MECHANICAL PROPERTIES LASER WELDING AUTOMOTIVE STEEL SHEETS

Anna Lišková[1)],Mária Mihaliková[1)], Lukáš Dragošek[2)], Róbert Kočiško[2)], Róbert Bidulský[2)]*
[1)] Technical University of Košice, Department of Material Science, Faculty of Metallurgy, Košice, Slovakia
[2)] Technical University of Košice, Department of Metals Forming, Faculty of Metallurgy, Košice, Slovakia

Received: 16.03.2015
Accepted: 14.09.2015

[*]Corresponding author: A. Lišková, e-mail: anna.liskova@tuke.sk, Tel.:+421 55 602 2782, Department of Material Science, Faculty of Metallurgy, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia

Abstract
The experimental and theoretical investigation deals with laser welding of automotive thin steel sheets. As tested materials were used Interstitial Free Steel (IF) from type of Hight Strength Low Alloy (HSLA) and the second is S420 steel (Micro-Alloyed Steel). Weld quality has been measured with the help of microhardness test and microstructure. Changes of properties of these materials were carried out by static conditions. The tensile properties of the welded samples have been set in the both longitudinal directions. The structure of welded joints these two materials were investigated by metallographic analysis. Metallographic analysis confirmed the formation of favourable structure of weld metal and heat affected zone. Obtained results showed that by laser welding it is possible to create the high quality welded joints with positive mechanical properties on used in automotive industry.

Keywords: laser welding, high strength low alloy (HSLA) steels, interstitial free (IF) steels, tension test, mechanical properties, microstructure

1 Introduction
Over the recent years, traditional automotive welding methods like resistance spot welding and MAG welding have been substituted to a significant degree by laser welding. The new generation of high power lasers presents several benefits for automotive industrial purposes [1]. The advantage of laser welding is the lower heat input as compared to MAG (Metal Active Gas) welding and the continuous seam as compared to spot welding, namely high power with low beam divergence, flexible beam delivery, low maintenance costs, high efficiency and small implantation space. In this paper special attention is paid for progressive laser welding of IF Steels and Micro-Alloyed Steels in research. The advantage of laser welding is the lower heat input as compared to MAG welding and the continuous seam as compared to spot welding, namely high power with low beam divergence, flexible beam delivery, low maintenance costs, high efficiency and small implantation space. Laser beam welding is a joining technology, which is applied more and more in the manufacture of car bodies and chassis structures, in order to realize lightweight structures with sufficient stiffness [1-2]. These days, car body structures often involve several tens of meters laser weld seam in the assembling process. The low heat input limits the volume of material with altered properties to a minimum while the continuous

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156

seam allows a much better force flow and thus leads to a lower specific stressing of the material [1]. Properties are derived in terms of influencing the alloy design, the welding process as well as the material selection for a given application [3].

Laser welding

The active medium in a fiber laser is the core of the fiber doped with a rare earth (erbium, ytterbium, neodymium or thallium). The pump beam is launched longitudinally along the fiber length and it may be guided by either the core itself, as occurs for the single-mode lasers or by an inner cladding around this core (double-clad fiber laser). Bragg gratings, which reflect a predetermined narrow or broad range of wavelengths of light incident on the grating, while passing all other wavelengths of the light are written into the fiber generating the laser emission and resulting in an efficient, compact laser source with high beam quality [1].

IF steel

Interstitial Free Steel (IF) contain only a small amount of carbon (C <0.005%) [4]. There basic mechanical properties include a very good deep-ductility, which results low values of yield strength (YS= 100-310 MPa) and good deep-ductility results higher values of ultimate tensile strength (UTS =140-450 MPa). This material has ability to deform plastically oneself without breaking is determined by YS/UTS ratio [5-7]. High strength IF steels are typically based on niobium stabilization. The stabilization of residual solute carbon and nitrogen (less than 30 ppm each) after vacuum decarburization in interstitial free (IF) steels is typically achieved via small additions of titanium and/or niobium. Compared to a titanium grade the niobium stabilized IF steel exhibits always finer grain size and thus higher yield strength. The finer grain size derives from the already finer grain size in the hot strip material as a result of niobium's role to retard the austenite recrystallization during the final rolling passes [8]. Niobium in solid solution of the austenite also retards the transformation into ferrite, which has an additional grain refining effect. It should be noted however, that niobium stabilized IF steel requires a somewhat higher annealing temperature to achieve complete recrystallization after cold rolling as compared to titanium stabilization. Overegging is not required since there is no interstitial carbon available. The increased strength compared to mild IF steel is achieved by adding solid solution hardening elements, and besides manganese of around 0.35 % the very effective element phosphorus is widely used [9].

S420 steel

The development of microalloyed medium carbon steels has been one of the significant advances in the 1970s [10]. The main benefit of microalloyed steels lies in the prospect of important energy and cost savings in the manufacturing of forged components for automotive applications [11-12]. Micro-Alloyed Steels are characterized by a ferrite-pearlite fine-grained structure with small quantities (max. 0.15%) of combination of elements of Al, Ti, Nb and V [13-14]. These elements are bonded to C and N. The size and percentage distribution of ferrite and the pearlite within the microstructure play an important role on the final mechanical properties [15-16]. Pearlite properties are influenced by nodule or colony size, ferrite strength and the thickness and spacing of the carbide laths [11]. The current high strength steels mean

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156

the steels with a nominal yield stress equal to or above 420 MPa. The mechanical properties of the Micro-Alloyed Steels are largely given by a type of microstructure which depends on the chemical composition and the processing technology [17, 18].

2 Experimental materials and methods

Two different types of laser welded steel alloys were used in the experiments, an IF steel and microalloyed S420 steel. The chemical compositions are given in Table 1. Table 2 show welding parameters.

Table 1 The chemical composition of the steel sheets [wt. %]

	C	S	N	Mn	P	Si	Al	Nb	V	Ti
IF	0.013	0.0105	0.0017	0.82	0.011	0.006	0.055	0.001	0.002	0.04
S420	0.12	0.002	-	1.44	0.009	0.05	0.046	0.035	0.2	0.016

Table 2 Welding parameters [17]

Parameters	Value
Laser power [kW]	2
Welding speed [m/mm]	2
Feeding fibre diameter [μm]	100
Collimation [mm]	110
Focal length [mm]	200
Focal point position [mm]	190
Shielding gas	Nitrogen

The automotive IF steel and S420 steel 1.90 mm were used for a static and dynamic tensile test. A static test was realized according to standard EN ISO 6892-1 [19] by the Zwick 1387 tensile testing machine. Dynamic tests were performed according to ISO 26203-2 [20] Standard by Tinius Olsen H300KU .The materials was available as sheets describe **Fig. 1**.

Fig. 1 The size of the test bars

The observation of macrostructure was used macroscope LEICA WILD M 32. Microhardness measurements were made with the aid of Hanneman microhardness tester under a load of 0.49N with a dwell time of 10s. The test was realized according to standard EN ISO 9015-2 [21, 22]. The hardness distribution in heat-affect zone (HAZ), weld–diffusion zone (W–FZ) and base materials are observed. The metallographic samples used for the examination were cut from the weld cross-section, the polished and etched with a 2% Nital solution. Microstructure of welded steel sheets was observed by optical microscope OLYMPUS.

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156

3 Discussion and conclusion

Mechanical properties

Static tensile properties were characterized in terms of the yield strength (YS), ultimate tensile strength (UTS) and total elongation (TE). **Table 3** provides the measured value after static tensile test.

Table 3 Mechanical properties from the static condition

Sample		Mechanical properties			
	Strength [N]	Yield stress [MPa]	UTS [MPa]	Elongation (%)	YS/UTS
a	11090	123	339	18.6	0.3628
b	11055	119	323	25.7	0.3684
c	12100	197	326	10,6	0.6043
d	12800	175	345	12,3	0.5072

Fig. 2 (a, b, c, d) shows macrostructure of welded steel sheets under static condition. The specimens under static condition were fractured in the parent material away from the weld region. The samples were broken on the side IF steel basic material. The tensile testing has proven that the infringement of the sample occurred at approximately the same amount of place (**Fig. 3**). **Fig. 3** show macrostructure laser welded automotive steel in static condition (a, b) 1mm/min (b) 500mm/min (c) 20mm/min. **Fig. 4** show dependence force of IF and S420 steel sheets at time in static condition (500 mm/s). **Fig. 7** show dependence force of IF and S420 steel sheets at time in static condition (20 mm/s).

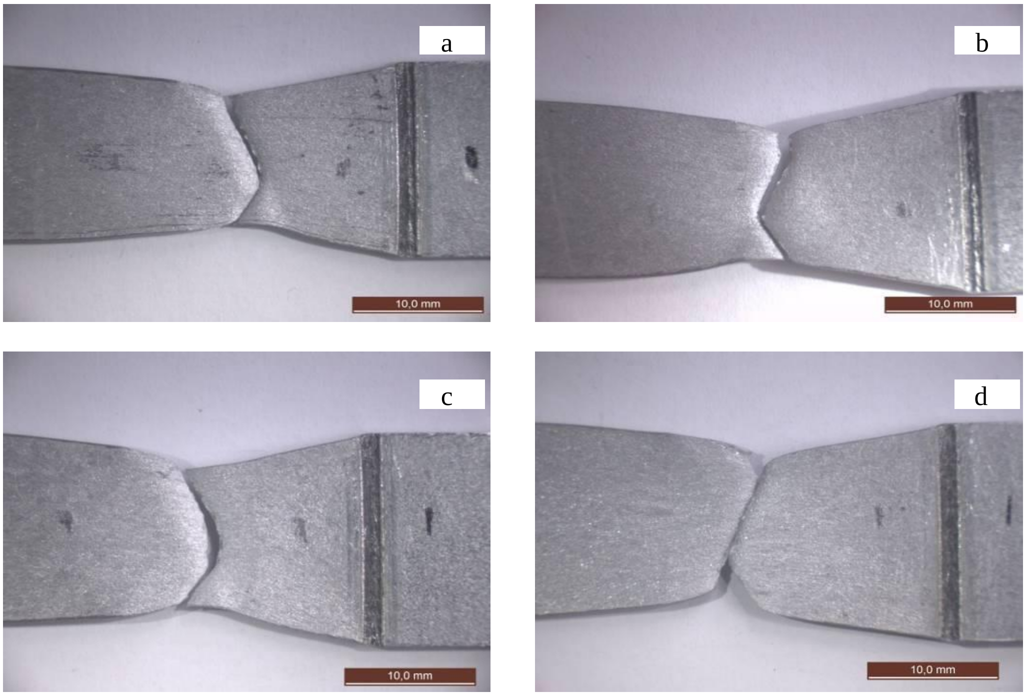

Fig. 2 Macrostructure laser welded automotive steel in static condition (a, b) mm/min, (b) 500mm/min, (c) 20mm/min

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156

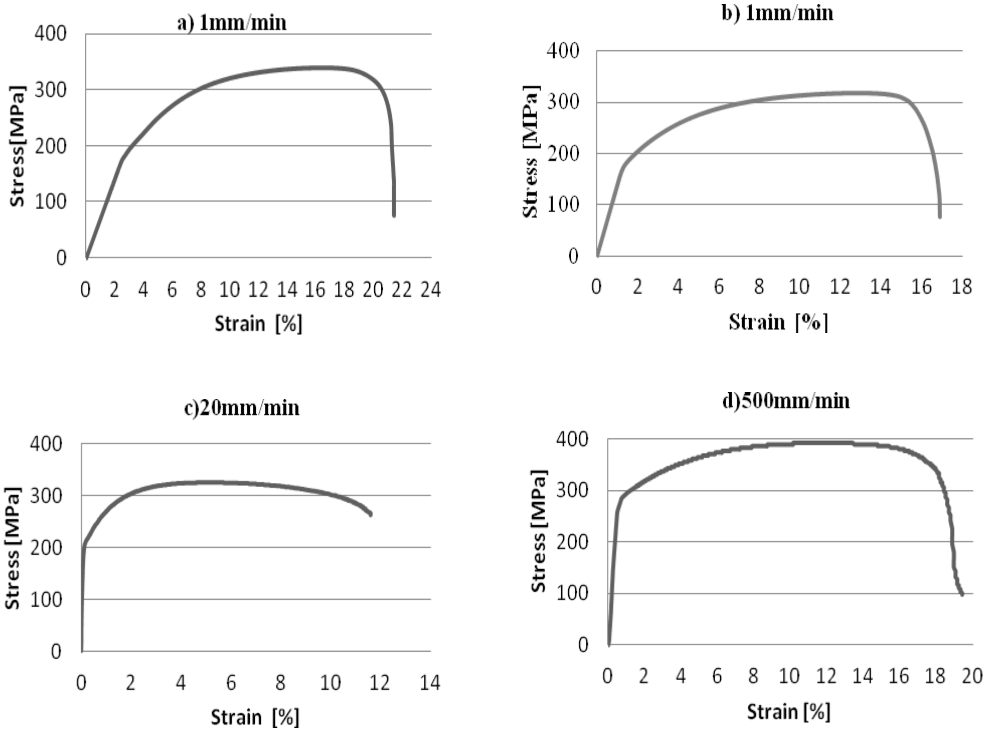

Fig. 3 Dependence force of IF and S420 steel sheets at time in static condition: a) 1 mm/min, b) 1 mm/min, c) 20 mm/min, d) 500 mm/min

Microhardness

Fig. 4 shows the line injections in the measurement of microhardness HV0.005. The values of microhardness HV0.005 in different zones welded joint are on **Fig. 5**. The indentations were positioned at regular intervals of 150 µm. IF Steel significant increase the value microhardness HV0.05 in HAZ up to 235. S420 steel was microhardness up to 190. Furthermore, it is seen from Figure 7 that the width of the HAZ and FZ in all the welded joints (i.e., IF steel and HSLA steel) was similar.

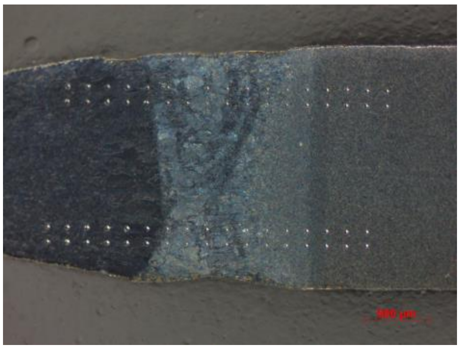

Fig. 4 Line injections

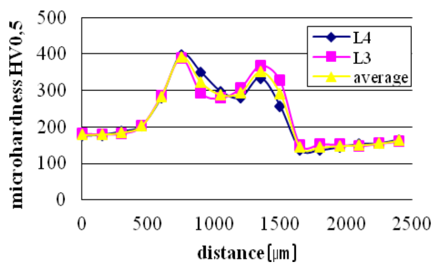

Fig. 5 Cross weld microhardness profile of S420 and IF laser welded steel sheets

DOI 10.12776/ams.v21i3.611
p-ISSN 1335-1532
e-ISSN 1338-1156

Microstructure

Microstructure of S420-IF welded joint are shown in **Fig. 6**. **Fig. 7** (**a**) shows micro-alloyed steel which are characterized by a ferrite-pearlite fine-grained structure. **Fig. 7** (**b**) shows interstitial free steel with structure ferrite. **Fig. 8** (**a, b, c**) shows structures of the etched cross section for welded joints, i.e. different zones with different microstructures characterise the welded specimen: base metal (BM), heat-affected zone (HAZ) and fusion zone (FZ). All examined specimens showed weld bead, with an average width of about 1.5 mm on the side basic material. **Fig. 6** (**a**) show a mixed-microstructure formed by low-carbon bainitic structures, surrounded by eutectoid α-ferrite. Instead, the FZ of joints is predominantly formed by ferritic structures, with some grains of low-carbon bainite. In all welded joints examined, the HAZ is characterised by large α -ferrite columnar-shaped grains on the side IF steel (**Fig. 8 c**).

The microstructure of S420 steel of HAZ is very similar to that described for IF welded steel (**Fig. 8 b**). Instead, the FZ has a bainitic structure.

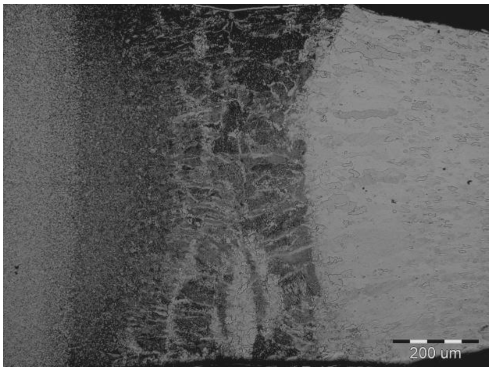

Fig. 6 Microstructure of welded joints

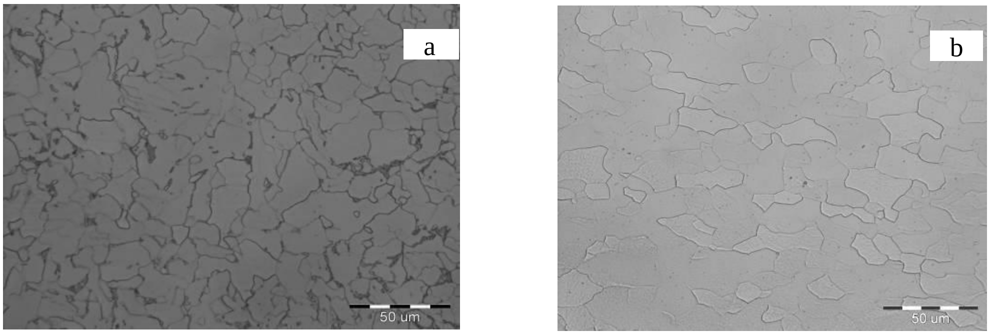

Fig. 7 Microstructure of based welded steel, (a) S420, (b) IF

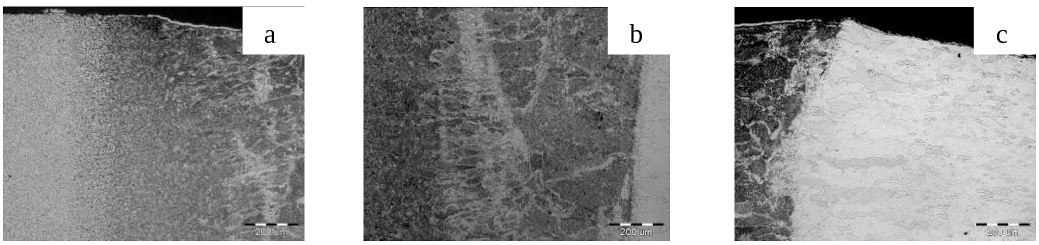

Fig. 8 Microstructure of welded steel (a) HAZ on the S420 steel side, (b) Haz and FZ, (c)

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156

Conclusions

This paper presented a mechanical and microstructural characterisation of laser-welded joints S420 steel and IF steel sheets. Welding parameters were identical to the parameters of the author [17]. Welded specimens were studied. Characterisation was based on metallurgical observations, micro-hardness measurements and static tensile tests of welded experimental specimens.

The main findings of these theses can be summarized as follows:

- The samples were broken on the side basic material IF steel.
- The yield stress (YS) was measured in the range 119-123 MPa, ultimate tensile strength (UTS) 323-339 MPa and elongation 18.6-25.7% under static condition 1mm/min.
- The yield stress (YS) was measured 197 MPa, ultimate tensile strength (UTS) 345 Mpa and elongation 10.6 under static condition 500mm/min.
- The yield stress (YS) was measured in the range 175 MPa, ultimate tensile strength (UTS) 345 MPa and elongation 12.3% under static condition 500mm/min.
- Results of microhardness measurement of laser welded S420 steel and IF steel sheets has been found, that the extent of enhanced microhardness was found to decrease with the increasing distance from the weld centre. The welded joint exhibited distinct HAZ on each side of the weld due to the difference in the basic material microstructures between HSLA (S420) steel and IF.
- The microstructure of the FZ clearly shows a highly typical structure which was
- atributed to the high cooling during laser welding.

References

[1] L. Quintino, A. Costa, R. Miranda: Materials & Design, Vol. 28, 2007, No. 4, p. 1231-1237, DOI:10.1016/j.matdes.2006.01.009

[2] W. Guo, S. Dong, W. Gou, J. A. Francis, L. Li: Materials Science and Engineering: A, Vol. 625, 2015, p. 65-80, DOI:10.1016/j.msea.2014.11.056

[3] C. M. Sonsino, M. Kueppers, M. Eibl, G. Zhang.:International Journal of Fatigue, Vol. 28, 2006, No. 5-6, p. 657-662, DOI:10.1016/j.ijfatigue.2005.09.013

[4] S. Takaki, D. Akama, N. Nakada, T. Tsuchiyama: Materials Transactions, Vol. 55, 2014, No. 1, p. 28-34, DOI:10.2320/matertrans.MA201314

[5] M. Cabibo, A. Fabrizi, M. Merlin, G. L. Garagnami: Journal of Materials Science, Vol. 43, 2008, No. 21, p. 6857-6865, DOI:10.1007/s10853-008-3000-8

[6] J. Hudák, M. Tomáš: Evaluation of material formability high-strength steel for the automotive industry, Vol. 13, 2009, p. 104-108, (in Slovak)

[7] S. I. Kim, S.H. Chooi, Y. C. Yoo: Materials Science Forum, Vol. 495-497, 2005, p. 537-542, DOI:10.4028/www.scientific.net/MSF.495-497.537

[8] J. Slota, M. Jurcisin, E. Spisak: Acta Metallurgica Slovaca, Vol. 18, 2012, No. 4, p. 200-209

[9] H. Mohrbacher: *Modern steel grades and advanced steel semi-products for automotive body applications*, In.: Metal, Hradec nad Moravici, 2005, p. 1-13

[10] M. Jahazi, B. Eghbali: Journal of Materials Processing Technology, Vol. 113, 2001, No. 1-3, p. 594-598, DOI:10.1016/S0924-0136(01)00599-4

[11] G. Krauss, S. K. Banerji.: Materials and Manufacturing Processes, Vol. 5, 1984, No. 1, p. 125-127, DOI:10.1080/10426919008953234.

[12] J. Slota, M. Jurcisin, L. Lazarescu : Acta Metallurgica Slovaca, Vol. 20, 2014, No. 2, DOI:10.12776/ams.v20i2.287

[13] K. Zhu, C. Oberbillig, C. Musik, D. Loison, T. Iung: Material Science and Engineering A, Vol. 528, 2011, No. 12, p. 4222-4231, DOI:10.1016/j.msea.2011.02.022
[14] M. Cabibbo, A. Fabrizi, M. Merlin, G. L. Garagnani: Journal of Materials Science, Vol. 43, 2008, No. 21, p. 6857-6865, DOI:10.1007/s10853-008-3000-8
[15] L. F. Porter, P. E. Repas: Journal of Manufacturing, Vol. 34, 1982, No. 4, p. 14-21, DOI:10.1007/BF03337994
[16] T. S. Srivatsan: *Fundamentals of Microalloying forming steels*, In.: Materials and Manufacturing Processes, edited by G. Krauss, S. K. Banerji, TMS Warrendale, Pensylvania, 1990, p. 125-127
[17] M. E. Haque, K. V. Sudhakar: International Journal of Fatigue, Vol. 24, No. 9, 2002, p. 1003-1010, DOI:10.1016/S0142-1123(01)00207-9
[18] D. Benasciutti, A. Lanzutti, G. Rupil, E. Fraenkel Haeberle: Materials & Design, Vol. 62, 2014, p. 205-216, DOI:10.1016/j.matdes.2014.05.005
[19] ISO 6892-1: Metallic materials – Tensile testing - Part 1: Method of test at room temperature; 2009
[20] ISO 26203-2: Tensile testing at high strain rates - Part 2: Servo-hydraulic and other test systems; 2011
[21] ISO 9015-2: Destructive tests on weld in metallic materials – Hardness test – Part 2: Micro hardness testing on welded joints; 2003
[22] M. Mihaliková, M. Német: Acta Metallurgica Slovaca, Vol. 17, 2011, No. 1, p. 26-31

Acknowledgements
This study was supported by the Grant Agency of Slovak Republic, grant project VEGA 1/0549/14.

DOI 10.12776/ams.v21i3.611 p-ISSN 1335-1532
e-ISSN 1338-1156