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Fiber laser-MIG hybrid welding of 5 mm 5083 aluminum alloy

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ABSTRACT

Aluminum and its alloys are difficult to weld due to their specific characteristics. New joining methods such as high power fiber laser-MIG can provide higher overall productivity compared to the arc welding or laser beam welding. There is huge lack of information on how the specific welding parameters in laser-arc hybrid welding affect quality of welds such as torch arrangement, distance between heat sources and shielding gas composition while other parameters were kept at constant. Laser-arc hybrid welds with short separation distance between sources produced severe porosity in one pass 5 mm thick aluminum alloy sheets welding due to unstable interactions and keyhole frequent collapses. Higher process stability and lower porosity level can be achieved by applying trailing torch arrangement. Addition of significantly more expensive helium to the shielding gas did not provide any benefits in terms of porosity decrease, process stability and mechanical properties of welds overall as was expected with selected welding parameters.

1. Introduction

Aluminum alloys welding can be challenging due to their specific properties such as high thermal conductivity that requires higher energy density power sources, high thermal expansion causing higher distortions, high hydrogen and nitrogen solubility at high temperatures during fusion welding processes which generates porosity, aluminum oxide film Al_2O_3 causing incomplete penetration, and low surface tension or viscosity. Aluminum alloys welding with laser beam sources is more difficult due to stronger evaporization of alloying elements with high power densities that can cause decreased mechanical properties of welds as stated Seto et al. (2001). Since aluminum is highly reflective material for long-wavelength (10 600 nm) laser beams like CO_2, therefore a high power density threshold is required to form and maintain keyhole during welding process (Olsen, 2009). This can be maintained by application of short-wavelength (about 1000 nm) laser beams that require much lower minimum power density threshold to form a keyhole.

In the past three decades, aluminum was welded with a success with proven TIG, MIG, PAW electric arc processes, as well as with Nd:YAG and CO_2 laser beam power sources. Hybrid welding where mainly CO_2, Nd:YAG laser beams coupled with TIG, MIG arc sources has proven its application. Due to inherited filler wire deposition, MIG process can be more advantageous for welding aluminum alloys compared to TIG due to possibility to manipulate microstructure, better bridgeability, and higher weld metal deposition capability. Nd:YAG and CO_2 have been utilized for many years with TIG sources to join various aluminum alloys. As a result, no much information is available on fiber laser-MIG hybrid welding. (Olsen, 2009)

The first published research on fiber laser-MIG hybrid welding of aluminum alloys was in 2004 by Thomy et al. (2005). Subsequently Allen et al. (2006), Wagner et al. (2006), Yan et al. (2014a,b), Leo et al. (2015), Casalino et al. (2014) applied fiber laser and MIG power sources with limited success. Casalino et al. (2014) reported coarse porosity, in form of ellipses, issues in welding of 3 mm thick AA5754 due to interrupted dynamics of the keyhole related to low laser-to-arc ratio.

According to Leo et al. (2015), where the laser-to-arc power ratio was used as main variable as well, welded 3 mm 5000 series aluminum alloy, revealed micro-porosity throughout welds and evaporation of the alloying elements (Mn, Mg) which reduced mechanical properties when laser power was increased. The same problems with evaporization of magnesium and manganese related to deterioration of mechanical properties of joints were reported by Yan et al. (2014a,b). According to the aforementioned research it can be concluded that no much attention were made to the helium

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Table 1
Chemical composition (by weight) of base and filler material.

Material	Al%	Mn%	Cu%	Zn%	Si%	Fe%	Mg%	Cr%
AA 5083 (Base)	balance	0.7	–	–	–	–	4.4	0.15
OK Autrod 5183 (Filler wire)	balance	0.8	<0.10	<0.25	0.4	<0.4	4.8	0.15

Table 2
Mechanical properties of base and filler material.

Material	Min. Yield point R_{eh} [N/mm^2]	Ultimate tensile strength R_m [N/mm^2]	Break elongation A [%]
AA5083 (Base)	130	280	22
OK Autrod 5183 (Filler wire)	140	300	25

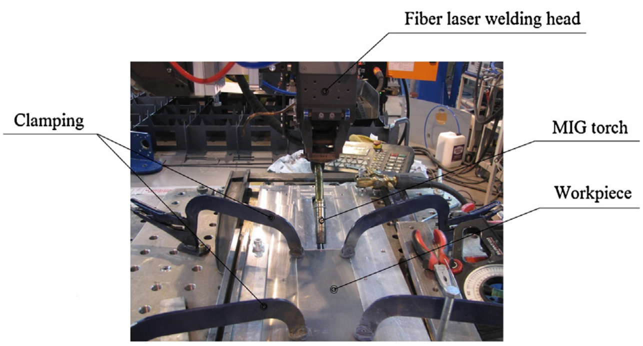

Fig. 1. The fiber laser-MIG setup of experiment.

as shield gas composition utilization, arc torch arrangement and separation distance between power sources on weld quality.

This paper reveals the coarse porosity formation during fiber laser-MIG hybrid welding of 5 mm AA5083 where aforementioned parameters were studied. Coarse porosity was attributed to significant keyhole collapse. Helium as a preferable shielding gas for aluminum welding had no advantages neither in reduction in porosity nor in quality of welds overall. The paper provides clarification how to avoid the coarse porosity in hybrid welding of Al-Mg alloys, effect of shielding gas composition and torch arrangement on weld quality.

2. Experimental

2.1. Materials and consumables

The material for experimental welding was non-heat treatable, wrought aluminum alloy 5083-O (O designates annealed state—heat treatment method) of thickness of 5 mm. AA5083 is strengthened by a solid solution of magnesium in the aluminum matrix as most of 5000 series alloys. Weldability of AA5083 is good compared to other aluminum alloys and not sensitive to hot cracking, therefore hot cracking problem is not expected in results. The test workpieces were cut with CO_2 laser into sizes 250 × 100 mm. The edge surface quality was rough and heavily oxidized. The chemical composition of the AA5083 is presented in Table 1.

For AA5083 base metal alloy, the filler wire must have nearly the same chemical composition (the percentage of alloying elements should be higher to partly compensate evaporization of these elements during welding) and mechanical properties must be a bit greater in order to avoid problems during and after welding to compensate the deterioration of mechanical properties after welding. Therefore, AA5183 filler wire composition is selected. ESAB OK Autrod 5183 is similar to composition of AA5083, the diameter of the wire used was 1.2 mm, to provide sufficient filling in thickness exceeding 3 mm. The chemical composition of filler wire is shown in Table 1 and mechanical properties are shown in Table 2.

2.2. Welding setup and equipment

High power laser IPG Photonics YLS-10000 ytterbium fiber laser was used for experiments. The maximum output power of the laser is 10 kW, the beam was delivered from the equipment to workpiece via 200 μm optical fiber. Fiber laser beam was collimated with 150 mm lens and had 250 mm focal length. KEMPPI Pro Evolution 5200 was used as MIG source. Constant welding parameters used in the experiments are listed in Table 3 and varying welding parameters are presented as the experimental design matrix in Table 4.

The schematic welding setup used for experiments is shown in Fig. 1 Fig. 2. The joint type used was I-butt joint without beveling and welding was done in flat position (PA position according to EN ISO 6947). No air gap was used in testing and workpieces were tack welded at both sides with MIG source to ensure rigidity and decrease the distortions after welding. Before welding, the AA5083 plates were mechanically cleaned with stainless steel brush in order to eliminate the aluminum oxide layer.

3. Results and discussion

3.1. The effect of process distance and MIG torch arrangement on welds made in pure argon shielding gas

The full penetration was achieved with the leading torch setup with each process distance (see Fig. 3) as it was expected due to preheating mechanism of the arc source before laser impingement. Preheating mechanism increases the temperature of material, simultaneously the absorption for the laser beam increases, and, consequently, penetration increases as well. However, according to Fig. 3 it was not possible to distinguish how much penetration varies with increasing separation distance between sources due to full penetration in all cases. These results contradicts to Casalino et al. (2013) who also studied the effect of arc position on quality of welds where TIG was used as arc source, and it was shown that arc trailing arrangement provided higher penetration depth at the same speed.

Considering the quality, it is noticeable that all welds had sagging, probably due to excessive laser power and/or arc power or too low welding speed. The sagging problem can be also related to the surface tension property, where it is lower than in steels. The problem with low surface tension is that aluminum has a poor ability to support the root side of the melt pool. The sagging problem may be eliminated by implementing the backings strips with narrow groove, however it will increase the costs of operation.

In contrast, with trailing MIG torch setup, full penetration was reached only with minimum separation distance of 1 mm. When 3 mm separation process was used, partial (intermittent) penetration occurred. Further increase in separation distance by 2 mm (5 mm in total) leads to incomplete penetration also greater distortions of the workpiece. Incomplete penetration was caused due