An effect of various shielding gases on material properties of laser welded steel sheets

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Abstract: The aim of this work was to compare mechanical properties of steel sheets made of S355J2 steel welded by diode laser with using six different shielding gases / mixtures of gases Ar, He, C12X2, He3H1, C6X1 and He50 were used as shielding gases. Residual stresses, microstructure, hardness and microhardness, notch toughness and fatigue resistance of weld joints have been tested and evaluated.

Keywords: fatigue, residual stress, laser welding, shielding gas.

1 Introduction

The welding of structural steels is one of major joining processes of many industrial areas. Using laser technologies in welding is one of many options how to achieve required results. Every technology has its own possibilities, pros and cons. The properties of laser welded joints were tested in last decades but still there are many questions. Main properties such as tensile strength, notch toughness, bending fragility etc. are more or less known and standardized. For many applications the knowledge of these properties is not enough. Fatigue properties of some types of joints made by specific conditions were tested and published [1-4]. This paper focused on testing various mechanical properties of laser welded joints where different shielding gases have been used. Except of this experimental program the residual stresses analyses were performed because of their direct connection to fatigue resistance of welded joints. The redistribution of residual stresses in weld joint [5] significantly affects the areas of fatigue cracks initiation. Shielding gas significantly affects melting and cooling rates and afterwards residual stresses and weld design. From theoretical point of view the effect of shielding gas on static and dynamic properties should be expected.

2 Experimental

In this work the effect of various shielding gases on material properties of laser welded joints prepared by high-power diode laser (HPDL) has been investigated. Power of the HPDL was set to 3,2 kW, the welding speed was 0,5 m/min and flow rate of shielding gas 15 l / min (equal rate for all types of shielding gases). The steel sheets with 4,6 mm thickness made of S355MC steel have been used as experimental material. A description of used shielding gases is in Table 1.

The XRD measurements of residual stresses were performed on PROTO iXRD COMBO diffractometer in ω-goniometer or iso-inclination mode with CrKα radiation. The line {211} of α-Fe phase was measured with the interplanar lattice spacings computed from maxima of Pearson VII functions fitted to $CrK\alpha_1$ profiles after $CrK\alpha_2$ stripping carried out by Rachinger method. The stresses were computed presuming biaxial state of residual stresses (RS) using Winholtz-Cohen method and X-ray elastic constants $\frac{1}{2} s_2 = 5.76\ TPa^{-1}$, $-s_1 = 1.25\ TPa^{-1}$.

Table 1: A description of used shielding gases

Shielding gas	Composition
Ar	argon 5.0
He	helium 4.6
C12X2	12 % carbon dioxide, 2 % oxygen, 86 % argon
He3H1	3 % helium, 1 % hydrogen, 96 % argon
C6X1	6 % carbon dioxide, 1 % oxygen, 93 % argon
He50	50 % helium, 50 % argon

The metallographic analyses and mechanical tests were performed in SVUM laboratories in compliance with international standards for weld joints. The high cycle fatigue tests were performed at high frequency testing frame Amsler HFP45 up to 10^7 cycles with loading asymmetry R = 0 (pure tensile). The fractographic analysis using SEM has been used for evaluation of fracture surfaces and areas of fatigue cracks initiations.

3 Results and conclusions

Analyses of residual stresses of all sheets were performed. C12X2 mixture as shielding gas shows most promising results. On the other hand, the worst results of all tested shielding gases were found in case of using He3H1 mixture.

Metallographic analysis of macro- and microstructure was performed at specimens from all sheets. In general, there are no significant differences in microstructure. Fig. 1 – 4 show typical microstructure in weld metal, weld metal-heat affected zone borderline, heat affected zone (HAZ) and base metal on sheet where argon has been used as a shielding gas. The microstructure at other sheets is very similar.

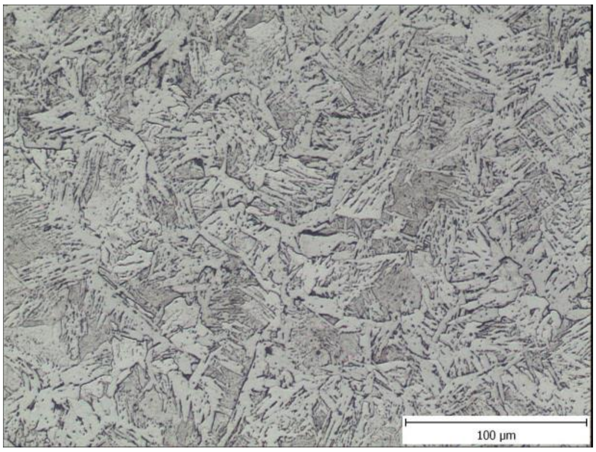


Fig. 1 The microstructure in weld metal

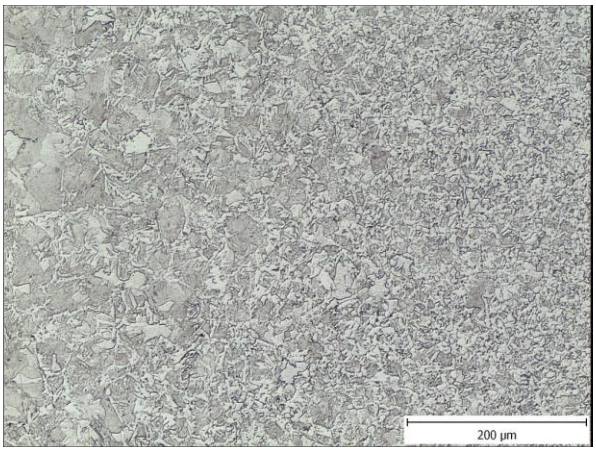
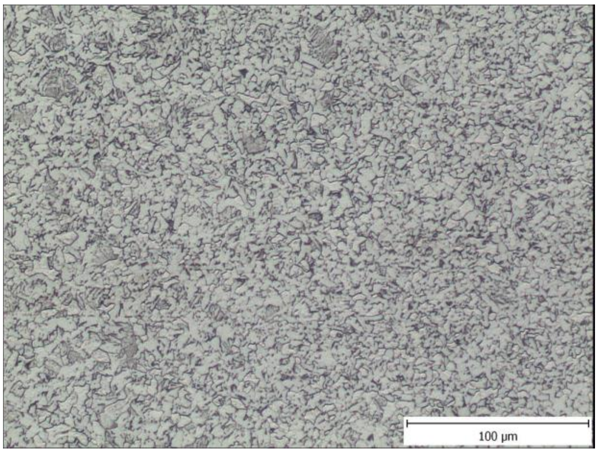


Fig. 2 The microstructure at weld metal-HAZ borderline



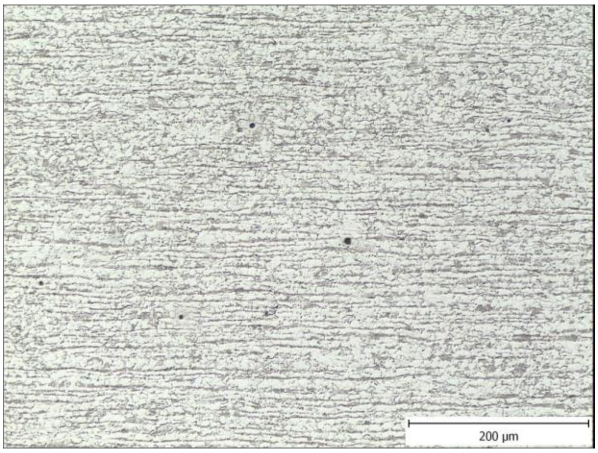


Fig. 3 The microstructure in HAZ

Fig. 4 The microstructure in base metal

The macrostructure analysis showed that all weld joints are suitable from defects presence point of view. Using of different shielding gases can affect cooling rate of welding process. This rate differences leads to different dimensions (widths) of weld metal and HAZ. The results of widths measurement are summarized in Table 2. The largest weld joint was found at sheet welded with using 0,9 mm laser beam wide and argon shielding gas. On the other hand using C12X2 mixture as shielding gas leads to smallest weld joint. In general, minimal heat influencing of material by welding is required so C12X2 is the best option from this point of view.

Table 2: Results of dimension measurements

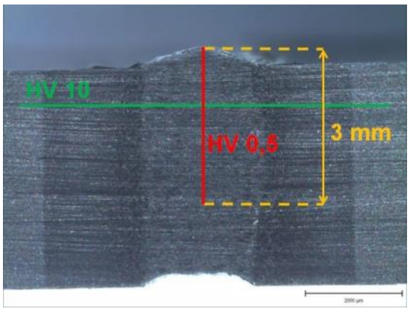
Shielding gas	**Width of weld metal [mm]**	**Width of HAZ [mm]**	
C12X2	2,55 – 2,70	1,82 – 1,86	1,45 – 1,58
He3H1	2,47 – 3,29	1,67 – 2,06	1,75 – 2,02
C6X1	2,62 – 3,33	1,83 – 2,02	1,74 – 2,21
He50	2,50 – 3,04	1,52 – 1,76	1,87 – 2,14
He	2,87 – 3,08	1,85 – 1,91	1,85 – 1,89
Ar (0,9 mm laser beam width)	3,33 – 3,60	1,89 – 2,05	1,79 – 2,01
Ar (1,2 mm laser beam width)	2,52 – 3,17	1,74 – 2,07	1,74 – 2,09

The specimens used for metallographic analysis were also used for hardness profile measurement HV10. For S355 steel the maximal hardness 380HV is allowed. Our results showed that the effect of using different shielding gases on hardness in weld metal or HAZ is minor – see Table 3.

Table 3: Maximal values of HV10 hardness in weld joints

Shielding gas	**C12X2**	**He3H1**	**C6X1**	**He50**	**He**	**Ar (0,9 mm laser beam width)**	**Ar (1,2 mm laser beam width)**
max HV	190	196	201	197	188	187	185

At the same specimens the microhardness HV0,5 profile measurement in axis of weld metal was performed. The area of microhardness measurement is indicated at Fig. 5, the results of measurement are summarized at Fig. 6. A significant difference could be seen only in case of sheet with He50 shielding gas. The results from other sheets/shielding gases are very similar.



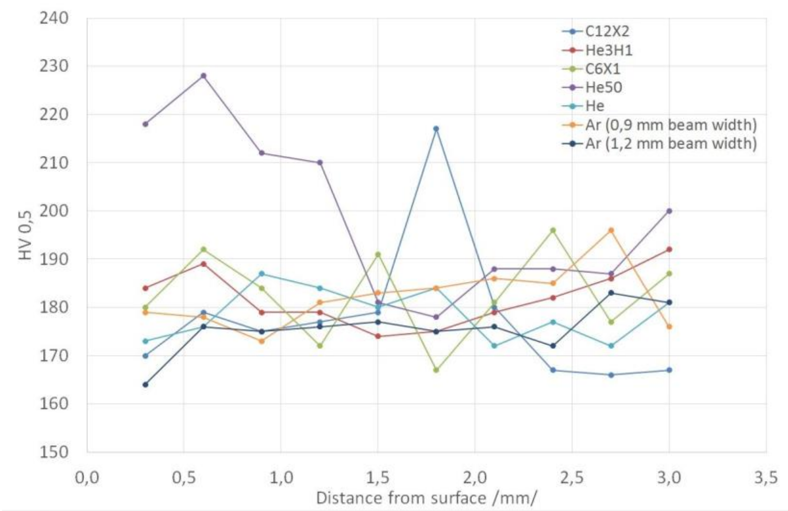


Fig. 5 and 6 Summary of microhardness HV0,5 profile measurement

The results of Charpy impact tests are summarized in Fig. 7. The results show that using argon as shielding gas leads to highest values of absorbed energy / notch toughness. The specific of argon using is also very significant when we investigate fracture surface and evaluate the ratio between areas of brittle and ductile fracture – as well seen at Fig. 7 (red columns). The comparison of different laser beam widths in using argon shielding gas shows no significant differences.

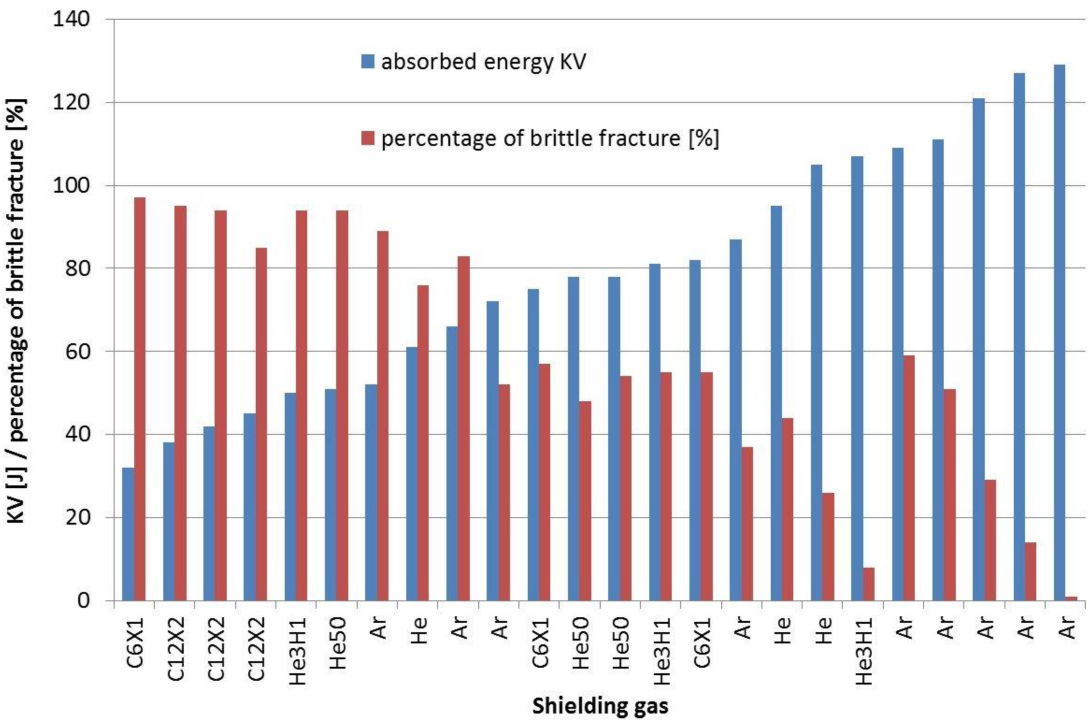


Fig. 7 An effect of shielding gas on the results of notch toughness

Two different laser beam width (0,9 and 1,2 mm) were used for welding of sheets with argon shielding gas. Specimens for fatigue tests were manufactured and tests performed. The results are summarized in Fig. 8.

It is obvious that different optics leads to different fatigue behavior and fatigue limit – σ_C = 250 MPa for 0,9 mm laser beam width and σ_C = 240 MPa for 1,2 mm laser beam width.

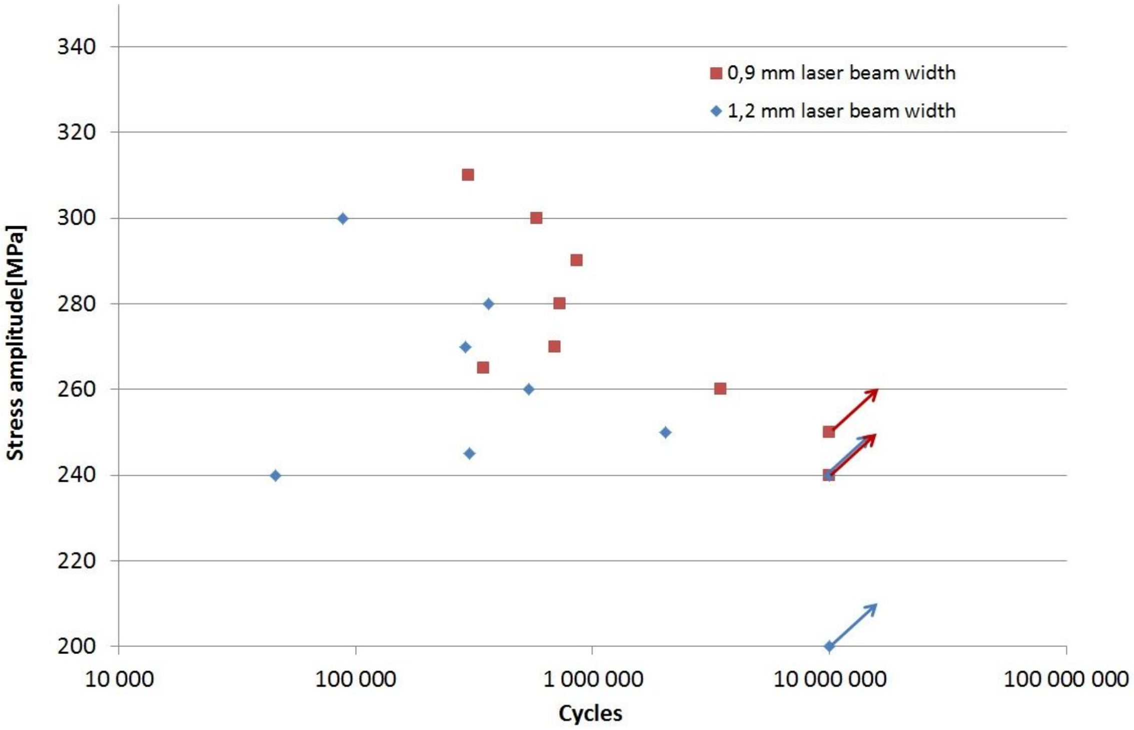


Fig. 8 The results of fatigue tests

Two specimens were prepared and tested from other sheets/shielding gases. All specimens were tested at the same stress amplitude – 255MPa – slightly above fatigue limit. The results of this comparison are summarized in Table 4. The values from sheets with argon shielding gas were statistically calculated from Wöhler curves of each sheet.

Table 4: Comparison of fatigue results for all sheets tested at the same stress amplitude

Sheielding gas	**Stress amplitude**	**Fatigue life [cycles]**	
		Specimen No. 1	**Specimen No. 1**
C12X2	255 MPa	1 123 307	10 000 000 *)
He3H1		173 512	434 404
C6X1		812 562	1 071 736
He50		906 514	1 408 651
He		496 768	682 503
Ar (0,9 mm laser beam width)		approx. 3 000 000	
Ar (1,2 mm laser beam width)		approx. 1 300 000	

) the specimen run out up to 10 000 000 cycles without failure

According to notch toughness results where argon shielded sheets show best results the fatigue results from these sheets were used as a "standard". Significantly worst fatigue resistance has been reached at specimens where He3H1 and He shielding gases were used. C6X1 and He50 sheets showed from fatigue point of view very similar results to our "standard". Using of C12X2 mixture as shielding gas lead to best fatigue resistance from all tested sheets. These results are in good agreement with residual stresses analyses where sheets welded with C12X2 shielding gas showed highest compressive residual stress in surface area. Our further work will focus on fractographic analysis of fracture surfaces after fatigue testing in combination with hardness profile in weld joint, evaluation of grinding / machining before welding on initiation of fatigue cracks and on evaluation of weld design on fatigue limit and fatigue crack initiation.

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