0.22 % max.

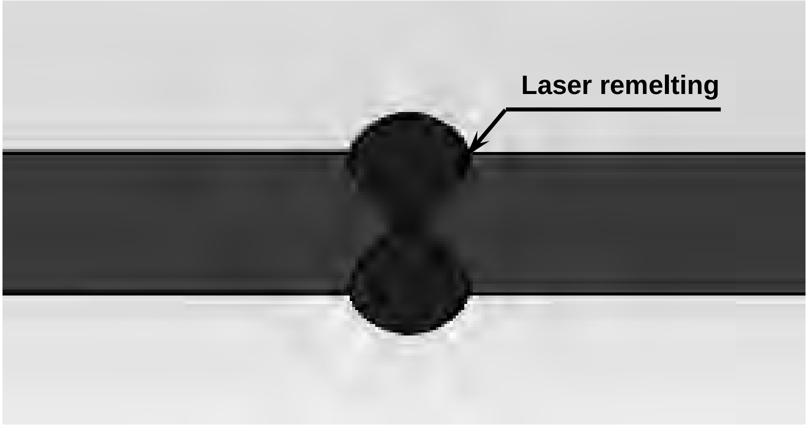
The mechanical properties according the SAAB manufacturer standard are provided inTab.2.

Tab. 2 *Mechanical properties of Domex® 700*

Yield strength Re_H N/mm^2 min	Tensile strength Rm N/mm^2 min - max	Elongation on failure < 3 mm A80% min	Elongation on failure > 3 mm A5 % min
700	750 - 950	10	12

The weld joint was manufactured from two identical plates with 10 mm thickness, with weld shape as double V with 60° angle.as shown in the Fig.1. Welding was carried out by the MAG welding method with CO_2 protective atmosphere. Welding parameters were: I = 140 A, U = 22 V. The OK AristoRod 69 wire with 1 mm in diameter was used as filler material.

Fig. 1 *Weld joint*



The weld wire chemical composition and mechanical properties according to the manufacturer standard are provided in Tab.3. and Tab.4 respectively.

Tab. 3 *Chemical composition of Ok AristRod 69, weld (wt. %)*

C	Si	Mn	Mo	Cr	Ni	V
0.08	0.60	1.60	0.25	0.30	1.40	0,07

Tab. 4 *Mechanical properties of Ok AristRod 69, weld*

Yield strength R_{eH} N/mm^2	Tensile strength R_m N/mm^2	A_5 %	KV (J)/°C		
			+20	-20	-30
730	800	19	100	70	60

3.Experimental work

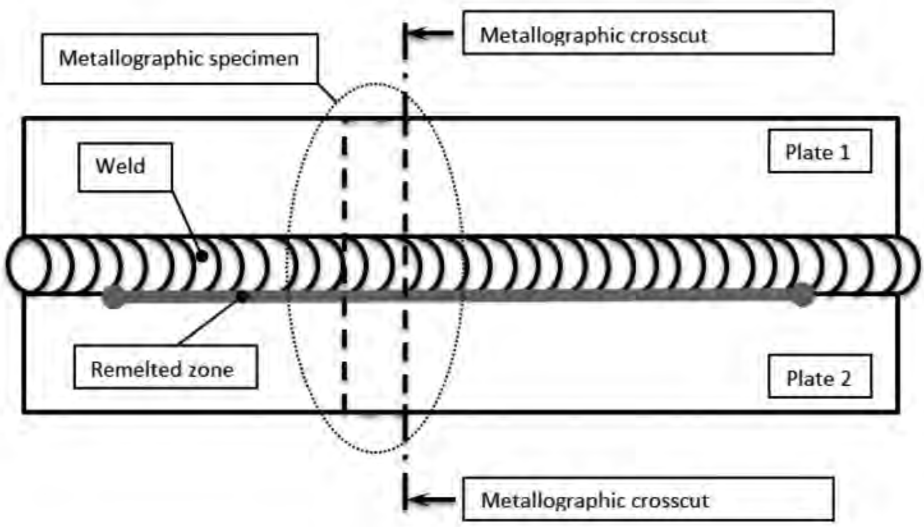
The Nd-YAG laser ALM 200 digital was used for the weld toe improvement. The German company Alpha Laser GmbH is the manufacturer of ALM 200 digital. The ALM 200 digital is the laser welding device with 1024 ηm wavelength. This device is working in the pulse mode, with maximal pulses frequency up to 20 Hz and maximal pulse duration up to 20 ms. The effective maximal laser output power is 200 W. For the experiment purpose was used the parameters shown in the Tab.5. It has been chosen 33.1 J energy output and 18 ms pulse duration, according to the previous experimental works [8, 9]. It has been chosen 100° deflection angle between the vertical axis of laser head and the vertical axis of the weld. The 99.8 % Argon gas, directly supplying to the remelting zone, was used as a protective atmosphere.

Tab. 5 *Mechanical properties of Ok AristRod 69, weld*

Pulse duration ms	Pulse frequency Hz	Impact zone mm	Pulse energy J
18	7	1.6	33.1

Specimen was cut from the welded plates for the metallographic analyses as show the Fig.2. The Nital 2 % was chosen for the specimen etching. The Metallographic analyses were followed by the hardness measuring in the remelted zone

***Fig. 2** Specimen manufacturing*



4.Results

The result before the laser remelting can be observed on metallographic crosscut in Fig.3. The specimen was cutted out from laser beam the not affected place. The weld toe radius after the welding was 0.6 mm.

***Fig. 3** The weld toe radius after the welding;, cross-cut; etch. Nital 2 %.*

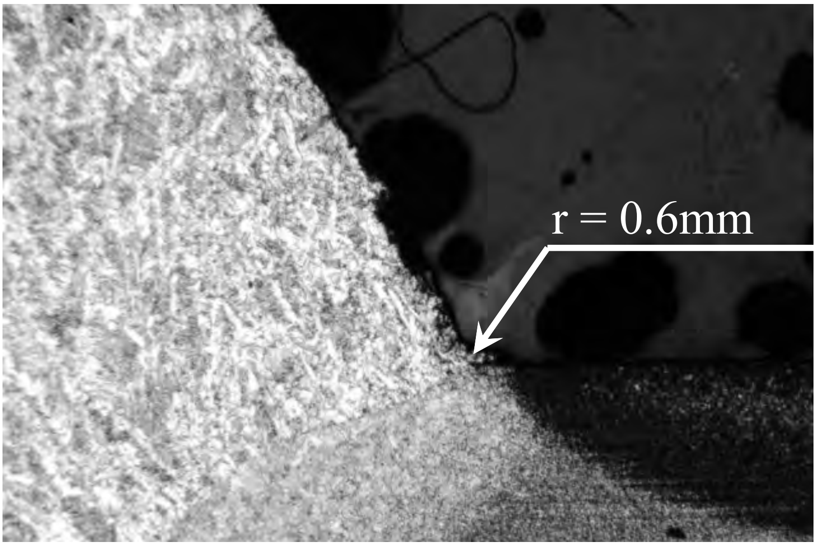
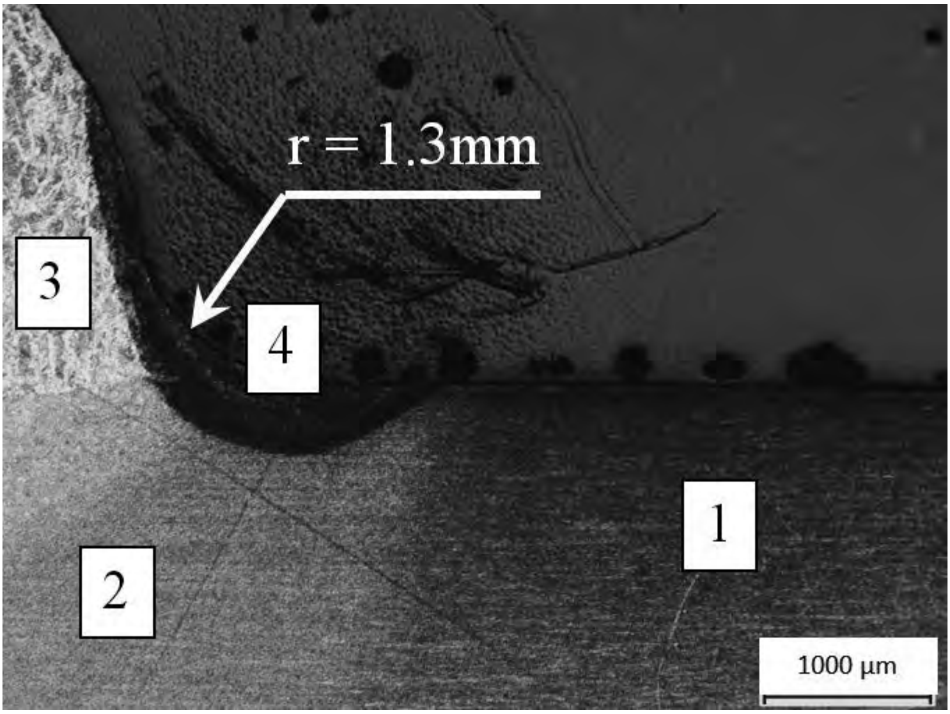


Fig. 4 *The weld toe radius after the remelting proces; cross-cut; etch. Nital 2 %.*



The state after the remelting process is on the Fig.4. The base Domex® 700 steel can be observed on the right side (1). The heat affected zone (HAZ) is in the left bottom corner (2). The weld is located in the left upper side (3). The remelted zone can be observed in the middle (4). The weld toe was remelted to the shape of 1.3 mm radius (from original 0.6 mm radius). Overall width of affected area (4) is 1.8 mm. The maximal depth of influence reaches 0.45 mm. It can be observed that the size of laser beam impact zone is large enough for creating the sufficient remelted zone and covers all HAZ (2) and also a part of the weld (3).

Fig.5 shows the detail of incurred structures after the remelting process. The gradual coarsening of the ferrite grains in the HAZ can be observed (2). This coarsening is caused by the thermal cycle from the welding process. In the HAZ the originally polyedric ferrite grains in approximately 200 μm width area have been transformed to the acicular ferrite, (W) This structure can be identified by the metallurgical analyses as a Widmannstetter structure. The weld is created by standard casting structure, with the dendrite creation in the way of heat dissipation (3). The detail character of the structure after the laser remelting process can be seen in left corner of the Fig.4 (4). It can be observed that all structures mentioned above have been transformed. The originally inhomogeneous structures have become more homogenous after the remelting process. The metallographic analyses and hardness measurements have identified this structure as very fine bainite.

Fig. 5 *Structural state after the remelting proces; cross-cut; etch. Nital 2 %.*

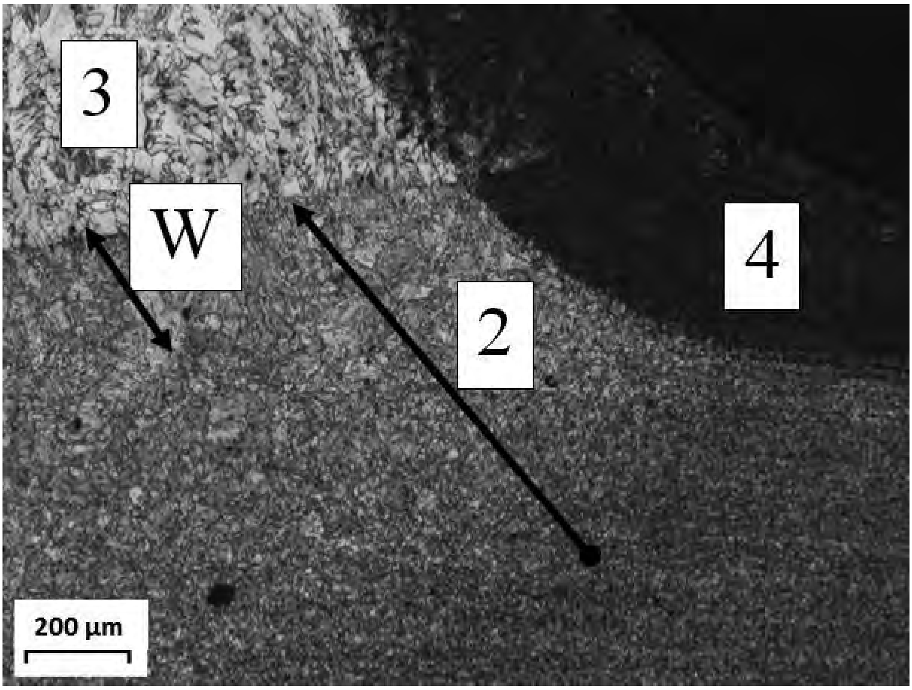
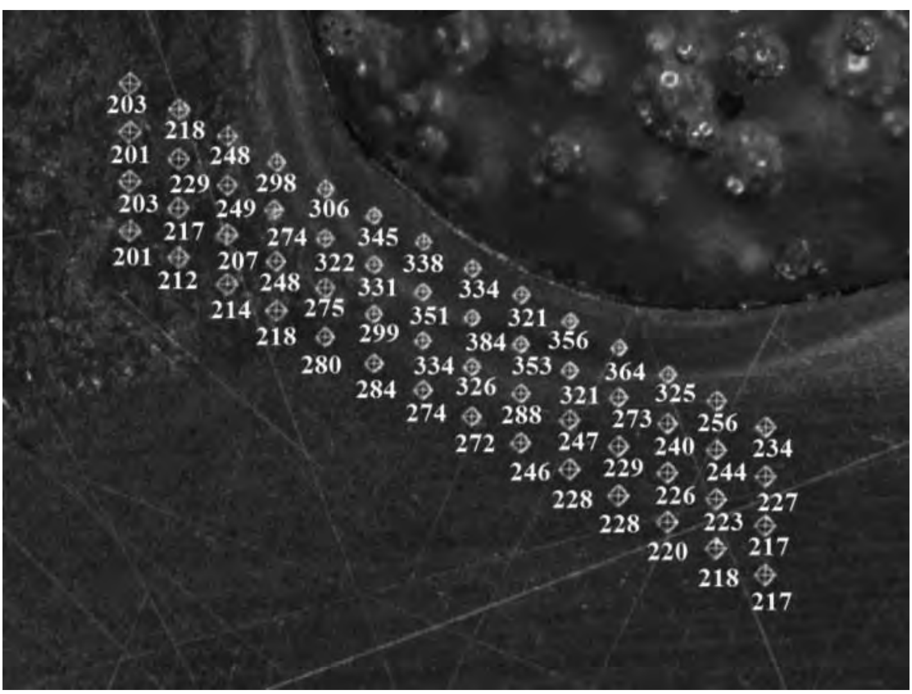


Fig. 6 *Hardness measuring after the remelting proces; cross-cut; etch. Nital 2 %*



The hardness state after the remelting process can be seen in the Fig.6. The measuring was carried out by Vickers hardness device with 0.5 kp load for 10 seconds. The 56 independent hardness measurements were carried out on specimen with aim to create the hardness map. These measurements brought significant information, which can be compared with TIG dressing technology. Hardness map shows the marginal increase of the hardness after the remelting process. The maximal increase can be observed in the middle of the laser beam impact zone. The maximum hardness values reaches up to the 384 HV0.5/10, which means increase up to 82 % when compared to the HAZ and 65 % when compared to the base Domex® 700 material.

It is very important, that no hardness dropping can be observed in the remelting zone. According to work [10], a major concern performing the TIG dressing in high strength steel is whatever it will caused excessive softening of the material. The investigation showed resulting hardness drop of approximately 15-20 % in the TIG dressed area. The laser remelting process gains the advantage from the strictly limited amount of the heat and impact zone. The very quick heat dissipation has concluded to the fine grain structure and hardening of the incurred structure (fine bainite).

5. Conclusions

According to experimental works carried out on weld toe of Domex® 700 steel, remelted by laser beam can be concluded:

- The remelting process has created the fine bainite structure.
- The remelting process has increased the weld toe radius from original 0.6 mm to 1.3 mm (increase up to 116 %).
- According to the work [7] conclusion: „A change in residual stress for about 15 % at the 300 MPa stress level had the same effect on fatigue strength as the increase of the weld toe radius by approximately 85 % from 1.4 mm to 2.6 mm.", it is necessary to make the similar experiment to test the influence of this technology on fatigue life.
- The laser remelting process has increased the inflected zone overall hardness up to 85 % when compared to the HAZ and 65 % when compared to the base Domex® 700 material.
- According to conclusions of other works based on the TIG dressing [4, 5], it can be concluded that this technology has a big potential for increasing of weld fatigue strength.

6.Acknowledgement

The research was supported by European regional development fund and Slovak state budget by the project "Research Centre of University of Žilina", ITMS 26220220183 (70 %), Scientific Grant Agency of the Ministry of Education, Science and Sports of the Slovak Republic and Slovak Academy of Sciences, grant No.: 1/0123/15 (20 %) and by, the Slovak Research and development Agency under the contract No. SK-CZ-2013-0047 (10 %).

7.Literature

1. SSAB, http://www.ssab.com/en/Brands/Domex/Solutions1/ (10.4.2015)
2. LACROIX, R., KERMOUCHE, G., LENS, A., BERGHEAU, J. M., KLÖCKER, H. Original test device for crack propagation in the weld nugget of advanced high strength steels., Engineering Fracture Mechanics, 138, (2015), pp. 156-168
3. ZHOU, B, THOULESS, M.D., WARD, S.M.. Predicting the failure of ultrasonic spot welds by pull-out from sheet metal : Int. J. Solids Structures, 43 (25–26) (2006), pp. 7482–7500
4. HUO, L., WANG, D., ZHANG, Y. Investigation of the fatigue behaviour of the welded joints treated by TIG dressing and ultrasonic peening under variable-amplitude load., International journal of fatigue, 27 (2005), pp. 95-101
5. DAHLE T. Design fatigue strength of TIG-dressed welded joints in high-strength steels subjected to spectrum loading., International journal of fatigue, 25 (1998), pp. 677-681
6. GERRITSEN, CH., VANROSTENBERGHE, S., DORÉ, M., Diode Laser Weld Toe Re-melting as a Means of Fatigue Strength Improvement in High Strength Steels, International journal of fatigue. 66 (2013), pp. 171-180
7. HARATI, E., KARLSSON, L., SVENNSON, L., DALAEI, K., The relative effects of residual stresses and weld toe geometry on fatigue life of weldments, International journal of fatigue, 77 (2008), pp. 160-165
8. LAGO, J., BOKŮVKA, O., Eliminácia Praskania Laserových Návarov Ocele X153CrMoV12 PredohrevomZákladného Materiálu., SEMDOK 2015
9. LAGO, J., MORAVEC, J., Laser welding of X153CrMoV12 tool steel with use of X45CrSi9-3 filler material.J. Technológ (2014)
10. [PEDERSEN, MIKKEL MELTERS; MOURITSEN, OLE ØSTERGAARD; HANSEN, M. R; ANDERSEN,J. G.; WENDERBY, J., Comparison of Post Weld Treatment of High Strength Steel Welded Joints in Medium Cycle Fatigue, Welding in the World - Soudage dans le Monde, 13, (2010), pp. 480-518

Summary

The weld toe improved by a laser remelting process in coparation with a classic TIG-dressing technology

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This paper deals with usage of a laser beam as a new technology for a weld toe improvements.The aim is to show the possibilities of using laser beam for increasing the fatigue life of welds. The conclusions of this work are compared with conclusions from works based on the classic TIG dressing technology. The main difference between the laser and TIG is the way and amount of heat input. This difference caused the difference in the weld toe shape and also the incurred structures after the remelting process. The experimental work was carried out on the Domex 700® steel. The weld joint was manufactured from two identical Domex® 700 plates. For experimental work the double V weld shape has been chosen. The welding was carried out by the MAG welding with CO_2 protective atmosphere. The solid state pulse Nd-YAG laser was used for the remelting process. The experimental work is focused on the weld toe shape after the remelting process and identification ofof incurred structures after the remelting process brings the metallographic analyses. The microhardness measurement has shown the structural hardness state after the remelting process.