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Full Length Research Paper

Fatigue life of fully Penetrated Hybrid Laser Fillet Welds

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Conventional MIG welding is a relatively slow and high heat input welding process. This high heat input, leads to residual stress and distortion. This distortion has a negative effect on the fillet welds. In order to avoid the problem of distortion, laser hybrid welding was used because it is a low heat input process and faster in terms of productivity compared with conventional MIG process. It also has a good joint bridging ability. In laser hybrid welding, the deep penetration characteristic enables it to achieve full penetration, when welding from one side of a fillet weld. This research investigates the effects of the welding parameters on the fatigue life of fully penetrated laser hybrid fillet welds. Also, in this work we are comparing the mechanical properties of hybrid laser welds and conventional MIG welds.

Keywords: Hybrid, Laser, Welding, MIG

INTRODUCTION

Hybrid Laser Arc Welding

Arc welding is a relatively low speed and high energy process with limited depth penetration as compared to laser welding. During fabrication, it allows more tolerance due to its joint bridging ability. Laser welding on the other hand, is a lower energy process in respect to arc welding. Due to its smaller beam diameter, it has a high depth to width ratio with high cooling rate and poor fit up tolerance. One of its major characteristic is high welding speed. It is advantageous to combine arc and laser welding. Hybrid laser arc welding is a process that combines (GMAW) gas metal arc welding and (LBW) laser beam welding which is focussed in the same weld pool. Steen and Eboo first developed this process in the late 1970s (Steen and Eboo, 1979). Until recently, there has been limited research work on the process. This is because of availability and cost of high power lasers. Also, from early research work it has been seen that hybrid laser arc welding compared to ordinary laser beam welding, there is an increase in the process stability, efficiency and welding speed. To date, there are still limited applications of hybrid laser welding in the industry. It also has good gap bridging ability, can weld reasonable material thickness as well as the welding quality with reduced susceptibility to cracks and pores (Bayer, 2001). Furthermore, with respect to arc welding, the hybrid laser arc welding has deeper penetration, higher welding speed for productivity and low heat input thereby reducing residual stress and distortion. There is an improvement on the mechanical properties of the weld due to its bridging ability and slowed cooling rate. This is due to the interaction of the arc source in the process (Allen et al., 2007; Gao et al., 2006). Hybrid laser arc welding seems to be advantageous for several applications due to its characteristics, which includes

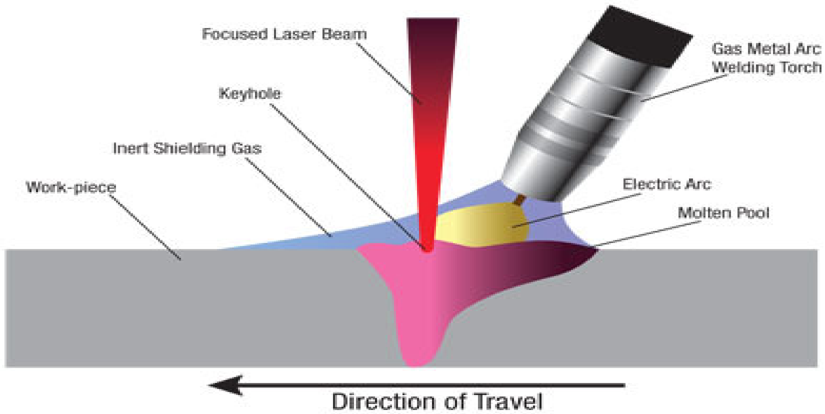

Figure 1 Schematic diagram of hybrid Laser GMAW Welding process

pipelines, power generations and ship building (Gerritsen et al., 2005a; Gerritsen et al., 2005a). Fillet welds are generally used in ship building and the automotive industries. But when hybrid laser welding is used, there are more benefit compared to conventional MIG process. Fillet welds has five essential parts namely, face, root, toe, throat and leg length (Sasayama et al., 1955). This process has many parameters that can affect it. Hybrid laser arc welding is required to find the effect of welding conditions on the weld profile and mechanical properties.

Effect of Parameter on Weld Profile

New parameters have been defined due to the combination of laser and arc sources. They include leading and trailing, laser arc power ratio, laser arc separation distance and the work and travel angles of both sources independently. Butt welds configuration of hybrid welding is commonly used in most research work.

Configuration of Laser-Arc

Leading laser-arc welds exhibits a wider bead and less penetration in hybrid welding than leading arc-laser welds ("Qualification and approval of hybrid laser-arc welding in shipbuilding", 2006; Qin et al., 2007). In leading, the laser preheats the base plate thereby improving the weld quality and wettability ("Qualification and approval of hybrid laser-arc welding in shipbuilding", 2006).

Interaction of Laser-Arc

Three major factors are important in laser-arc interactions. They are heat input effect, laser plasma effect and arc rooting effect. In hybrid laser-arc welding, it was concluded that for a given arc power, at a particular laser power density weld bead humping was prevented. This was due to the laser heat source which causes more time for capillary instability to form a hump in the weld bead. Furthermore, hybrid laser-arc welds showed less bead humping than (GMAW). Toe angles were larger in hybrid laser-arc welding. There was a conclusion from the author that toe angle increases as the laser power increases but reduces humping (Choi el al., 2006). Also, an increase in wire feed speed, travel speed and arc power increases humping. But for CO_2 laser setup no plasma shielding effect occurs in either. In return, the uses of optimum shielding gases are commonly used. In CO_2 laser setup, laser power increment leads to more material vaporization which enhances conduction of the arc plasma. This is because of difference in wavelength. The weld profile is also affected by the mode of metal transfer (Abe and Hayashi, 2001). The plasma induced at the keyhole exit in hybrid laser welding stabilizes the arc but the effect becomes less efficient at higher speed. This makes it to be unstable (El Rayes, 2004).

Weld Bead Width

An increase in arc power increases the weld bead (Qin et al., 2007; El Rayes, 2004; Gao et al., 2008). In several studies, with non-synergy power sources in which the WFS and the current could be changed independently, the WFS and current were kept constant. The power of the arc was varied by altering the voltage. Apart from heat input variation, the arc length is also affected thereby changing the arc profile, which increases the wetted area. Laser power increment increases the width of the bead due to molten material increment. This can be achieved at a constant arc power (Qin et al., 2007; El

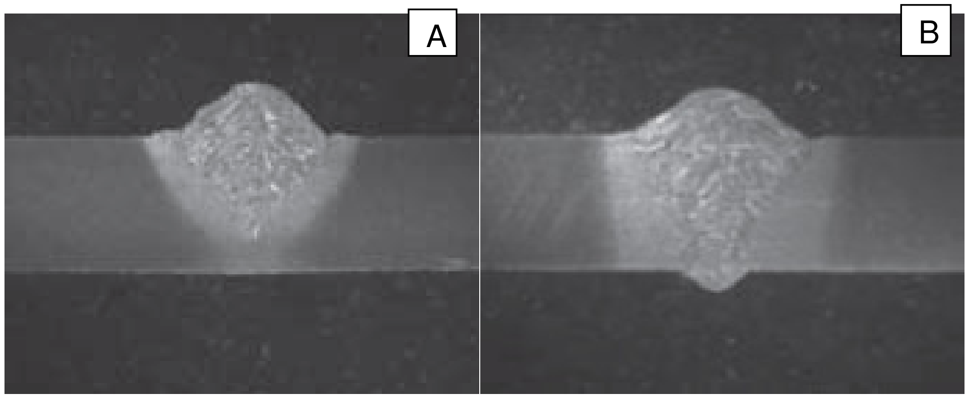

Figure 2 Effects of laser power (A 4kW, B 6kW) on weld profile

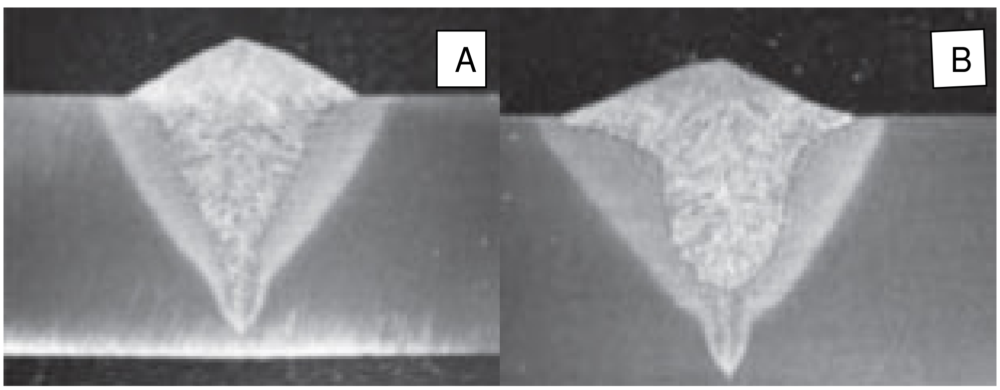

Figure 3 Effects of separating distance (A 4 mm, B 6 mm) on weld profile

Rayes, 2004). It was shown that from fitted linear relationship between heat input and weld area; heat input due to arc component (varying arc power by WFS changing in a synergy power source) in most conditions, the weld profile is controlled by the arc power and depth of penetration by laser energy. But this will vary with the ratio of arc energy and laser energy (Roepke and Liu, 2009). In hybrid welding, in certain conditions only, the effect of the current waveform shows that continuous current waveform increases the weld bead width (has higher width) when compared to pulse current waveform (Campana et al., 2007). In (DC) mode, the current and the arc power is greater than pulse mode average power which in turn in DC mode gives a higher heat input. However a better quality and more stable process are generally achieved in pulse current. With an increase in laser power, it was observed that there is an increase in the lower partial penetration width of the weld (Abe and Hayashi, 2001). This would also be dependent on the material properties and power density.

Weld Penetration

Laser power increment increases penetration (El Rayes, 2004; Processing Technology). Two distinct shapes in hybrid laser-arc welding of butt joint configuration were also observed by some researchers (Gao et al., 2006). Welds with different penetration depths are shown in Figure 2. In situations like this, the power ratio plays a vital role (Roepke and Liu, 2009; Roepke et al., 2010). It is observed that penetration is also a function of current which indicates that it is dependent on the arc power (Camilleri, 2012; Rethmeier et al., 2009). It can be seen that not only the laser and arc powers that affects the penetration but also, the laser power density, arc pressure and the specific process energy (Rethmeier et al., 2009).

Separation Distance

It was reported in previous work that hybrid welds tends to lack fusion at larger laser-arc separation distance and the generation and maintenance of the keyhole was made easier when the two sources were brought close (Abe and Hayashi, 2001). Total depth of penetration and weld bead is maximised when the separation distances of the two sources are decreased but its bead reinforcement is decreased. As shown in figure 3a. This is because both processes interact more. This is due to the fact that the MIG deposits the wire behind the laser and the laser does not affect the bead shape in a large extent.

Previous studies have shown the effect of the separation distance between the sources on the melting energy. It was concluded that at a separation distance greater than 4 mm, with a CO_2 laser, the melting relies on the preheating mechanism. While the interaction of the plasma on the arc, determines the melting at a separation distance of less than 4 mm (Gao et al., 2006). In Nd:YAG and CO_2 lasers, 2-4 mm is the optimum separating distance (Campana et al., 2007).

Laser Angle

From previous research work, there is an increase in the ratio of melted material at the back side of a t-joint fillet when the laser angle is varied from 45^0 to 25^0. In general, this in turn shows that a reduction in laser angle gives more material deposition at the back of a t-joint fillet weld (Camilleri, 2012).

Torch Angles

It was concluded that the depth of penetration in butt welding configurations was independent on the torch travel angle (Choi el al., 2006).

Defects in Hybrid Welds

Porosity and Cracks

Porosity and cracks was seen to be significantly reduced in fully penetrated welds as compared to partially penetrated welds. Partially penetrated welds were seen to be susceptible to cracks and porosity than fully penetrated welds. This is due to opening which allows all gases to escape. Also in partially penetrated welds porosity decreases with increasing speed. (Choi el al., 2006).

Fit-Up Tolerance

It was shown from previous research that one of the main issues in hybrid welds is fit-up tolerance. Some of the effect of misalignment and gap bridging ability in hybrid laser has been studied (Gerritsen et al., 2005b). A misalignment of maximum joint gap tolerance of 2 mm was achieved. Chamfers were seen to enhance fit-up tolerance in partially penetrated fillet configurations of hybrid laser welding (Caccese et al., 2006). It was stated that with the appropriate chamfer, with high enough arc parameters, the process is tolerable up to a gap of 3 mm. It was further suggested that the fit-up tolerance is dependent on the beam positioning and laser power (Caccese et al., 2006). Though these parameters have an effect on the allowable gap limit, other studies indicates that some other parameters like arc power influences the fit up tolerance. Furthermore, it was suggested to oscillate the laser beam perpendicular with the welding direction in larger gaps (Alam et al., 2010).

MECHANICAL PROPERTIES

Fatigue Properties of Hybrid Welds

Fatigue is a material failure which occurs due to cyclic stresses. This happens because of the formation and growth of crack. Fatigue cracks are often initiated at region of stress concentration in welded joints. In cyclic loading, it can be seen that fatigue is the primary mode of failure (Caccese et al., 2006). This is mostly dominant in the welded zones of components where defects such as undercuts are likely to occur. This is due to the presence of local stress due to weld geometry, existing flaws at the weld toe and tensile residual stress around and in the weld. It is very important that welding is done to a satisfactory standard and appropriate weld profile is achieved. This in turn reduces weld defects and also reduces the likelihood of fatigue crack initiation (Alam et al., 2010). There have been a lot of work reported on comparison of hybrid and GMAW welds.

It was shown that hybrid laser-arc has a better fatigue life than GMAW (conventional) in cruciform joints and eccentric fillet joints configurations. It was noted that there are two types of cracks, those at the weld bead surface due to ripple and those that originated from the weld toes (Caccese et al., 2006). The ripples at the weld surface acts as stress raisers which in turn decreases the fatigue performance. However, welds that fails from the bead surface shows greater fatigue performance than welds that fails from the toe (Alam et al., 2010).

There are contradicting findings on the other hand, in

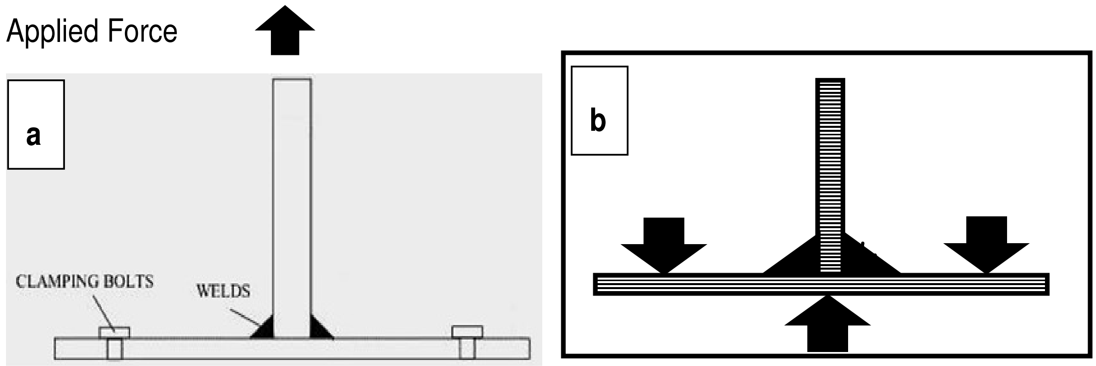

Figure 4 Principle of fatigue testing of fillet welds with two methods (a) pulling method (b) three point bend method.

Table 1 Composition of filler wire and steel plate

	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Ti	Zr
Filler	0.06	0.94	1.64	0.01	0.01	0.02	0.02	0.005	0.02	0.004	0.002
Plate	0.155	0.016	1.02	0.012	0.014	0.02	0.01	<0.005	0.02	0.02	

respect to toe size effect on fatigue life, it was concluded that fatigue life is only dependent on radius of the toe not the size (Caccese et al., 2006). It was further explained that in fatigue life, the toe size plays a vital role. And also, due to smaller toe throat, the lower toe radius is more detrimental to upper toe radius. This implies that increment in the toe size, increases the toe throat which enhances fatigue performance. On the other hand, fatigue life is improved by reducing the toe angles (Alam et al., 2010).

Method of Fatigue Testing of T-Shape Joints

There are several methods of fatigue testing which include pulling method and three point bending (Alam et al., 2011). In the pulling method as the name implies, the sample is secured at two points along its base, by means of passing bolts over two holes at a particular distance apart as shown in figure 4a. In the three point bend method, the forces are applied from the top of the sample and below. It is restrained at both top end, at base plate and compressed load is applied at the bottom. It is clearly described in figure 4b.

Experimental Method for Welding

Three welds were achieved with two processes. Hybrid horizontal and hybrid vertical were compared with a MIG reference weld. This was done to investigate the effect of welding parameters (laser power, WFS and positioning) on the weld profile and the fatigue life of the fillet weld.

MATERIALS

In this research work, S355 carbon steel with dimensions (750mm x 600mm x 300mm x 6mm) was used to make the fillet weld. Before the welding was done, the plates were grinded, tacked and cleaned with acetone to remove grease and contamination from the surface. The sample was the fixed to a jig and clamped. The composition of the filler wire and the plate is given in the table above.

Reference MIG Welding

The reference weld was done in S355 carbon steel plate using a MIG (GMAW) process. In this process, a single torch was attached to the robot, and at an angle of 45^0 to the work piece. A Lincoln power source (455M/STT) with a CTWD of 19 mm was used during the welding process. The shielding gas was BOC argon heavy (Argon mixture, 20% CO_2, 2% O_2) with a flow rate of 15 l/min. The wire diameter used was 1.2 mm (Supra MIG ultra, ISO 14341-A:G4Sil) as shown in table 1. This process was carried out horizontally. The GMAW welding process set up are shown in Figure 5.

Figure 5 Setup for MIG welding.

Figure 6 Setup for hybrid laser MIG welding.

Table 2 Hybrid laser welding parameters

Process	Hybrid (Laser/GMAW)
Welding robot	6 axes, Fanuc robot M710i
Power sources	8 kW laser type and Lincoln Power Wave (455M/STT)
Shielding gas	BOC Argo shield heavy (Argon78%, 20% CO_2, 2% O_2)
Gas flow rate	15 l/min
Wire diameter	1.2 mm
CTWD	15 mm
Wire type	Supra MIG ultra, ISO 14341-A:G4Sil
Beam Diameter	0.75mm
Leading Source	Laser (horizontal) MIG (vertical down)

Hybrid Laser-Arc Welding

The hybrid (vertical down) laser arc welding was done in two positions. The first one was vertical and the second was in a horizontal position which is shown in Figure 5B. Fibre laser of a maximum power of 8kW was used with the following optical setup. Optical fibre 300 µm, collimating lens of 125mm and focal lens of 300 mm. This gave a beam size of 0.75 mm. The table above shows the welding parameters used for both processes.

Vertical down Position of Hybrid Laser-Arc Welding

Before the commencement of the vertical welding, the t-joint plate was clamped to a jig. The laser was perpendicular to the work piece and the MIG torch was at an angle of 25^0 as shown in figure 7. After the initial study, the optimum configuration was determined. There was a separating distance of about 3 mm between the laser and the MIG torch. During the welding process, the MIG torch was below thereby leading the welding

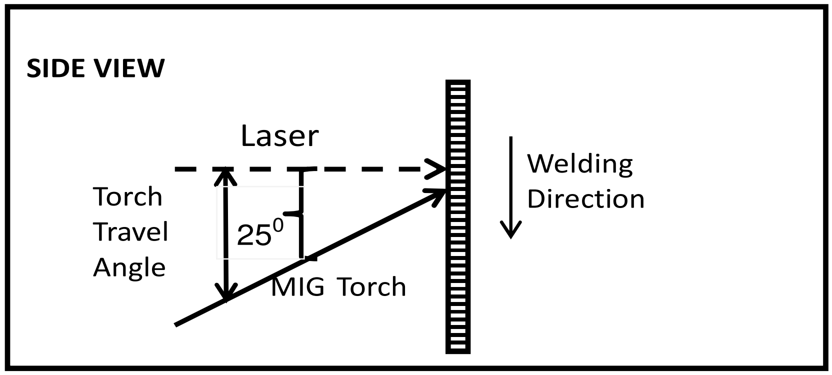

Figure 7 Schematic of position of laser and MIG in vertical down hybrid welding.

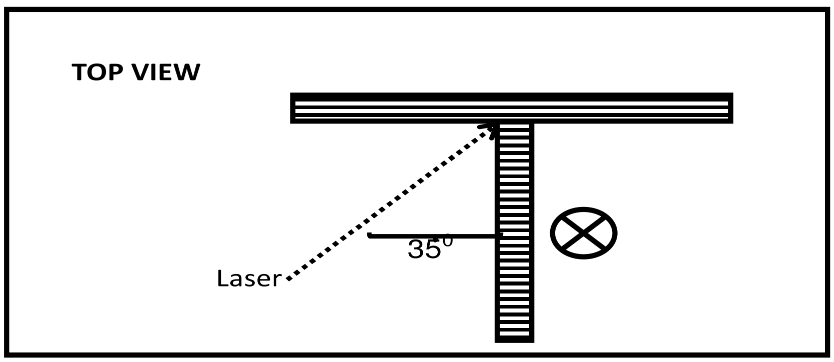

Figure 8 Vertical positions (top view) of t-joint hybrid laser arc welding.

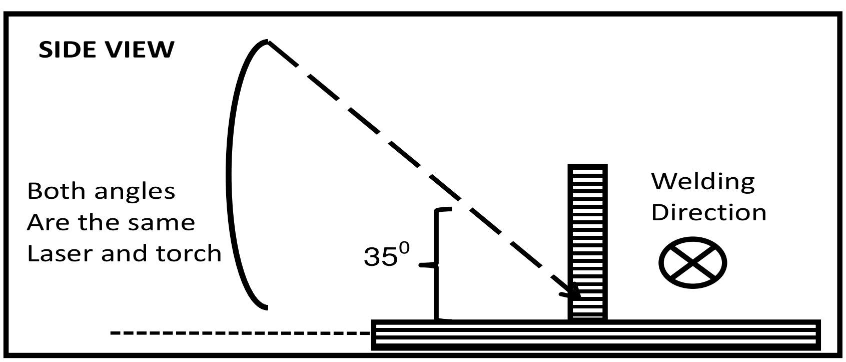

Figure 9 Schematic of position of MIG and laser in horizontal hybrid welding.

process. A schematic diagram of the process is shown in figure 7 above.

Horizontal Position of Hybrid Laser-Arc Welding

The t-joint plate was clamped to the jig before welding started. In this case, the both the MIG torch and the laser was at an angle of 35^0 to the t-joint The laser was in front of the MIG torch and they were both moving in the horizontal direction. A schematic diagram of the process is shown in figure 8.

Preparation of Sample for Macrographs

Samples from the t-joint welds were cut to a size of 30mm by 20mm and mounted in a cup using epoxy resin.

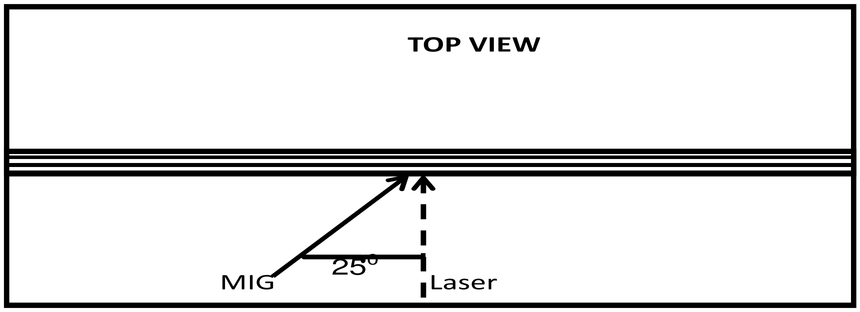

Figure 10 Horizontal position of t-joint hybrid laser arc welding.

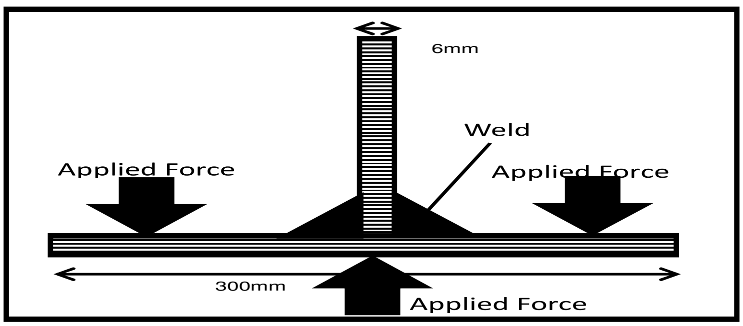

Figure 10 Fatigue test sample.

Welds were sectioned at half way into bits, mounted, polished, etched with 10% nital solution to review the weld profile. The macrographs were analysed under an optical microscope. The macrograph pictures of the samples were taken and recorded.

Experimental Method for Mechanical Testing

Fatigue Test Sample

Amongst all the welds, those with the optimum weld profile were selected from vertical and horizontal position and samples for fatigue test were extracted. Also, a reference MIG sample which had the same melts volume of fusion zone as hybrid weld. For statistical accuracy three specimens were extracted from each weld. To evaluate the yield strength, tensile test was carried out on the parent material and the fatigue test was carried out at 62% of the yield strength.
The sample dimension was 300mm x 50mm x 6mm.

Fatigue Test Procedure

Testing was performed in three-point bending (150mm span) with the fillet welded side in tension, using an R-ratio of 0.1 and a max stress of 62% of the parent plate yield strength. The maximum and minimum loads for each test, reported in the results section, table 4, were determined from the width and thickness of each specimen and the Rp0.2 value from the tensile test. Sinusoidal loading was used at a frequency of 5 Hz. Each fatigue test was completed upon specimen failure. The maximum test time or no failure conditions were assumed if no crack occurs after 1,296,000 cycles corresponding to 3days of testing. The tests were conducted in load control mode, in a 50kN capacity universal servo-hydraulic machine (FF125). The strain gauge outputs were logged automatically every 1800 seconds (9000 cycles).

RESULTS

These results shows distinctive features when several parameters are implemented. These parameters are discussed below each macrograph.

It can be seen from the macrograph on figure 12a and 12b that laser power does not affect the weld shape. Also, increase of laser power increases the depth of penetration but does not affect the reinforcement at the back of the weld in this case it only affects the depth of penetration.

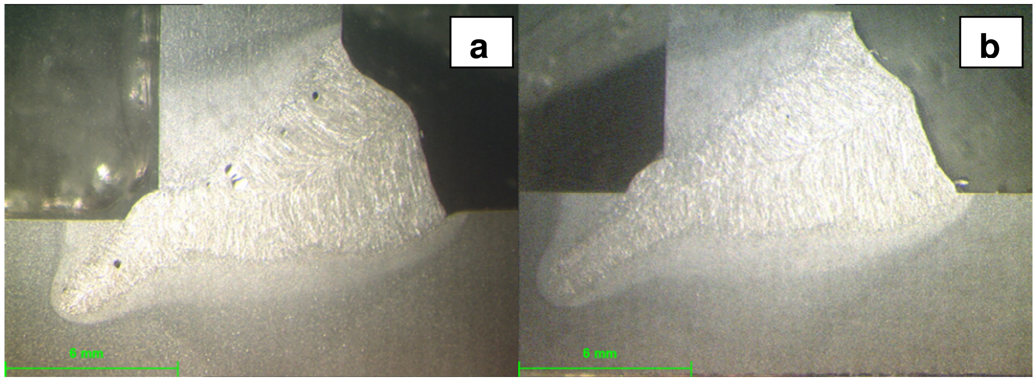

Figure 11 Effect of laser power on weld profile at constant WFS and travel speed. (a) horizontal, LP 6.5kW, WFS 12m/min and TS 1m/min (b) horizontal, LP 7kW, WFS 12m/min and TS 1m/min.

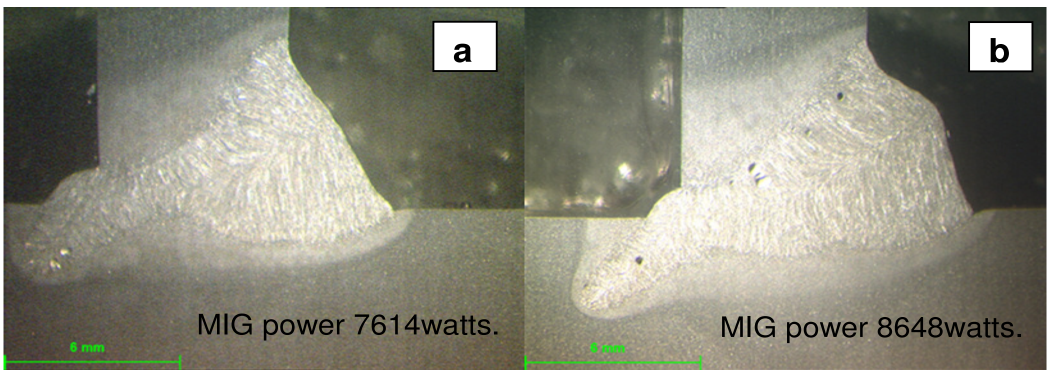

Figure 12 Effect of WFS on weld profile at constant laser power and travel speed. (a) horizontal, LP 6.5kW, WFS 10m/min and TS 1m/min (b) horizontal, LP 6.5kW, WFS 12m/min and TS 1m/min.

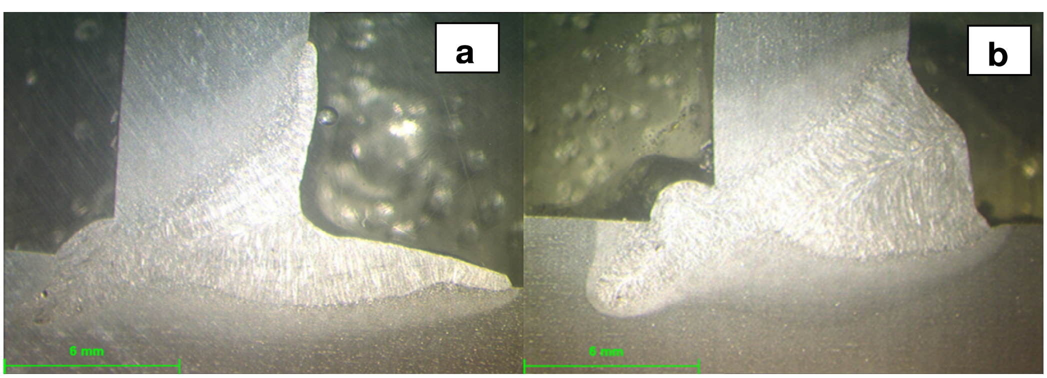

Figure 13 Effect of welding positioning on weld profile in hybrid laser at constant laser power, WFS and travel speed. (a) vertical, LP 7kW, WFS 12m/min and TS 1m/min (b) horizontal, LP 7kW, WFS 12m/min and TS 1m/min.

From figure 13a and 13b shows that an increase in WFS (wire feed speed) increases reinforcement at the front of the weld because of more metal deposition. It also affects the width of the weld on the narrowest point. Note that as the WFS increases the current also increases due to synergy of the MIG power source and more metal is deposited at the front. There is some visible porosity due to an optimized shielding condition.

In order to investigate the effect of welding parameters on weld profile of fully penetrated fillet welds series of

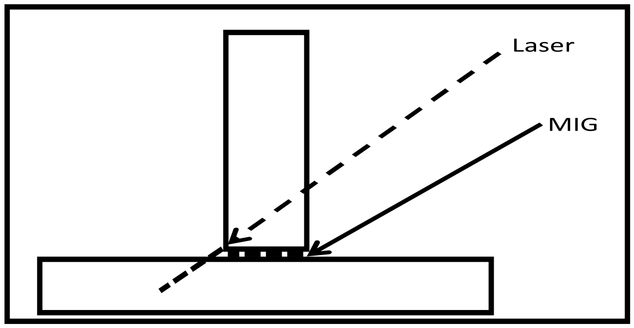

Figure 14 Diffusion of different weld profile.

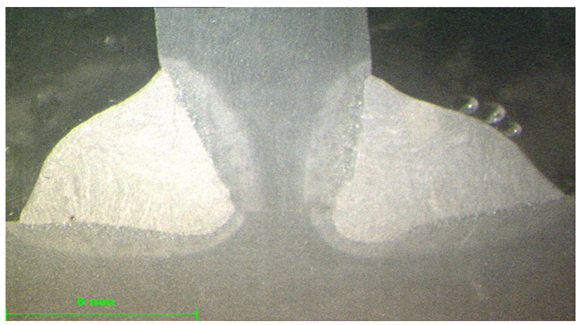

Figure 15 Shows reference MIG weld.

Table 3 shows the result of tensile test of parent metal.

Plate	Rp0.2 (MPa)	Rm (MPa)
	318	518

Table 4 results of fatigue test for MIG reference weld (MIG 1, 2 &3), laser hybrid horizontal (laser H1, H2 and H3) and laser hybrid vertical (laser V1, V2 and V3).

Welds	Width (mm)	Thickness (mm)	Max. Stress (MPa)	Max. Load (KN)	Min. Load (KN)	Cycles		Cracked Yes/no
						Total	Initiation	
MIG 1	58.26	6.78	197	2.34	0.23	1296000	-	no
MIG 2	61.68	6.68	197	2.41	0.24	1296000	316030	yes
MIG 3	56.73	6.65	197	2.20	0.22	1296000	467280	yes
Laser H1	54.58	6.66	197	2.12	0.21	769609	424530	yes
Laser H2	60.80	6.68	197	2.38	0.24	1296000	-	no
Laser H3	58.06	6.73	197	2.3	0.23	1015044	325030	yes
Laser V1	60.33	6.65	197	2.34	0.23	1296000	190040	yes
Laser V3	57.99	6.70	197	2.28	0.23	1296000	-	yes
Laser V3	59.54	6.61	197	2.27	0.23	1296000	865020	yes

hybrid laser weld with different (laser power, WFS) were carried out in two different position. Full details are given on the methodological section. Welding position affects the weld profile significantly. It can be seen from figure 14a and 14b that on vertical downwards, there is smooth transition and a very small reinforcement at the back. The horizontal looks like standard laser hybrid weld with a slightly convex weld bead. The horizontal has similar weld profile (top bead shape) to conventional MIG weld shown in figure 15 but the MIG weld has lesser penetration.

Figure 16 Photograph of oil film visible cracks (MIG 2) reference MIG weld 2.

Figure 17 Photograph of oil film visible crack (MIG 3) reference MIG weld 3.

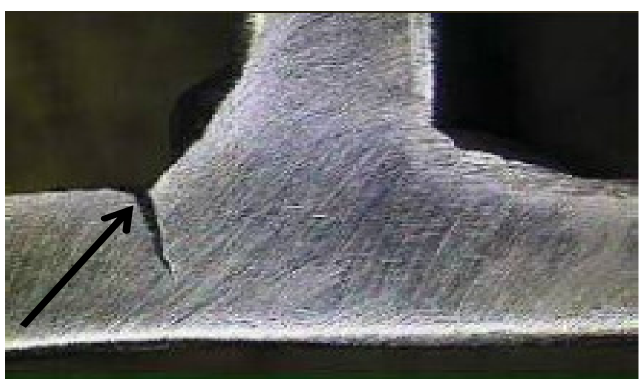

Figure 18 Macrograph of laser (H1) laser hybrid horizontal 1.

Figure 12 and 13 shows a distinctive line running through the weld bead. This line is there because the metal freezes quickly as the welding commences and the MIG tends to follow the line between the plates. This is illustrated in the diagram above.

MIG Reference Weld

From figure 16, this macrograph shows the significant features of a conventional MIG weld as compared with laser hybrid weld.

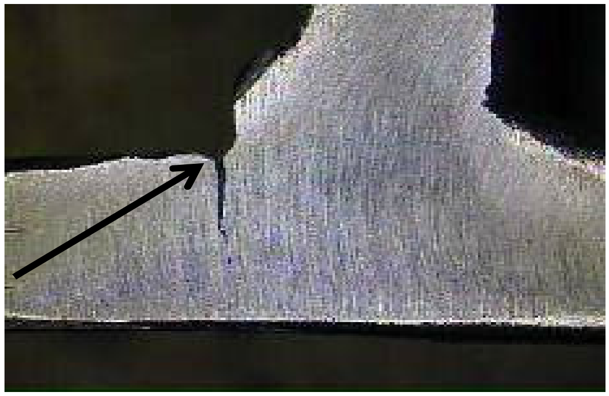

Figure 19 Macrograph of laser (H3) laser hybrid horizontal 3.

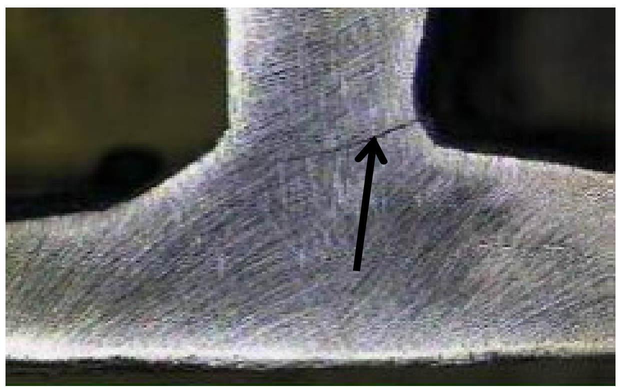

Figure 20 Macrograph of laser (V1) laser hybrid vertical 1.

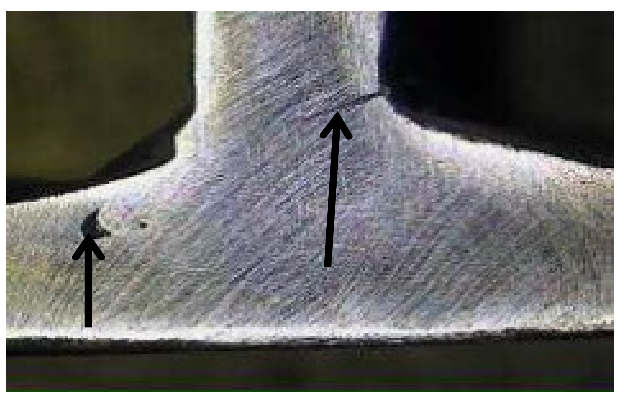

Figure 21 Macrograph of laser (V2) laser hybrid vertical 2.

Results of Tensile Test of Parent Metal

From the table above it can be clearly seen that the tensile strength of the parent metal is 318MPa. 62percent of the tensile strength was used in carrying out the fatigue testing which is 197MPa.

Results of Fatigue Test

The fatigue performance of several welds was tested. The welds from figure 16 to figure 22 were tested. The laser hybrid welds were carried out at the same welding conditions apart from positioning. They were compared

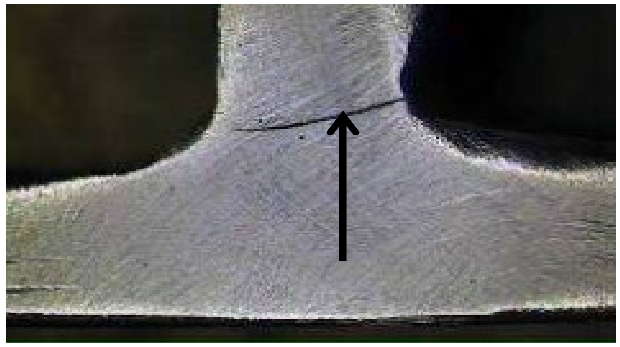

Figure 22 Macrograph of laser (V3) laser hybrid vertical 3.

with the reference MIG sample. The reference MIG sample has the same melt as the hybrid welds. In order to determine the load for the fatigue testing, the yield strength of the base metal was determined from the tensile test seen in table 3. The tensile strength is 318MPa. For the fatigue test, 62percent of the tensile test result was used.

From table 4 result, It can be seen that three samples were tested from each piece. One sample from each set completely failed fatally. It can also be seen that MIG 1 and laser H2 appears to have no cracks after the completion of 1296000cycles. All the others at certain numbers of cycles had a crack initiated. Laser H1 and laser H3 could not complete 1296000 cycles before it failed completely. The samples failed randomly which seems to be independent of the welding profile.

Photograph of Fatigue Test Sample

Figure 17 (MIG 2) and figure 18 (MIG 3), there was no crack visible on specimen edges but with the application of oil film crack is visible in weld toe in the centre of the specimen which is shown by the arrows.

Micrograph of Fatigue Test Sample

From the macrograph on figure 19, 20, 21, 22 and 23, it can be clearly seen that the fatigue failures occurred at the weld toe which is shown by the arrows. Figure 21 also has porosity at the weld.

DISUSSIONS

Effect of Welding Parameters on Weld Bead

The effect of laser power shown in figure 12a and 12b indicates that it has no effect at the back of the weld reinforcement. Most of the laser power was used to penetrate the base metal therefore it did not contribute to the reinforcement at the back. This is due to the laser angle applied to this configuration. At this angle most metal have been locked by partial penetration in the base plate and the liquid metal cannot be transported by the laser. The reinforcement could increase if the metal width increases. It is likely at a shallow angle, it is believed that the ability of the laser to redistribute the metal will be higher. Also at shallow angle, it is believed that the reinforcement will be higher at higher power. This is beneficial from the process tolerance from point of view. If there is small change in power the reinforcement and weld shape are not affected. However the partial penetration of weld is prone to porosity.

There was a similar observation for WFS. With the increment of the WFS the reinforcement at the back was not affected only the front was and the current also increases. The reason for the partial penetration of the reinforcement at the back is due to the angle of the laser and effect of locking of the material on the base plate.

Effect of Positioning

The effect of positioning is shown in figure 14a and 14b has a big effect on the weld profile. Note that both welds were achieved at exactly the same welding parameters. The horizontal weld bead is more convex because of the fast solidification. As the MIG torch and the laser combines to weld the metal at relatively fast speed, the metal solidifies immediately. There is no flow of the metal towards the toe. Whereas in vertical down position, the filler metal is deposited by the MIG and the parent metal is melted by the laser. Both heat sources flow with the direction of gravity. The difference is probably due to the fact that the deposited metal flows towards the heat sources by gravity force. This increases the temperature of the fusion because it extends the time of interaction between the heat source and the molten metal. The molten metal has higher temperature hence better wettability. Due to the downward acceleration it is spread uniformly resulting in nice and smooth weld profile. The electromagnetic force of MIG actually contributes to this spreading force.

It was actually possible to achieve good quality fully penetrated fillet welds with both welding positions. The same weld joint with four times production increment as compared to MIG is achievable.

Reference MIG Weld

It can be clearly seen from the micrograph of the reference MIG weld (figure 15) that the weld profile shows an incomplete penetration and it was carried out from both sides.

SUMMARY

- It is possible to get fully penetrated welds from horizontal and vertical position.
- Horizontal and vertical hybrid laser welds profiles are satisfactory.
- Productivity increases by 4 times when compared with conventional MIG weld.
- The laser power, wire feed speed and angle of the laser are key factors in the weld bead shape. The laser angle, determines the reinforcement at the other side of the weld.

The result of the fatigue test is discussed below.

Fatigue Test Discussion

Results were random which indicates that the weld profile is the main factor which determines crack initiation and fatigue life. This confirms that in the initiation of cracks in the toe of the weld. It is also confirmed in the theory of the literature. Despite the fact that the fatigue life of hybrid laser welding is not worse than MIG, the optimisation of weld profile particularly the toe transition would be desirable.

CONCLUSION

- Hybrid laser welding is capable of fully penetrating fillet weld from one side.
- Hybrid laser welding speed is four times faster than conventional MIG welding process.
- Fatigue failure does not depend on the weld process it depends on the weld profile

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