Effect of Shielding Gas on Residual Stresses and Mechanical Properties of Laser Welding of S355 Steel

K. Kolařík [1], N. Ganev [2,a], K. Trojan [1], J. Sís [3], S. Němeček [4]

[1] *CTU in Prague, Department of Solid State Engineering, Faculty of Nuclear Sciences and Physical Engineering, Trojanova 13, 120 00 Prague 2, Czech Republic*
[2] *TU of Liberec, Institute for Nanomaterials, Advanced Technologies and Innovation, Studentská 1402/2, 461 17 Liberec 1, Czech Republic*
[3] *SVÚM a.s., Strength Department, Tovární 2053, 250 88 Čelákovice, Czech Republic*
[4] *Matex PM, s.r.o., Morseova 1126/5, 301 00 Plzeň, Czech Republic*
[a] *nikolaj.ganev@fjfi.cvut.cz*

Abstract: The aim of this article is to assess the impact of the behaviour of the molten bath, penetration geometry, mechanical properties and mainly residual stress surface distribution of laser welded joints. In the case of classic fusion welding an exothermic or endothermic effect of the used shielding gas can be observed according to its dissociation energy. The presented experiments verify this behaviour also for laser welding, which could affect much higher rate of melting and cooling in compassion with other classic arc welding methods.

Keywords: laser welding; shielding gas; S355 steel sheets; XRD; residual stresses.

1 Introduction

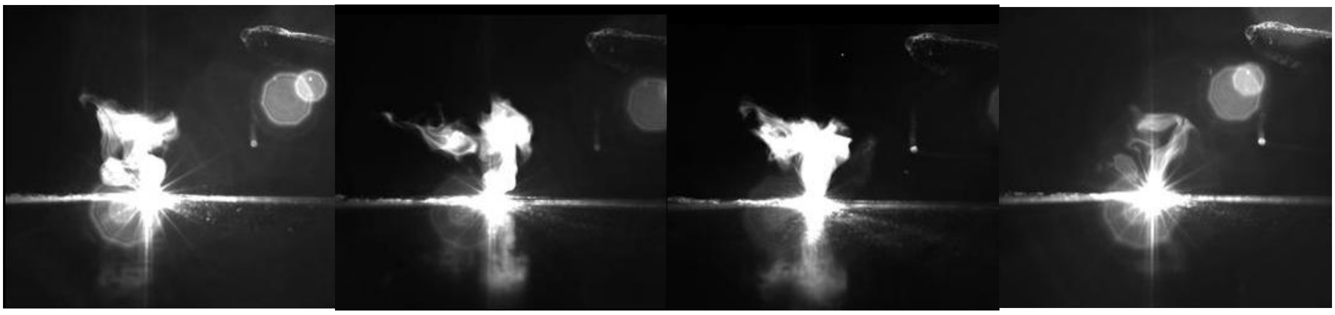
While in the case of conventional arc welding methods effects of shielding gases are already described, literature for laser welding is not adequately documented. Firstly, the parameters of fibre diode laser welding were optimized to obtain stable keyhole. After that the aim of the research was to describe the influence of classic shielding gases taken from arc welding methods to the width of the weld and heat affected zone (HAZ). The effect of gases on the resulting surface residual stresses and possible changes in mechanical properties, which have a significant effect on the fatigue life under dynamic fatigue stress [1], was also investigated. Another aim was to describe whether the higher cost of shielding gases provides sufficient added value of more expensive compounds. From the records of speed camera during welding, see Fig. 1, different plasma formations were demonstrated. The smallest plume of plasma and the highest stability was observed using He, which has a higher thermal conductivity and the highest ionization potential [2]. To avoid loss of the power input, the minimum content of 30% He is needed in the gas mixture for the elimination of the formation of plasma plum above the welding surface for laser technologies according to the literature [3]. The use of pure argon as a shielding gas in arc methods leads to a reduction in penetration and degradation of weld quality due to the low thermal conductivity of argon [4]. Gas mixture using active components CO_2, O_2 are used mainly in arc methods for reducing the surface tension of molten metal due to formation of oxide surface layer, which stabilizes the arc [4, 5]. The impact of individual gases and gas mixtures are not fully understood for fibre diode laser welding yet.

2 Experimental

Altogether, six welded plates 150×200×4.6 mm^3 were prepared from S355J2 steel sheets using a 3.2 kW laser with 0.5 m/min beam speed and optimized welding parameters. One side of the samples was ground before welding and the other side was not machined. Different shielding gas was used for all samples, i.e Ar, C12X2 (12 % CO_2, 2 % O_2, 86 % Ar), He3H1 (3 % He, 1 % H_2, 96 % Ar), C6X1 (6 % CO_2, 1 % O_2, 93 % Ar), He50 (50 % He, 50 % Ar), He. The X-ray diffraction (XRD) measurements were performed by a PROTO iXRD COMBO diffractometer with ω-goniometer and {*211*} diffraction line of α-Fe was measured by CrKα radiation. Residual stresses (RS) were calculated from the lattice deformation by using generalized Hook's law. RS were obtained in both the directions, i.e. perpendicular and parallel to the weld. Aside from stresses, macro-photos of welds macrostructure and heat affected zone (HAZ) were taken. Furthermore, welds were subjected to impact test and tensile test in SVÚM, a.s. Pictures of welding process with different shielding gases from speed camera were taken in the company MATEX PM.

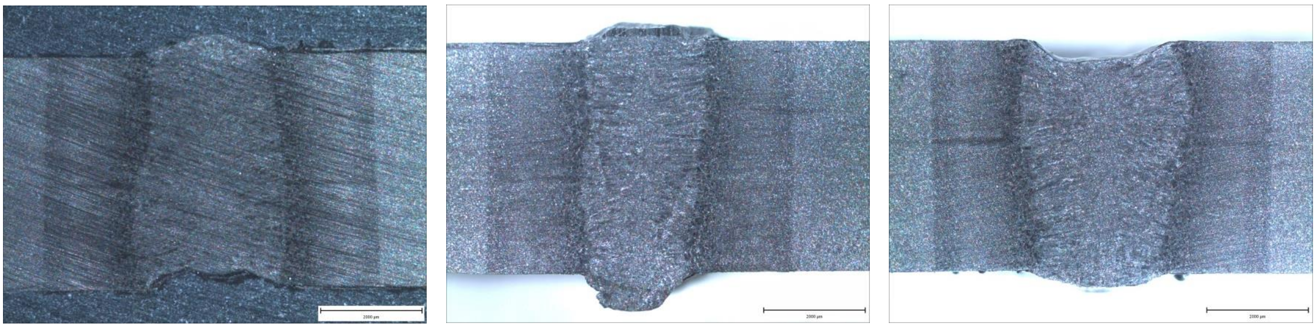
3 Results

Selected pictures of welding process with different shielding gases from speed camera are demonstrated in Fig. 1. Macrostructure photographs of laser welded joints using different shielding gases are presented in Fig. 2. Surface residual stresses obtained by XRD on all six samples are depicted in Figs. 3 and 4.

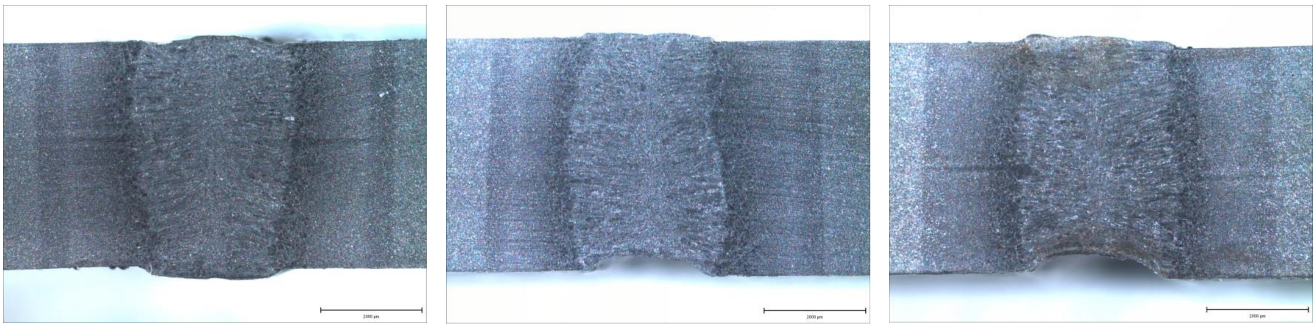


a) sh. gas Ar b) sh. gas C12X2 c) sh. gas He3H1 d) sh. gas He

Fig. 1: Records of welding process with different shielding gases from speed camera.

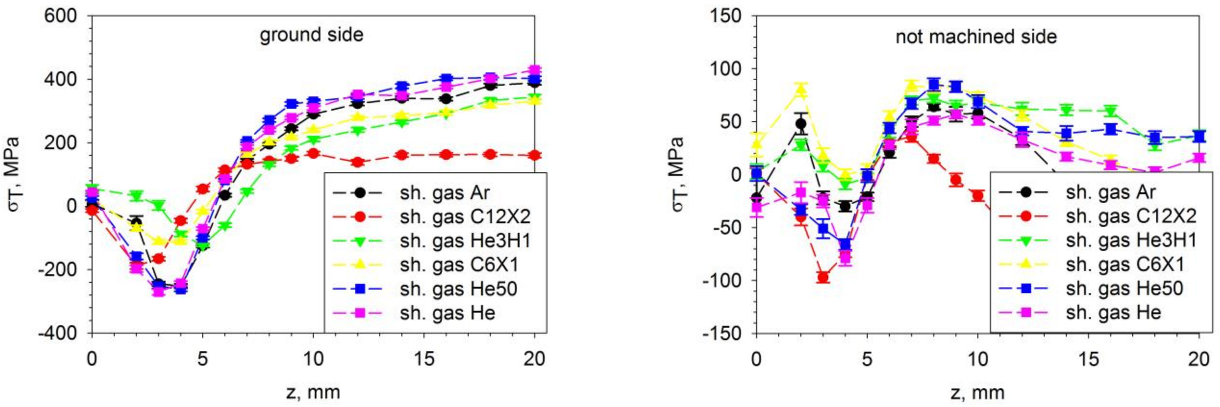


a) sh. gas Ar b) sh. gas C12X2 c) sh. gas He3H1



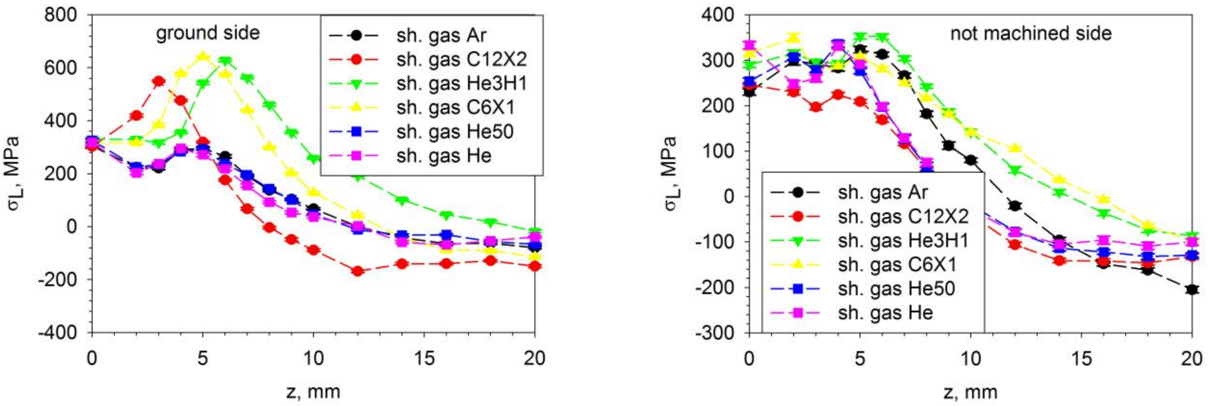
d) sh. gas C6X1 e) sh. gas He50 f) sh. gas He

Fig. 2: Macrostructure photographs of laser welded joints using different shielding gases; ground sides are at the bottom of the welds.



a) ground side b) not machined side

Fig. 3: Comparison of surface residual stresses gradients (thickness of the irradiated area approx. 4 μm) in the direction perpendicular to the weld for both sides of samples.



a) ground side b) not machined side

Fig. 4: Comparison of surface residual stresses gradients (thickness of the irradiated area approx. 4 μm) in the direction parallel to the weld for both sides of samples.

4 Discussion

All used shielding gases meet the minimum requirements of weld quality in terms of notch toughness and hardness. The results of the impact bending tests show that regarding strength currently the most widely used shielding argon gas appears to be the best. There was not significant effect of shielding gas to the width of welds and HAZ from the macrostructure photographs of laser welded joints (see Fig. 2). But there was some change in the actual geometry of the weld itself, which is reflected at the position of maximum of RS observed on both the analysed surfaces. A greater difference in the width of the welds would probably occur when higher laser power input is used, which could highlight different ionization potential of the individual gases.

The gas C12X2 reported narrowest HAZ according to macrostructure photographs (Fig. 2) and values of RS (Figs. 3 and 4). Furthermore, the gas C12X2 reported the best result of fatigue life test. Not machined side for gas C12X2 also has the highest observed surface compressive residual stress. In contrast, sample welded using shielding gas C6X1, which contains half of the content of active components, reported according to Fig. 2 wider fusion zone and HAZ. Surface residual stresses of the sample C6X1 are in all cases qualitatively higher compared to sample C12X2, see Figs. 3 and 4. The sample welded using shielding gas C6X1 also exhibits lower values of the fatigue life. Using gas with hydrogen has led to a similar course of the RS as the gas C6X1 but resistance to fatigue damage was unfavourable. Hydrogen is generally not recommended for ferritic steels, since it causes hydrogen cracks in the welds [5].

Ground sides in comparison with not machined surfaces have different gradients of surface RS in the HAZ but RS have a similar pattern in the fusion zone, see Figs. 3 and 4. The growth of macroscopic RS in the direction parallel to the weld in the HAZ and in the direction perpendicular to the weld outside the HAZ compared to the not machined side is caused by grinding technology. During interaction of the cutting tool (grinding wheel), tensile stresses are formed. Due to the superposition of RS resulting from grinding and substantial contraction of the cooling plate along the weld, the tensile RS on the machined side of the HAZ in the direction parallel to the weld are formed and the compressive stresses are formed in the second direction. On the not machined side of the samples, of course, the superposition is not observed. The macroscopic surface RS in the direction perpendicular to the weld on not machined sides are in comparison with the ground side qualitatively lower and their values are in the range from –100 to +100 MPa. This may be important when the cracks are initializing during the fatigue life tests, which were performed in SVÚM.

The macroscopic residual stresses observed in direction parallel to the weld are on the not machined surface for all the gases similar and on the ground side is a noticeable drop in surface residual stresses for gases He, He50 and Ar. However, gas mixtures using hydrogen or a low content of the active components exhibit unfavourable results of RS at the interface of the HAZ and the base material. Shielding gas mixtures using helium (He, He50) showed on the not machined side in direction perpendicular to the weld similar progression of surface RS in the fusion zone and HAZ as when is used only pure Ar as a shielding gas.

Consequently, further experiments are necessary to describe different process of formation of surface residual stresses and the associated different results of fatigue life for the shielding gas C12X2. Observable difference in weld geometry, see Fig. 2, and the results of surface RS and fatigue life for gas C12X2 is probably due to sufficient positive effects of active components in shielding gas. These components sufficiently modify the surface tension of the molten metal and thus completely penetrated weld was formed without an unfavourable undercut and also without a high overlap.

5 Conclusion

The effects of different shielding gases for laser welding of S355 steel plates to residual stresses and mechanical properties were investigated. Generally speaking, the most suitable distribution of residual stresses and the best fatigue life were achieved with a shielding gas C12X2. On the contrary, the unsatisfactory results showed the joint welded using gas He3H1. The use of pure inert gases or their combination showed similar macrostructure photographs, results of RS and mechanical properties.

Acknowledgement

This research was was carried out in the frame of the research projects LO1201 of the Ministry of Education, Youth and Sports in the framework of the targeted support of the "National Programme for Sustainability I" and by the Grant Agency of the Czech Technical University in Prague, grant No. SGS16/245/OHK4/3T/14. The authors thank MATEX PM for supplying the laser welds.

References

[1] Pan, Lingyun, et al., Welding residual stress impact on fatigue life of a welded structure, Welding in the World 57.5 (2013) 685–691.

[2] Quintino, L., et al., Gas shielding in fibre laser welding of high strength pipeline steel, Science and Technology of Welding and Joining 16.5 (2011) 399–404.

[3] Tani, G., et al., The influence of shielding gas in hybrid LASER–MIG welding, Applied Surface Science 253.19 (2007) 8050–8053.

[4] Wang, L. L., et al., Effects of shielding gas composition on arc profile and molten pool dynamics in gas metal arc welding of steels, Journal of Physics D: Applied Physics 47.46 (2014) 465202.

[5] Kah P., Martikainen J., Influence of shielding gases in the welding of metals, The International Journal of Advanced Manufacturing Technology 64 (2013) 1411–1421.