Pulsed LASER-TIG hybrid welding of coated unalloyed steel thin sheets

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Keywords

Pulsed LASER-TIG hybrid welding, coated sheets, welding technology, welding process efficiency

1. Introduction

The development of new processing technologies, the improvement of the existing ones, or the development of new processing equipment and parts are some of the main research and development directions in manufacturing focused toward the improvement of production lines' efficiency and of products' quality.

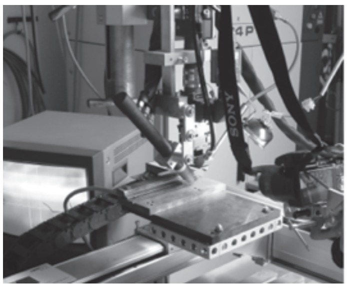
LASER-ARC hybrid welding process is not a new process [1] and falls also under this category, being characterised by an accelerated and continuous development towards industrial implementation [2] and extending its applicability [3]. At the same time, the researches regarding this process are focused on understanding and modelling the complex phenomena that characterizes the hybrid welding process [4, 5] and developing prediction models and tools to control it [6].

Following this trend with focus onto thin sheets joining applications a new laser-arc hybrid welding process was proposed [7] which combines the use of a pulsed laser source and a pulsed TIG process.

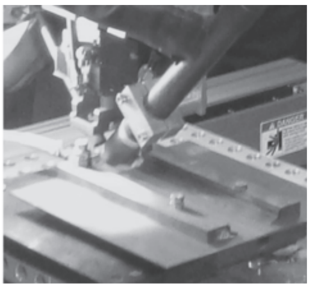
Using this new laser-arc hybrid process a joining technology was developed for butt welding of coated unalloyed steel thin sheets used in railway industry as an alternative to inline resistance welding.

2. Material and method

The experimental programme did make use of the developed experimental system for studying the process' characteristics [8], presented in Figure 1, and did include: a flexible laser beam micro-processing unit with an inertial table and a positioning system for the laser welding head - TIG torch assembly, a programmable pulsed Nd:YAG laser, Trumpf HL 124P LCU, with a maximum average power output of 150W, a TIG welding source, Kemppi MASTERTIG 2500 AC/DC, and torch, a cartesian xOy robot, YAMAHA FXYX-A1, a thermal imaging camera, FLIR Systeam A40, and two video acquisition systems - a CCD camera co-axial with the laser beam and a camera positioned transversal to the travel direction.



a)



b)

Figure 1. The Experimental system detail (a) and the fixture (b)

As base material for the butt welding joint, 160x100mm mechanically cut coupons of 1.5mm thick coated unalloyed steel thin sheets were used. The process variant used for butt welding of the thin sheets was pulsed TIG-laser variant (TIG was the leading process) and there was no special preparation of the welding joint (Figure 2). Also, for testing the possibility of increasing the productivity by reducing the joint preparation times, beside sheets with the coating mechanically removed from the nearby region of the joint, "as-is" sheets were also used.

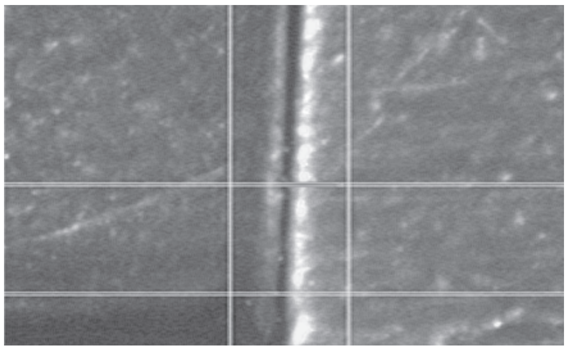


Figure 2. Joint aspect with mechanically cleaned coating of the joint nearby area

For all the experiments pulsed TIG-laser variant was used, the TIG torch - laser optics angle was set at 45?, Ar 99% both for TIG and as laser protection gas was used, the laser spot diameter was 0.8mm, laser pulse power was 1400W, pulse width was 3.4ms, the laser pulse repetition frequency was 23Hz, the hybrid distance (distance between the two processes) was set to 1.0mm, the TIG current frequency was set to 19Hz, the TIG current ratio was set to 50%, the TIG average welding current was varied between 30 and 36A and the travel speed was varied between 2.4mm/s and 5.2mm/s.

Macroscopic visual inspection was made to assess the imperfections of the welds. Weld surface was examined for craters on the surface, continuity, visible weld cracks, and surface inclusions. Microscopic analyses were performed on welded samples with an inverted metallographic microscope MeF2 Reichert (Reichert, NY, USA). The microhardness (HV5) was measured on polished surfaces at room temperature, using

Zwick 3212 (Zwick, Ulm, Germany) equipment, in base material (BM), welded material (WM) and heat affected zone (HAZ).

For tensile testing specimens from base material and welded joints were prepared. Both MB and welded samples were tested on a universal testing machine ZD 10/90 (WPM), Leipzig, Germany). The maximum force at break and area were measured after fracture and used to calculate the tensile strength (Rm). The BM tensile tests were done both on the lamination direction and on the transversal direction in order to compare the values with the results obtained from the welded specimens. Beside tensile tests, static load bending tests were done on both sides of the welded joint.

Based on the obtained results from the analysis and the testing, the process parameters for realizing the welded joint were determined.

3. Results and discussions

The visual aspect of the realized butt welded joints are presented in Figures 3 and 4 for the welded specimens with mechanically removed coating and "as is" respectively.

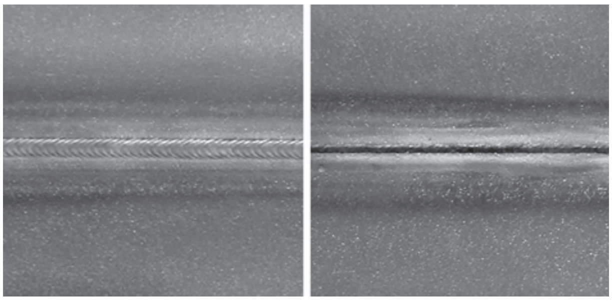


Figure 3. Visual aspect of the surface and root respectively of the weld (specimen with mechanically removed coating)

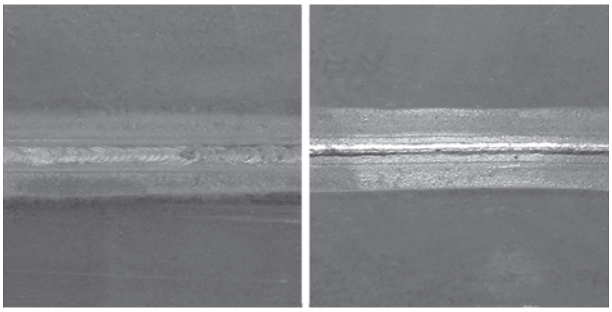


Figure 4. Visual aspect of the surface and root respectively of the weld (specimen "as is")

For the case of the welded specimens with the coating removed in the near-by area of the joint, increased thermal induced deformation of the welded sheets as well as a wider heat affected area could be observed while for the "as is" specimens minimum thermal induced deformations could be observed.

The macroscopic image of the joint presented in Figure 5 shows a full penetration weld, with a shape that is specific to laser-arc hybrid process and with no welding imperfections defects.

The observed structures (figures 6 to 10) of the weld's areas were:

• Base Metal (BM): ferrite, the real grain dimension presented in Figure 6.

• Heat Affected Zone (HAZ): perlite, ferrite and acicular ferrite mixture, the real grain dimension presented in Figures 7 and 8.

• Weld Metal (WM): perlite, ferrite and acicular ferrite mixture with a dendritic casting microstructure.

The HV5 microhardness tests were done in the welded joint's characteristic areas, according to Figure 11, with 3 tests in each area.

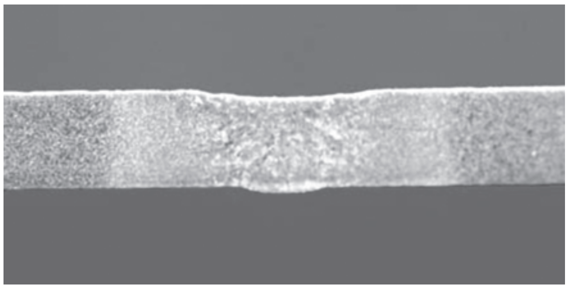


Figure 5. Macroscopic aspect of the welded joint [Nital 10%]

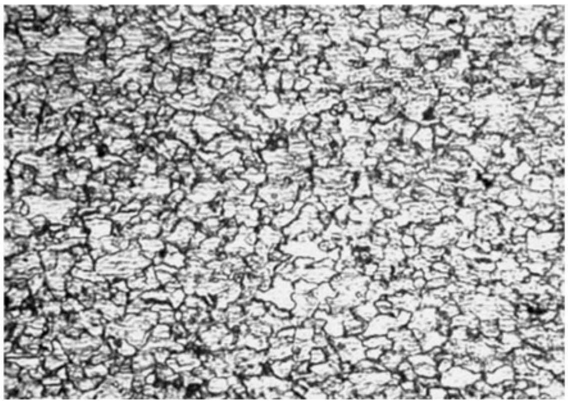


Figure 6. Microscopical aspect M1-BM1 [Nital 2%, 100×]

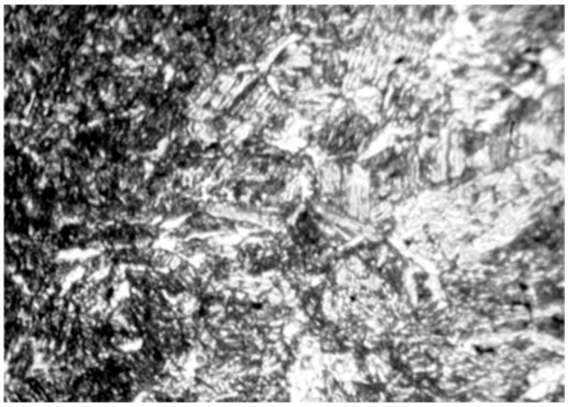


Figure 7. M1-HAZ1 [Nital 2%, 100×]

The measured values of the microhardness test are presented in Figure 12. The microhardness measured values do increase quasi-symmetrically towards the centre of the weld where the maximum value (an increase with 100%) was measured.

The lack of total symmetry of the micro-hardness values variation could be related to a slight miss-alignment of the TIG arc plane to the laser beam - travel direction plane which did lead to a non-symmetrical heating and cooling heat flow near the weld's core. At the same time, this lack

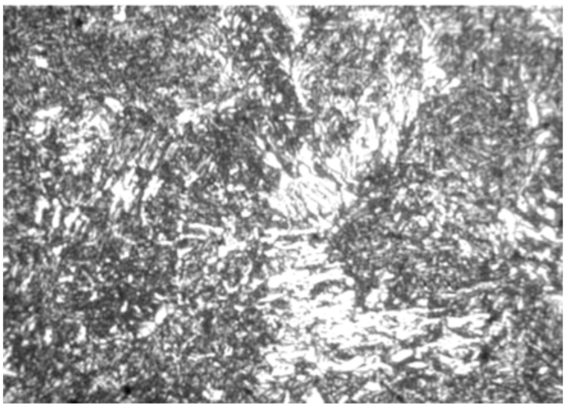


Figure 8. M1-WM [Nital 2%, 100×]

Figure 9. M1-HAZ2 [Nital 2%, 100×]

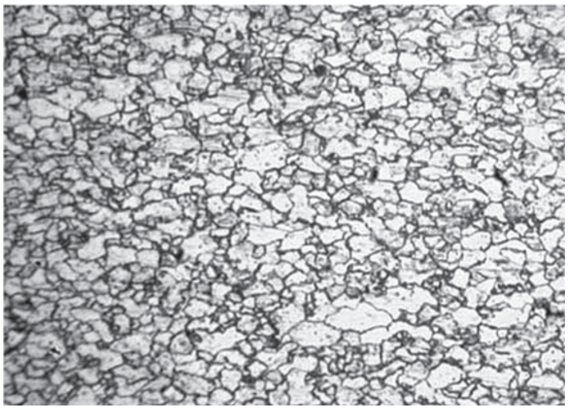


Figure 10. M1-BM2 [Nital 2%, 100×]

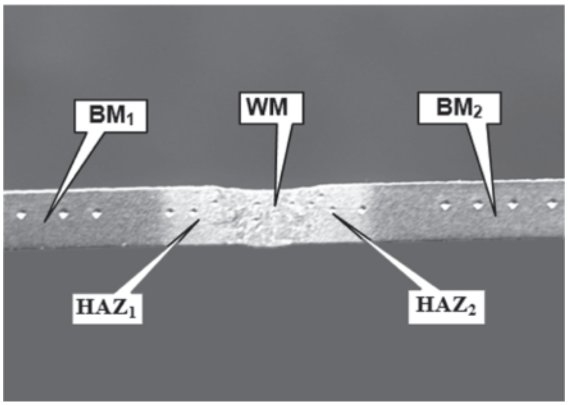


Figure 11. HV5 microhardness tests of the welded joint

of symmetry could be caused by the asymmetrical current flow and the inherent magnetic blow of the arc, caused by the transitory coupling phenomenon which is specific to this new process [7], during the base current period when the hybrid coupling of the two processes decreases in intensity.

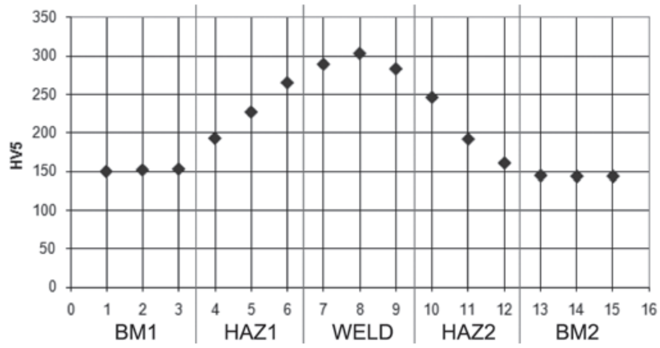


Figure 12. HV5 microhardness values of the joint

The static tensile tests did show that the welded specimens did break in the base metal (Figure 13) while the calculated tensile strength values were similar to the ones determined for the base material. The static load bending tests both for the root of the weld and the surface of the weld did show a maximum deformability degree (180^o) without cracks (Figure 14).

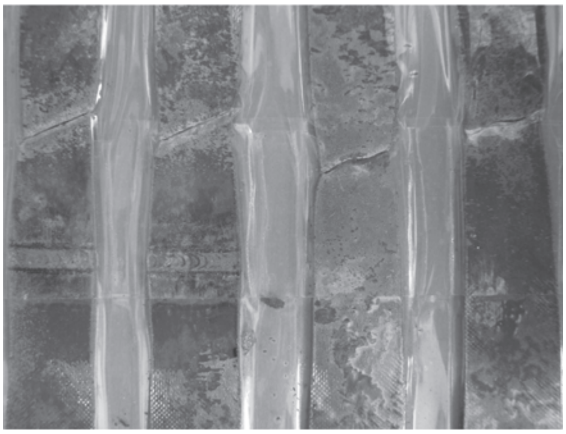


Figure 13. Tensile strength tests of the welded specimens

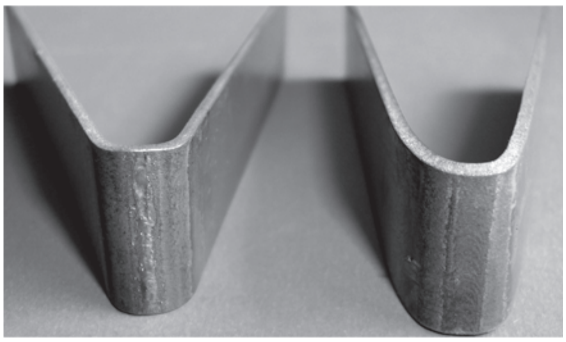


Figure 14. Static load bending tests specimens

To prove the increased efficiency of the hybrid welding process a test with the two processes separately on the same joint configuration was done using the same process parameters as the ones used with the hybrid welding technology. Used alone, neither of the processes could realize a weld even at lower speeds. The obtained penetration depths using each welding process separately are presented in Figures 15 and 16.

Based on the obtained results following the experimental programme, the tests and the analysis, one could conclude that the new laser-arc hybrid welding process is fit for replacing the usual arc welding process for the investigated base material and joint type with the proper welding technology. Furthermore, the use of pulsed TIG-LASER hybrid welding process variant insures a higher productivity in respect to the joint preparation procedures and processing speeds with lower thermal induced stresses due to the increased energy efficiency and gap bridge-ability of the hybrid welding process.

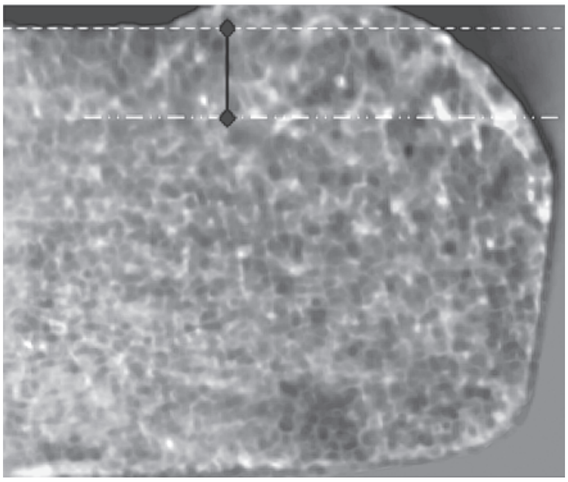


Figure 15. Maximum penetration depth using pulsed TIG process (same joint configuration, same TIG process parameters and lower travel speed)

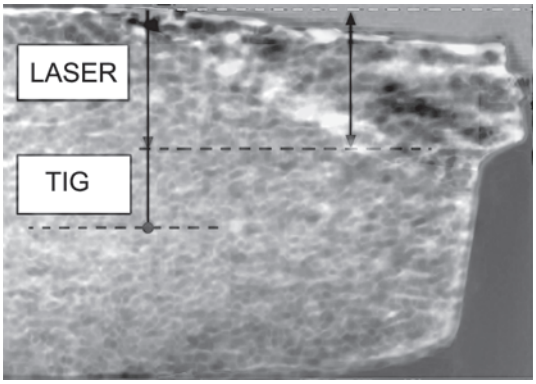


Figure 16. Maximum penetration depth using pulsed laser process (same joint configuration, same laser process parameters and lower travel speed)

4. Conclusions

The results obtained, following the experimental work and sample analysis, did permit to establish the proper process parameters for butt welding of coated unalloyed steel thin sheets and that the new laser-arc hybrid welding process can be used to replace classic arc welding processes.

Sound joints were obtained with less thermal induced stresses while no joint preparation was used for butt welding of the covered thin sheets.

The analysis performed on the welded samples revealed no imperfections and the tensile and static load bending tests did permit to establish a proper welding technology for joining the envised materials.

A lack of symmetry was observed for the micro-hardness values variation measured in the joint area which could be related to a slight miss-alignment of the TIG arc plane to the laser beam - travel direction plane or by the asymmetrical current flow and the inherent magnetic blow of the arc, caused by the transitory coupling phenomena, specific to the new hybrid process, during the base current period when the hybrid coupling of the two processes decreases in intensity.

The increased efficiency of the new laser-arc hybrid welding process was proved by comparing the effects of the two processes separately and the hybrid welding process effects respectively on the same joint type.

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