# Challenges of Hybrid Laser Arc Welding (HLAW): A Review

[1]S. Datta, [2]S. S. Mahapatra
[1]Assistant Professor, [2]Professor
Department of Mechanical Engineering, National Institute of Technology (NIT), Rourkeia-769008

**ABSTRACT**

HLAW combines best attributes of laser welding with those of conventional arc welding. Research related to this area is in fancy stage. Understanding of process phenomena, appropriate selection and precise control of process parameters may yield favorable high quality weld with respect to bead geometry, mechanical-metallurgical characteristics of the weld and HAZ. Apart from process modeling, simulation and parametric optimization, thermal aspects of this technique including interference of two different heat sources affecting weld quality, phase change and solidification phenomena are also important which need to be investigated thoroughly. The paper highlights challenges of Hybrid Laser Arc Welding (HLAW); prior state of art and future scope of work.

## INTRODUCTION

To cope up with gradually increasing customer demand and recent world economic trends, the fabrication world faces significant challenges for continuous improvement of quality as well as productivity. For successful survival in this competitive market, the companies are being encouraged to embrace new, state-of-art technologies, such as hybrid laser arc welding (HLAW) because it has the potential for offering the benefits of fast, high quality welds, resulting in high demand. Laser hybrid welding combines the positive aspects of both laser and conventional arc welding (MIG/MAG/GMAW/TIG) technology in order to meet increased demand in manufacturing and fabrication industries for high quality product in an economic cost. The widespread application areas of HLAW include shipbuilding, automotive, steelwork, construction, transportation, pipelines, vessels and infrastructure. With its farter welding speed and low heat input, HLAW reduces panel distortion and its resultant post weld repair costs. Both flat and sandwich panel construction get benefit greatly from this technology. HLAW reliably welds higher strength steels, alloying the use of thinner construction elements to reduce overall weight. Reduced wire usage further adds to weight reduction. Low heat input reduces distortion and improves the accumulative error of fit-up for assembly in shipyard applications. HLAW provides much faster welding speeds than SAW or GMAW, eliminating production bottlenecks. In addition to the benefits that HLAW brings to panel and profile welding, the deeper weld penetration facilitates single-pass welding and reduces weld joint volume requirements, providing substantial cost reduction. HLAW creates a longer cooling cycle, which controls levels of martensite in high-strength steel pipe, thereby reducing the risk of hydrogen cracking and embitterment. Moreover, it provides distortion (defect) free uniform weld resulting higher finished weld quality.

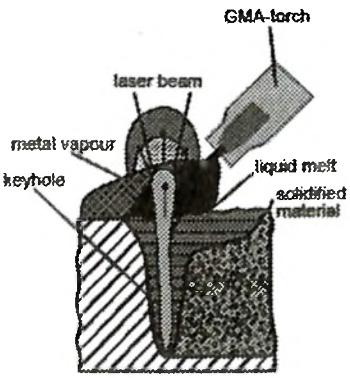
Due to these remarkable advantages, previous researchers have been found attracted in this encouraging field; however, it has been found that literature is not rich enough in this context. Work is still being carried out and results thereof being reported which clearly indicates that the scope of work in this particular field is vast and bright. It is significantly important as well. In order to obtain high quality of the welded joint by HLAW, it is felt necessary to gather in-depth understanding of the entire process behavior of HLAW. The effect of various process control parameters for both laser welding and conventional arc welding on different quality indices of the weld needs to be studied critically. Because these parameters are expected to interfere each other and their cumulative interaction effect may determine the extent of weld quality. The adjustment of the controllable factors coming from two different welding setup seem to be a difficult task in order to obtain favorable quality of the weldment. The relative distance between two different heat sources is another important criterion in this investigation.

It is known that several features influence weld quality: bead geometry; weld chemistry, mechanical properties and metallurgical characteristics of the weld metal as well as HAZ. Various quality indices can be defined and measured in a quantitative basis, which in term dictates weld quality, when they are accumulated to determine the overall quality index. Therefore, achieving an optimal weld of high quality seems to be a multi-criteria optimization problem in HLAW. Selection of optimal process environment in HLAW is nothing but a multi-attribute decision making problem, which needs to be carried out. Moreover, development of mathematical models and their experimental validation highlighting this dual hybrid welding technology have been found another aspect for study and analysis.

In addition to this, apart from process modeling, simulation and parametric optimization precise knowledge on thermal aspects of this dual beam hybrid welding is highly required prior to apply this technology in practical field. Few considerations have so far been reported earlier in this viewpoint. Mathematical models of individual heat sources, their interaction when combined during HLAW and how they influence weld quality, cooling cycle, phase change and solidification phenomena are other important aspects for research.

## PRIOR STATE OF ART

Laser-TIG hybrid welding was first presented by Prof. Steen and his co-workers at Liverpool University in 1970. In comparison to conventional welding technologies, the laser arc hybrid welding has its own particular advantages: (a) high efficiency and economy, (b) deep weld penetration and stable welding arc, (c) high gap bridging capacities, permissible tolerances and welding speed and (d) improvement in weld appearance and bead geometry by adjusting the ratios of these two heat sources. In recent time a number of variations of HLAW exist. Most common are the combination of GMAW (MIG/MAG), GTAW (TIG) or plasma with either the $CO_2$ or Nd: YAG laser welding. For heavy section welding traditional $CO_2$ laser has been used because of the desired power levels it is available in. But with regard to flexibility the Nd: YAG laser is a better choice as light can be transported by fibers that greatly influences the flexibility. Nowadays, HLAW is widely applied in various areas like shipbuilding, automotive, steelwork, construction, transportation, pipelines, vessels and infrastructure.



Schematic of the laser-arc hybrid welding process (Laser +GMAW)

In laser arc hybrid welding, heat and molten filler material are transferred to the welding zone by the MIG/MAG process in order to enhance the action of the deep penetration welding laser beam. In LAHW, cumulative interference of laser beam and arc column creates and pushes a common molten weld pool along the weld pass. The process should be controlled precisely in such a way that the MIG/MAG part provides the appropriate amount of molten filler material to bridge the gap generating a vapor capillary within the molten pool to ensure that the desired welding depth can be maintained. The combined hybrid process increases the welding speed above the sum of the single speeds and results an improved regularity and uniformity of the weld bead.

The advantages that LAHW offers are:

a) Increased penetration depth
b) Increase in welding speed
c) Substantial reduction in heat input
d) Improvement in tolerance to poor fit-up
e) Reduction in equipment cost due to usage of laser of low power
f) Better energy coupling
g) Precise control of seam width
h) Control of metallurgical features of the weld through addition of filler wire
i) Less material hardening
j) Improvement in process reliability
k) Higher electrical efficiency due to reduction in power consumption

Intensive research has been performed by previous researchers on different aspects of both laser welding as well as arc welding GMAW/TIG. But the complex behavior of this hybrid welding technology due to interaction of two different heat sources is still completely not yet known. Each technology has its own controllable parameters. During operation of HLAW, two sets of parameters (with different domains) coming from different welding setup superimpose and probably interact in a complicated manner which in tern influence the entire process behavior as well as process responses. Precise understanding and clear knowledge is essential regarding the cumulative effect of process parameters on bead geometry, weld chemistry and mechanical-metallurgical properties of the weld in order to select appropriate process condition to yield satisfactory quality of the weld. However, it is to be noted that the process parameters cannot necessarily be directly inferred from separate processes. Their combined effect needs in-depth investigations and analyses. Moreover, HLAW seems to be a complex process associated with a number of process variables when compared to the individual welding processes. The additional parameters include:

a) Distance between laser spot and MIG/MAG wire

b) Ratio between laser beam and MIG/MAG power

c) MIG/MAG leading or following

d) Angles of MIG/MAG torch and laser beam

Role-played by the aforesaid parameters in combination with other conventional process parameters, their cumulative effect or interactions add complexity in the process phenomena of HLAW.

Ono et al. (2002) successfully applied laser arc (MAG) hybrid welding in order to produce lap weld of zinc-coated steel sheets without causing blowholes. The welding speed of LAHW was found nearly equivalent to that of laser (YAG) welding. The authors concluded that LAHW produces high-quality lap joints and is ideal for assembly welding of automotive parts.

Chen et al. (2003) investigated the behavior of hybrid source i.e. $CO_2$ laser in combination with TIG arc. Assuming an energy model the temperature field as well as weld shape was determined. The heat transfer characteristics of the hybrid heat source to the parent metal and its combined effect to influence bead geometry were also analyzed. The authors finally obtained the critical energy that matched to introduce the enhancement effect of $CO_2$ laser-TIG arc hybrid welding.

Rayes et al. (May 2004) applied GMAW-$CO_2$ laser on the surface of a 316L austenitic stainless steel work material. In their study, arc and laser power were varied to examine their influence on various parameters of bead geometry. It was reported that arc powers, the mode of metal transfer impose predominant effect on bead width, arc and laser beam penetration and bead reinforcement.

Orozco et al. (2004) highlighted on development and validation of an automated large scale laser GMAW assisted welding procedure that can be applied in practice in order to fabricate high-precision lightweight structural shapes for shipbuilding and other industries. The developed Process Control System (PCS) was found excellent because it utilized weld quality attributes as process variables. The proposed system integrated those quality features with traditional process parameters like laser power, wire feed, GMAW voltage and active seam tracking. It was reported that this PCS had sufficient bandwidth and response time to achieve high welding speeds.

Petring and Fuhrmann (2004) reported that the integrated hybrid-welding nozzle of Fraunhofer ILT reliably avoided air entrainment into the interaction zone, ensured proper propagation and coupling of laser and arc and enabled the most compact and slender welding head design.

Choi et al. (August 2006) showed that the heat input from a defocused laser beam applied in front of a GMAW pool suppressed formation of weld bead hump defects and allowed higher traverse speed.

Casalino (2007) investigated on hybrid MIG-$CO_2$ laser bead-on-plate welding of 3 mm 5005 Al-Mg alloy. Based on full factorial design of experiment (DOE) and exploration of a regression model, the author estimated the main as well as interaction effects of process variables on penetration depth. The research outcome showed the significance of some important parameters and indicated the way to increase depth of penetration.

Katayama (2007) investigated on penetration and porosity prevention mechanism in YAG laser-MIG hybrid welding of aluminium alloy. It was reported that the distance between the laser spot and wire (arc) target positions was noted to have a significant impact upon the bead geometry, mainly penetration depth.

Campana et al. (2007) investigated on the stability condition of a hybrid laser $CO_2$-GMAW welding process by analyzing the influence of various process factors. Based on prepared I-butt joints of AISI 304 stainless steel sheet (8 mm thick), different bead geometry parameters were measured and analyzed to correlate them with the process control parameters by adopting statistical approaches.

Wang et al. (2006) reported the research outcome on laser-MIG arc hybrid welding of aluminium alloy A5052. Comparison was made on melting characteristics between YAG laser and diode laser.

Kim et al. (May 2008) optimized shielding gas composition and laser-arc interspacing distance for disk laser-GMA hybrid welding. It was reported that (80% Ar-20% $CO_2$) should be the appropriate composition of shielding gas mixture whereas 2 mm be the optimal interspacing distance to produce favorable bead-on-plate weld.

Campana, et al. (2008) investigated on some aspects of computational fluid dynamics and gas dilution into the molten weld pool of hybrid laser-MIG weld of aluminium alloys.

## CONCLUSION AND FUTURE SCOPE

The forgoing section highlights the latest work being carried out in the present field and the present state-of-art related to the subject. The literature review clearly indicates some international status in relation to the area of HLAW but at national level it is still infancy stage. Moreover, in literature no evidence has been found in the context of process modeling, simulation and optimization of this emerging welding technology. It seems necessary to derive mathematical models representing extent of correlation among different welding parameters and various weld quality indices. Graphical representation is therefore, required to visualize the direct and interactive effects of various process control parameters on different features of the weld quality. The degree/level of significance of the parameters on different weld quality characteristics seems to be other important aspects of study, which need to be carried out. In addition to this, selection of appropriate process environment by coupling laser beam with arc column i.e. two different welding technologies for achieving optimal quality weld is found very important in the present context. Moreover, there exists enough scope to develop mathematical formulation; numerical computation for simulation modeling and prediction of thermo-fluid phenomena, phase change, solidification behavior of this complicated hybrid-welding methodology.

Research in this encouraging field can be extended in the following directions:

1. To study the interactive effect of process parameters coming from two different welding setups on various quality attributes of the weldment as well as heat affected zone (HAZ).
2. In-depth study of process behavior highlighting correlation among various process parameters on bead geometry mechanical-metallurgical (microstructure and macrostructure) characteristics of the weld metal and HAZ.
3. Evaluation of the extent of influence of process control parameters on features of bead geometry, mechanical properties and metallur-gical characteristics of the HLA (hybrid laser arc) weld.
4. Mathematical modeling and simulation of process phenomena. To establish mathematical relationships reflecting direct and interaction effect of process factors on various process responses (outputs).
5. To determine the optimal process environment capable of producing high quality weld.
6. To solve multi-objective optimization problem in HLAW.
7. To investigate various aspects of weld chemistry: effects of process parameters on chemical composition of the weld metal as well as HAZ; correlation between weld chemistry as well as mechanical-metallurgical properties of the weldment.
8. Thermal modeling of HLAW phenomena: Interaction of two distinct heat source, simulation modeling by FDM/FEM/FLUENT; thermo-fluid phenomena.
9. To study the combinational effect of laser heat source and arc on phase change, solidification behavior and cooling cycle of HLAW.
10. Comparative study among HLAW, laser welding and conventional arc welding.

## LIST OF REFERENCES


1. Campana, G., Fortunato, A., Ascari, A., Tani, G., and Tomesani, L., 2007, "The influence of arc transfer mode in hybrid laser-mig welding", Journal of Materials Processing Technology, Vol. 191, pp. 111-113.
2. Wang, J., Takenaka, Y., Hongu, T. and Fujii, K., 2006, "Laser-MIG arc hybrid welding of aluminium alloy-comparison of melting characteristics between YAG laser and diode laser", Welding International, Vol. 21(1), pp. 32-38.
3. Campana, G., Ascari, A., Fortunato, A.,and Tani, G., 2008, "Hybrid Laser-MIG welding of aluminum alloys: the influence of shielding gases",

Applied Surface Science. (Article in press) doi: 10.1016/j.apsusc. 2008.07.169

4. Katayama, H., Uchiumi, S. and Mizutani, M., 2007, "Penetration and porosity prevention mechanism in YAG laser-MIG hybrid welding", Welding International, Vol. 21(1), pp. 25-31.

5. Choi, H. W., Farson, D. F. and Cho, M. H., August 2006, "Using a hybrid laser plus GMAW process for controlling the bead humping defect", Welding Journal, pp. 174s-179s.

6. Casalino, G., 2007, "Statistical analysis of MIG-laser CO2 hybrid welding of Al-Mg alloy", Journal of Materials Processing Technology, Vol. 191, pp. 106-110.

7. Tsubota, S., Ishide, T., Watanabe, M. and Akaba, T., April 2005, "Laser welding system for various 3-D welding-development of coaxial laser welding head", Mitsubishi Heavy Industries Ltd., Technical Review, Vol 42(2), pp. 1-5.

8. Defalco, J., October 2007, "Practical applications for hybrid laser welding", Welding Journal, pp. 47-51.

9. Petring, D. and Fuhrmann, C., 2004, "Recent progresses and innovative solutions for laser-arc hybrid welding", Proceedings of the 1st Pacific International Conference on application of lasers and optics 2004.

10. Chen, Y., Li, L., Fang, J. and Feng, X., 2003, "Numerical analysis of energy effect in laser-TIG hybrid welding", Journal of Materials Science and Technology, Vol. 19(Suppl. 1), pp. 23-26.

11. Orozco, N. J., Blomquist, P. A., Rudy, R. B. and Webber, S. R., 2004, Proceedings of the 23rd International Congress on applications of lasers and electro-optics 2004.

12. José Pablo Sánchez Sánchez and Jorge Vázquez Cancela, 2007, "Laser and hybrid laser-MIG welding for Boron 02-Docol 420 and Usibor 1500P-Dogal 420 lap joint", Master's thesis, Department of Applied Physics and Mechanical Engineering, Division of Manufacturing Systems Engineering, Luleå University of Technology.

13. Rayes, M. El, Walz, C. and Sepold, G., May 2004, "The influence of various hybrid welding parameters on bead geometry", Welding Journal, pp. 147s-153s.

14. Ono, M., Shinbo, Y., Yoshitake, A. and Ohmura, M., 2002, "Develop-ment of Laser-arc hybrid welding", NKK Technical Review, No. 86, pp. 8-12.

15. Kim, C.-H., Lim, H. S. and Kim, J. K., May 2008, "Position welding using disk laser-GMA hybrid welding", Journal of Achievements in materials and Manufacturing Engineering, Vol. 28(1), pp. 83-86.

16. Allen, C. M. 2007, "A brief review of recent developments in laser welding processes for ferritic pipe steels", Australasian Welding Journal, Vol. (52) (4th quarter), pp. 21-22.

17. Allen, C. M., Verhaeghe, G.,Hilton, P. A., Heason, C. P. and Prangnell, P. b., July 2006, "Laser and hybrid laser-MIG welding of 6.35 and 12.7mm thick aluminium aerospace alloy", Paper presented at International Conference on Aluminium Alloys (ICAA 10), Vancouver, 9-13 July 2006.

18. www.fronius.com