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Hybrid welding of 45 mm high strength steel sections

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Abstract

Thick section welding has significant importance for oil and gas industry in low temperature regions. Arc welding is usually employed providing suitable quality joints with acceptable toughness at low temperatures with very limited productivity compared to modern high power laser systems. Laser-arc hybrid welding (LAHW) can enhance the productivity by several times due to higher penetration depth from laser beam and combined advantages of both heat sources. LAHW was applied to join 45 mm high strength steel with double-sided technique and application of metal cored wire. The process was captured by high speed camera, allowing process observation in order to identify the relation of the process stability on weld imperfections and efficiency. Among the results, it was found that both arc power and presence of a gap increased penetration depth, and that higher welding speeds cause unstable processing and limits penetration depth. Over a wide range of heat inputs, the welds where found to consist of large amounts of fine-grained acicular ferrite in the upper 60-75% part of welds. At the root filler wire mixing was less and cooling faster, and thus found to have bainitic transformation. Toughness of deposited welds provided acceptable toughness at -50 °C with some scattering.

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Keywords: hybrid welding; high strength low alloy steel; thick section; acicular ferrite; toughness

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1. Introduction

Fusion welding is an essential manufacturing process used in heavy industry where 10-60 mm thick plates are frequently used. Thick section welding is of great interest, in recent years, for low temperature applications. A well-established arc technique, such as metal active gas (MAG) welding is commonly used for this task. However the process has limited welding speeds and overall productivity compared to the laser beam welding (LBW) technology. Modern fiber laser beam technology with high powers offers much higher production rates due to higher penetration depth (Ono et al., 2002). By adding MAG process to LBW, making so-called laser-arc hybrid welding (LAHW), the productivity can be increased even further with ability to manipulate microstructure though added filler wire (Moore et al., 2004) and moderate cooling rates which are extremely important for achieving acceptable toughness at low temperatures by facilitating high amount of acicular ferrite (Svensson and Gretoft, 1990). LAHW using a fiber laser is reported by a few research groups in providing good results in achieving toughness. Grünenwald et al. (2010) applied LAHW on 9.5 mm high strength steel (HSS) with high welding speeds, at 2 m/min, high impact toughness (more than 100 J) at -20 °C was achieved. Joining 8-12 mm root in 20-23.4 mm X80 and X120 high strength steel by LAHW with modified spray arc process, by using both solid and metal cored electrode, provided excellent impact toughness even at -60 °C giving 190 J on average (Gook et al., 2014). First attempts by Akselsen et al. (2014) to weld 20 mm structural HSS by using keyhole LAHW provided reasonable impact toughness only at -30 °C due to high cooling cycles in the middle of the plate consisting of bainitic-martensitic microstructural development. Pan et al. (2015) performed one-pass welding of 11 mm HSS, where joints had minimum of 150 J impact toughness at -40 °C.

A relatively new cold metal transfer plus pulsed (CMT+P) arc mode, characterized as short-circuiting phase combination with pulsing, providing significantly lower the heat input (Pang et al., 2016) than standard Pulsed arc mode. The usage of CMT+P in combination with metal cored wire can be a perspective arc mode and overall improvement used for joining thick high strength low alloy steel sections by combining it with fiber laser to form hybrid welding process. Such combination applied for thick steel section welding was not reported.

In this paper, 45 mm HSS was joined by deep penetration LAHW, in double-sided technique, with acceptable weld quality and toughness at -50 °C as a partial penetration joints due to lack of fusion in most of welds. The stability of the process was observed by high speed camera in order to understand the effect of various welding parameters and generated imperfections. Testing a wide range of parameters including different arc modes (CMT+P/Pulsed), air gaps, travel speeds, filler wire feed rates (arc power) and torch arrangement revealed that upper part of welds had favorable microstructural development whereas at the root bainite was commonly observed related to difficulties of filler wire delivery and substantial increased cooling cycles.

2. Methodology

The LAHW setup is illustrated in Fig. 1a, where a 15 kW IPG Laser YLR-15000 ytterbium fiber laser (wavelength 1070 nm) was applied. The laser had a fiber core diameter of 400 µm, beam parameter product 10.3 mm·mrad, was operating in continuous wave mode and focused below the surface (-7 mm focal spot position) by 300 mm focal length optics to a spot size of 800 µm diameter with resulting Rayleigh length ±4 mm was applied. The laser was combined with MAG welding equipment TPS4000 VMT Remote from Fronius GmbH. The wire feeder is a combination of a continuous feeding unit VR7000 with a Robacta Drive unit that carries out the back and forth motion of the wire tip which enables the CMT process used in the experiments. To prevent high back reflections damaging the optical fiber, a slight tilting of 7° of the laser was applied. The MAG torch had the angle of 60±2° and 15±1 mm distance to the surface of specimen. Argon with 18% CO_2 shielding gas mixture was used with 25 L/min flow rate. The welds were carried out using an articulated robot from Motoman.

45 mm thick high strength steel plates (yield strength of 500 MPa) was used in the experiments and chemical composition is shown in Table 1. The plates were plasma cut by 500x125 mm and edges were milled for welding. The upper part near weld edge was sandblasted. The workpieces were fixed with heavy clamping system. Filler wire used was a metal cored wire Kobelco Trustarc MX-A55T of 1.2 mm in diameter with chemical composition presented in Table 1. High speed imaging (HSI) camera (Redlake) was used from the side, tilted by 55° from the horizontal (normal) surface. Region of interest had the resolution of 800x600 pixels with 10 bits pixel depth. Illumination pulsed