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IMPACT ANALYSIS OF THE HYBRID LASER ARC WELDING PARAMETERS OF STRUCTURAL STEELS – STATE OF THE ART

UTICAJA PARAMETARA REŽIMA HIBRIDNOG LASERSKOG ELEKTROLUČNOG ZAVARIVANJE KONSTRUKCIJSKIH ČELIKA – PREGLED STANJA

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Abstract

The effectiveness of the hybrid laser arc welding is based on the combination of two heat sources in a single welding process, resulting in welding process that is characterized with higher welding speed, increased productivity, deeper penetration, stable process, better gap bridging ability, less heat input to the welding material and high flexibility. The physical complexity of the process is a main disadvantage, i.e. an increased number of parameters that need to be synchronized and optimized in order to obtain a perfect weld. In this paper, based on the previous experimental research, a complete analysis of the primary hybrid laser arc welding parameters was performed, and general conclusions were drawn regarding their impact on the welding process stability, the weld shape and its mechanical characteristics. The introduction part contains a general analysis of previous research. In the second part, characteristics of the performed hybrid welds in structural steels and detailed analysis are presented. In the final part, general conclusions are made regarding the influence of the primary hybrid laser arc welding parameters on the structural steel.

Rezime

Efikasnost hibridnog zavarivanja na bazi laserskog zraka i električnog luka zasniva se na kombinaciji dva izvora toplote u jednom procesu zavarivanja, šta dovodi do procesom zavarivanja koji se odlikuje većom brzinom zavarivanja, povećanom produktivnošću i penetraciju, boljom sposobnošću premošćavanje zazora, stabilnim procesom, manji unos toplote u radni materijal i velika felksibilnost. Međutim, fizička složenost procesa je glavni nedostatak, odnosno povećan broj parametara koji bi treba da se sinhronizuju i optimizuju da bi se dobio kvalitetan zavareni spoj. U ovom radu, na osnovu dosadašnjih eksperimentalnih istraživanja, izvršena je kompletna analiza na primarnih parametara hibridnog laserskog elektrolučnog zavarivanje, i izvedeni su opšti zaključoci o njihovom uticaju na stabilnost procesa zavarivanja, oblik zavarenog spoja i njegove mehaničke karakteristike. Uvodni deo sadrži opštu analizu dosadašnjih istrastraživanja. U drugom delu su prikazane detaljne analize i karakteristike izvedenih hibridnih zavara u konstrukcijskih čelika, a u završnom delu se donose opšti zaključci o uticaju primarnih parametara hibridnog laserskog elektrolučnog zavarivanja konstrukcijskih čelika.

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1. Introduction

The conventional joining process Gas Metal Arc Welding – GMAW is widely used process for welding of structural steel in a number of engineering fields such as shipbuilding, civil construction, mining equipment and metallurgy [1]. Consequently, several innovations appear in this welding process that contributes for its improvement [2]. One of the improvements is automated hybrid laser arc welding, whereby combining the advantages of two different processes, Laser Beam Welding – LBW and semi-automatic welding processes such as Gas Metal Arc Welding – GMAW and Flux-Cored Arc Welding – FCAW represents an excellent substitute for conventional welding processes [17].

Hybrid Laser Arc Welding – HLAW combines the advantages of both welding processes, LBW and GMAW or FCAW, resulting in welding process that is characterized with high welding speed [4], low heat input, high penetration depth into the welding material, and the possibility of controlling the chemical composition of the weld bead [5]. According to Pekarska and Bunaziv [6, 7] HLAW gains increasing focus because it compensates the limitations of the individual LBW and GMAW processes, reduces the heat transfer out of the weld zone and increases the dimensional tolerances of the welding joints. Additionally, HLAW enables higher welding speeds [6], fewer numbers of welding passes, increased penetration depth [7], and narrow weld seam with a small heat affected zones and a stable welding process [8].

Although the hybrid laser arc welding process has numerous process advantages, the process has certain limitations too, such as: controlling large numbers of process welding parameters, requirement of accurate positioning and proper fit-up of the welding material, higher initial investment, and additional safety measures. Consequently, a precise study of all the parameters used in the hybrid welding is the basis for the stability and repeatability of the process and obtaining a weld with suitable mechanical and dimensional characteristics at the lowest possible operational cost.

Moreover, the values of the parameters that are ideal for each process separately are likely not to be optimal for successful welding with HLAW due to mutual influence.

Current research and experience have shown that, the parameters of the hybrid laser arc welding are not specified enough to replicate the conditions for a particular operation. Consequently, the user has to optimize the welding parameters before welding in order to get the best results. Generally, these parameters are dependent on the ratio between the two heat sources, which is calculated by dividing the laser power with the arc power [16, 17].

The flow chart [Figure 1] clearly shows, as with any other welding process, the capabilities of hybrid welding are essentially determined by appropriate selection of the system set-up and the parameter configuration.

Therefore, in this paper, a detailed analysis regarding the influence of the hybrid welding parameters for welding of construction steel is performed, such as: laser power, arc power, welding speed, the distance and set-up between both heat sources, laser focal positions, the angle of electrode, shielding gas composition and the gap configuration and edge preparation.

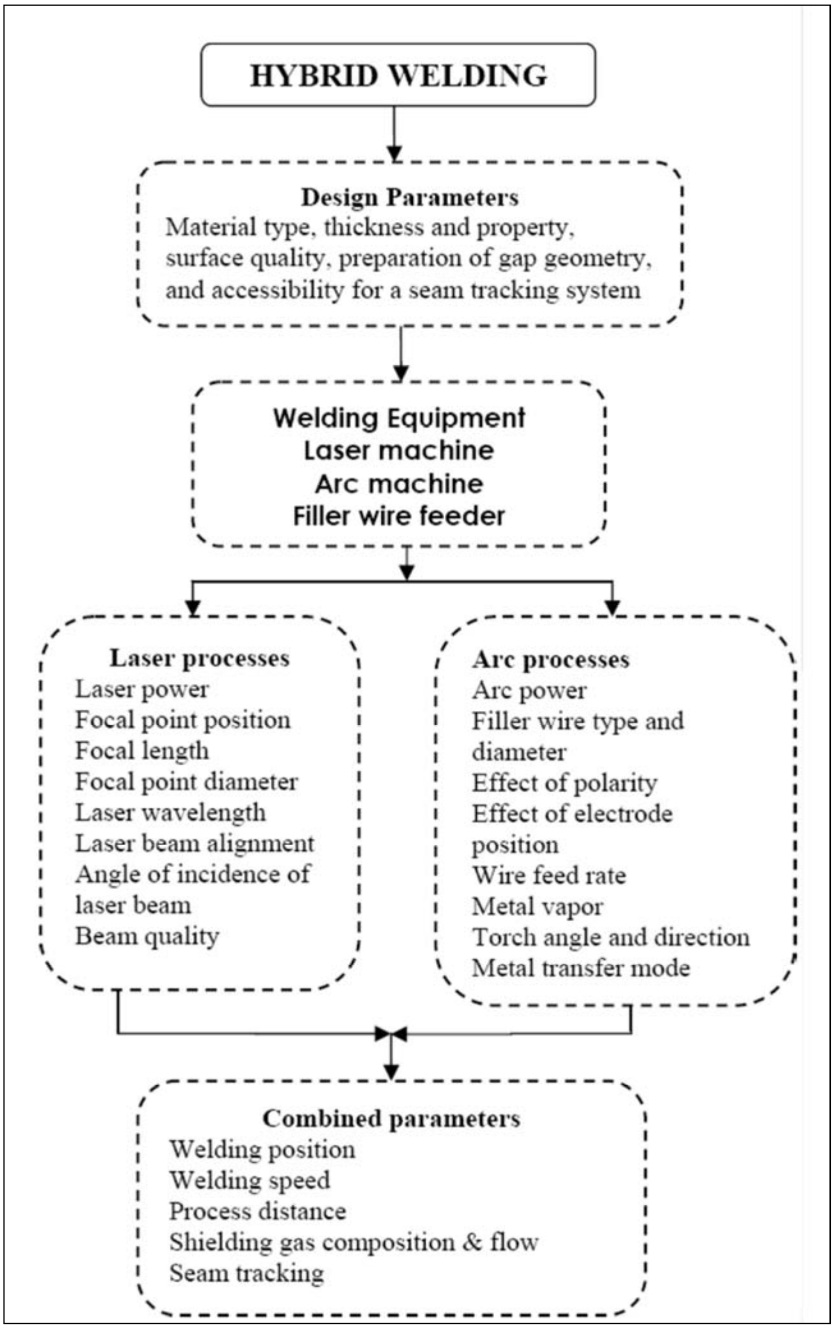


Figure 1. *Flow chart of process parameters in laser arc welding [12]*

Slika 1. *Dijagram toka parametara procesa pri laserskom elektrolučnom zavarivanju [12]*

2. Hybrid laser arc welding parameters

A detailed understanding of hybrid laser arc welding parameters is needed in order to understand their overall influence on the welding process. In HLAW, the laser power is the main heat source which determines the penetration depth, while the arc power influences the weld width and the weld gap fill [8, 20]. Hybrid laser arc welding has a higher melting efficiency compared to the individual LBW and GMAW welding processes based on weld cross-section area (Figure 2). Generally, the HLAW parameters are set up according to the type and thickness of the base material, the heat sources power, the joint geometry and the welding tolerances.

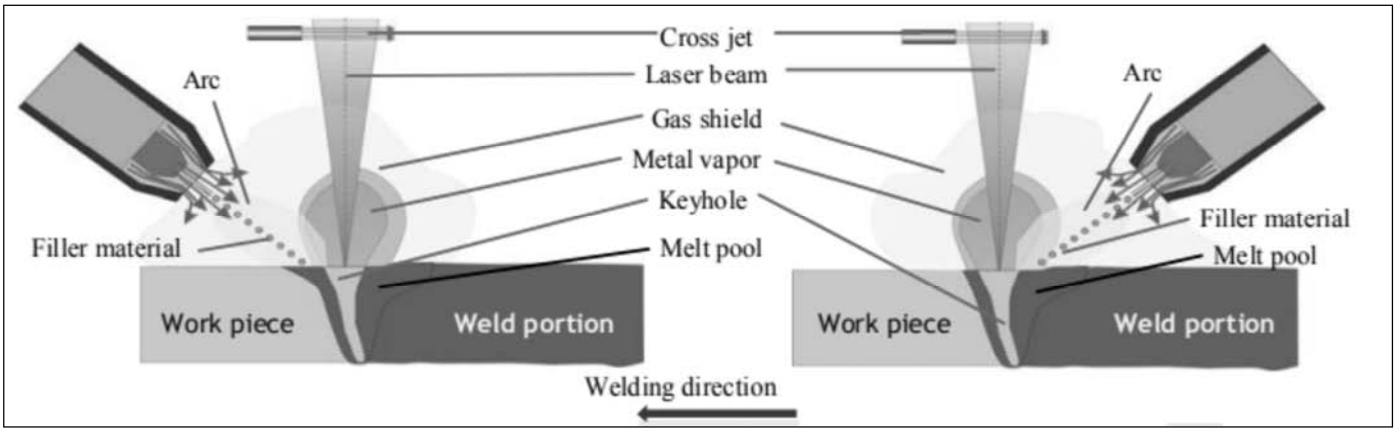


***Figure 2**. Schematic representation of laser hybrid welding with leading arc and leading laser arrangements [14]*

***Slika 2.** Šematski prikaz lasersko hibridnog zavarivanja sa vodećim električnim lukom i vodećim laserskim snopom [14]*

2.1 Laser type and power

The focused laser beam is one of the densest energy sources for welding. The output power P_L(W), the wavelength of the emitted light (λ) as well as the specific power output are the characteristics that should be taken into consideration for laser beam quality assessment [15].

The selection of the laser type is very important because it is the primary heat source that defines the efficiency of the whole process [13]. The total heat input in the workpiece material is a sum of laser beam as a primary heat source and the electric arc. This correlation is given in the equation:

$$Q_H = Q_L + Q_A = \frac{P_L\ x\ \eta_L\ x\ 60}{1000\ x\ V_t} + \frac{P_A\ x\ \eta_A\ x\ 60}{1000\ x\ V_t}$$

Where, P_L (kW) is the laser source power, P_A (kW) is the electric source power, V_t (mm/min) is the welding speed, while η_L and η_A are efficiency coefficients with a value of 0,7 for the laser beam and 0,8 for the electric arc [16].

Currently, the most often used high power lasers are the CO_2 lasers with continues-wave or solid state Nd:YAG lasers with pulsed operation. In addition to these, different types of solid state lasers such as Yb:YAG disc and Yb laser fiber are used nowadays which provide high output power and excellent laser beam quality (Table 1). The fifth type of laser recommended for welding is a high-power diode laser.

***Table 1.** Characteristics comparison of different types of lasers*

***Tabela 1.** Poređenje karakteristika različitih tipova lasera*

	CO_2 laser	Nd:YAG laser (lamp-pumped)	Nd:YAG laser (diode-pumped)	Disc laser	Fibre laser	Diode laser (fibre-coupled)
Lasing medium	Gas mixture	Crystalline rod	Crystalline rod	Crystalline disc	Doped fibre	Semiconductor
Emitted wavelength (µm)	10.6	1.06	1.06	1.03	1.07	0.808–0.98
Power efficiency (%)	10–15	1–3	10–30	10–20	20–30	35–55
Maximum output power (kW)	20	6	6	8	50	8
BPP at 4 kW (mm mrad)	4	25	12	2	0.35	44
M^2 at 4 kW	1.2	75	35	6	1.1	150
Fibre beam delivery	No	Yes	Yes	Yes	Yes	Yes
Typical fibre diameter at 4 kW (mm)	–	0.6	0.4	0.1–0.2	0.03–0.1	0.4
Mobility	low	low	low	low	high	high
Maintenance interval (h)	1000	500	10000	>25000	>30000	>25000

The output power and wavelength are the most important parameters for choosing the laser type. The penetration is directly proportional to the laser output power and therefore it represents the main parameter in the selection of the type of laser. Other parameters to consider when choosing the type of laser are welding speed, heat flux density, workpiece material and reflectivity, and joint geometry [15].

2.2 Relative positioning of the laser beam and the electric arc

The HLAW process can be oriented in two directions: arc leading or laser leading despite the fact that they act on the same point. The GMAW process can be positioned in front or behind of the travelling laser keyhole. If the GMAW process travels behind the laser beam, the HLAW process orientation is referred to as laser leading. If the GMAW process travels ahead of the laser, the HLAW process orientation is referred to as arc leading [3].

The selection of the orientation of the heat sources is based on multiple factors, such as; work piece material characteristics, the output power of the laser source and the electric arc [18]. The distance between the laser source and the arc is an important parameter to control the penetration in hybrid laser arc welding and normally is consisted of few millimetres value, separation distance is in the range of 0 to 5 mm [18]. Increasing the distance between the heat sources might result in loss of hybridization effects, i.e. to reduce the interaction between the laser beam and the electric arc [18]. When heat sources are placed in parallel or at a very short distance might lead to a problem of absorption of the laser energy by the electric arc, which partially blocks the laser beam resulting in less penetration [17, 27].

2.3 Focal positioning

Laser heat sources use a focusing system to focus the energy on a single point, thus increasing the heat flux. This is achieved using reflective or transmissive optics made of different materials depending on the wavelength. The distance to this focal point is called focal length and directly affects penetration (Table 2) [20, 21]. The focal point of the laser beam changes when it enters the weld pool. Furthermore, the convex shape of the weld face formed by the filler material affects the laser beam focus. According to the several experiments, the focus distance of hybrid welding using CO_2 laser is reduced by 0.7mm compared to an autogenously laser welding without filler material.

Table 2. *Power density at varying focal positioning and laser output power [21]*

Tabela 2. *Gustina snage pri promenljivom fokusnom pozicioniranju i izlaznoj snazi lasera [21]*

Defocused distance		Power density (kW/mm²)					
		-12 mm	-9 mm	-6 mm	-3 mm	0 mm	6 mm
Laser power	8 kW	4	8	16	47	113	14
	10 kW	5	10	20	59	141	18
	12 kW	7	11	24	71	169	22
	14 kW	8	13	28	83	197	25

2.4 Work angle of the electrode

The electrode to work angel is a parameter that affects the penetration of the weld provided by HLAW, this angle is related with the shielding gas flow and thus directly affecting the laser energy absorption [22]. Generally, the laser beam is directed normal to the welding material surface for better penetration. The angle of electrode is typically set around 45° – 65° from the welding material surface, which reduces the arc length, and the laser beam is focused on the welding pool [23]. However, during the welding of highly reflective materials the laser beam is tilted at an angle in order to avoid any damages of the laser head due to the reflected beam that must be different from the electrode's angle [24].

2.5 Shielding gas and flow rate

In order to protect the weld pool from surrounding atmosphere the shielding gases are mainly used. The use of shielding gases and their compositions also influence the arc characteristics, formation of weld profile, and mode of metal transfer. In HLAW the shielding gas has a fundamental role of stabilizing the arc, and in turn, the stability of the welding process, and the weld quality [9]. Generally, the shielding gas used in HLAW is mostly composed of an inert gas such as Argon (Ar) and Helium (He) [3], but, according to the material, laser type and arc parameters, carbon monoxide (CO) or carbon dioxide (CO_2) can also be used [26]. During hybrid laser arc welding with CO_2 laser, absorption of the laser energy by the laser induced plasma and reduction of the laser intensity that reaching the weld pool is often occurred, due to longer wavelength [19]. The use of high ionization potential shielding gas like helium reduces the effect of plasma absorption, therefore during hybrid laser arc welding with CO_2 laser, a mixture of argon, helium and CO_2 is used [19]. The use of helium ensures deeper penetration, the argon improves the arc stability, while a small percentage of oxygen less than 5% reduces the spatter formation and improves metal transfer during the welding process [3]. The mode of metal transfer is an influential parameter for stable and repeatable welding process, for hybrid laser arc welding pulsed/spray-arc is recommended in relation to short/globular-arc [25, 30].

In addition to shielding gas, the gas flow is also an important parameter of HLAW. In order to achieve the deepest penetration and the greatest efficiency, an optimal flow rate should be adjusted for different shielding gases. If the gas flowrate is too low, it cannot produce sufficient plasma suppression from the laser beam, while if it is too strong can produce turbulence on the weld pool surface reducing the protection of the weld pool [9].

2.6 Welding speed

One of the fundamental advantages of hybrid laser arc welding is the high welding speed and it is strictly related to the weld penetration. If we keep all the other parameters constant, the welding speed significantly influences the weld quality, the electric arc behavior, and the process stability [3]. The weld penetration and weld with are inversely affected by the welding speed [5]. The weld penetration increases when the welding speed decreases as a result of the higher heat input per unit length of weld [28]. The gap filling capability is improved at lower welding speeds, at constant filler wire feed rate [29]. The welding speed to filler wire feeding ratio is an important factor for the stability of the keyhole and the stability of the entire welding process. On the other hand, a too high welding speed leads to a fast heating and cooling cycle in the workpiece, which may result in metallurgical defects However, increasing the welding speed can effectively reduce the residual thermal stress concentration [10].

2.7 Wire feed rate

The crucial factor in avoiding a lack of deposited or increased filler material is the correct choice of wire feed rate. A higher wire feed rate allows a bigger cross-section geometry of the weld and helps to increase the welding speed [3]. Additionally, for an increased wire feed rate, a higher current is required in order to increase the rate of deposition and to maintain a constant arc length [20].

According to Guen [5], the shape of the bead is dependent on the deposed material, or the ratio between the welding speed and the wire feed rate. Consequently, the weld width and penetration are decreased with the increase of the welding speed, while the dimensions of the weld pool – width, length and depth are increasing with the increase of the wire feed rate.

2.8 The effects of Gas Metal Arc Welding Current, Voltage, and Polarity

HLAW brings challenges that are not common for GMAW mainly due to the high welding speeds. Consequently, the metal transfer mode is crucial to obtaining a stable and repeatable welding process. Therefore, spray transfer or pulsed GMAW are typically used instead of short-circuiting or globular transfer [3].

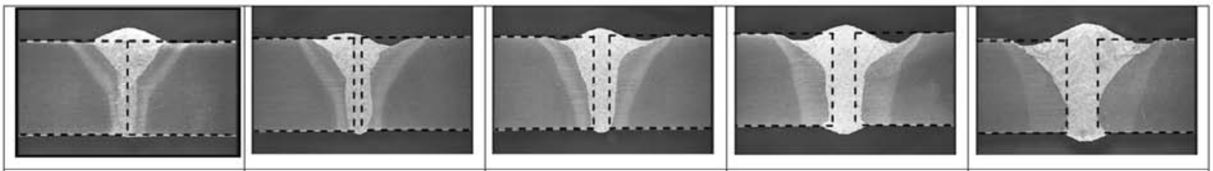
The effect of the electric arc voltage in HLAW is identical as in GMAW, i.e. arc voltage can be adjusted to increase or decrease the arc length. A longer arc length generally produces a wider melt width at the top surface of the weld and vice versa.

The type of the current and its polarity is a parameter that affects the process stability, it can be changed to affect the heat balance between the electrode and the work. The hybrid laser arc welding use direct current electrode positive polarity, resulting in good arc stability and low spatter generation.

2.9 Joint gap width and edge preparation

Compared to laser beam welding which can weld parts without visible defects with a gap up to 0.2-0.25 mm, HLAW can easily achieve acceptable welds with joint gaps of 1 mm. The main parameters which affect the deposition of the filler material to fill the joint gaps are the laser to arc energy ratio, laser arc distance, welding speed and the wire feed rate [26].

In HLAW the welding speed can be easily increased while welding parts with a joint gap up to 1mm, due to a smaller joint gap that simplifies the weld penetration as more filler material reaches the root of the joint [26]. On the other hand, an increase of the joint gap by more than 1 mm, requires a reduction of the welding speed and a proper selection of the other process parameters (Figure 3) [11].



a. Gap = 0 mm	b. Gap = 0.5 mm	c. Gap = 1.0 mm	d. Gap = 1.5 mm	e. Gap = 2.0 mm
P_{MIG} = 3.2 kW	P_{MIG} = 4.7 kW	P_{MIG} = 7.0 kW	P_{MIG} = 9.5 kW	P_{MIG} = 10.2 kW
U_{MIG} = 35 V	U_{MIG} = 36 V	U_{MIG} = 40 V	U_{MIG} = 42 V	U_{MIG} = 42 V
v_{weld} = 1.4 m/min	v_{weld} = 1.6 m/min	v_{weld} = 1.8 m/min	v_{weld} = 1.7 m/min	v_{weld} = 1.1 m/min
v_{wire} = 5 m/min	v_{wire} = 8 m/min	v_{wire} = 13 m/min	v_{wire} = 18 m/min	v_{wire} = 20 m/min

***Figure 3.** Cross-section of the weld performed with HLAW at different part gaps [11]*

***Slika 3.** Poprečni presek zavara izveden sa HLAW sa različitim zazorima kod delova [11]*

Additionally, HLAW requires proper edge preparation which mostly depends on the base material characteristics and its thickness. For hybrid welding of thin steel sheet metal with a thickness up to 8 mm no edge preparation is needed, whilst, for larger thicknesses, edge preparation is needed in accordance with the material thickness [31]. The edge preparations for HLAW are characterized by narrower angles, smaller gaps and higher roots compared to conventional arc welding [31].

3. Analysis of HLAW process parameters

Hybrid laser arc welding is suitable for joining materials with thicknesses in the range of 0.7-50 mm. According to Bunaziv [16], with a 16 kW disc laser, hybrid welding of 12 to 15 mm thick structural steel can be performed in a single pass.

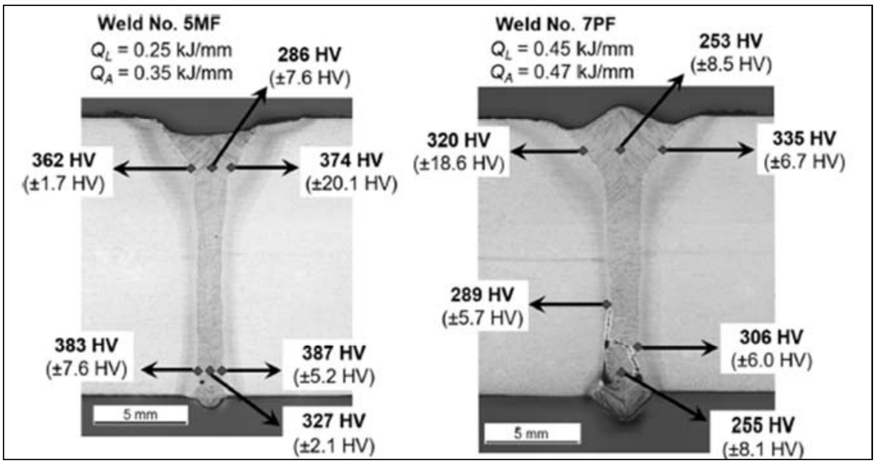


***Figure 4.** Cross-section of 15mm hybrid weld performed with a different output power of the heat sources [11]*

***Slika 4.** Poprečni presek hibridnog zavara od 15 mm izveden sa različitom izlaznom snagom izvora toplote [11]*

In both cases, a fine-grained structure appears in the upper area of the weld, which constitutes more than 60% of the weld, due to the influence of the filler material and the intense heat input from laser and arc sources. In the root, the weld microstructure is a mixture of bainite and martensite due to faster cooling rates. The weld with lower heat input 0,60kJ/mm, has higher hardness >325 HV in the weld and heat affected zone, that exceeds the limit values for acceptable quality (Figure 4) [11]. The mechanical characteristics and geometry of the weld are directly related to the position of the heat sources. According to Bunaziv, the laser leading process leads to insignificantly high heat input and welds with a conical shape, with increased tensile strength and decreased toughness.

The maximum weld penetration is achieved when the focal point is positioned below the material surface, in the focal point the laser beam diameter is the smallest and the energy density is the highest [21]. When the focal point has a negative value, the heat input in the work material is higher. On the other hand, a positive value causes insufficient weld penetration and increased volume in the upper part of the weld.

The weld penetration directly correlates to the angle of electrode. According to Ghazvinlool's results, an increased electrode angle corresponds with and increased weld penetration, which means that the root of the weld is directly exposed to the electric arc heat and vice versa (Figure 5).

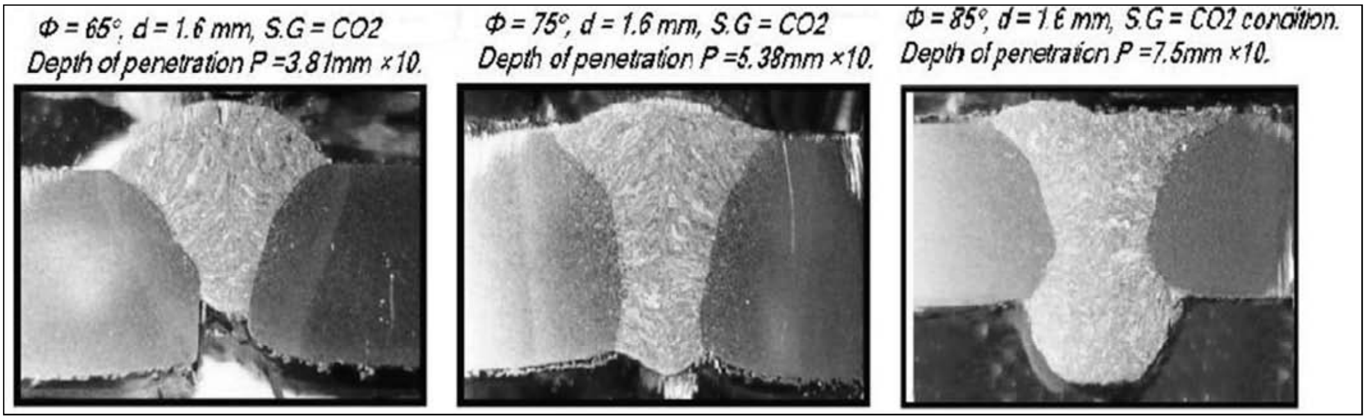


Figure 5. *Cross-section of hybrid weld performed with a different electrode angle [25]*

Slika 5. *Poprečni presek hibridnog zavara izvedenog sa različitim uglom elektrode [25]*

According to Kah [9], a surface hybrid weld has been made on 8mm thick structural steel using a 12kW CO_2 gas laser, in order to test the effects of the different ratios of an inert shielding gas of Argon (Ar) and Helium (He) (Figure 6). The results show that the laser penetration depth is significantly reduced by reducing the helium below 40%. Consequently, at least 50% of helium is required in the shielding gas to suppress the laser absorption while welding with CO_2 laser. Additionally, the composition of the shielding gas affects the optimal gas flow rate, with a shielding gas of at least 50% helium and a flow rate of 20 l/mm the best hybrid welding results can be achieved [27].

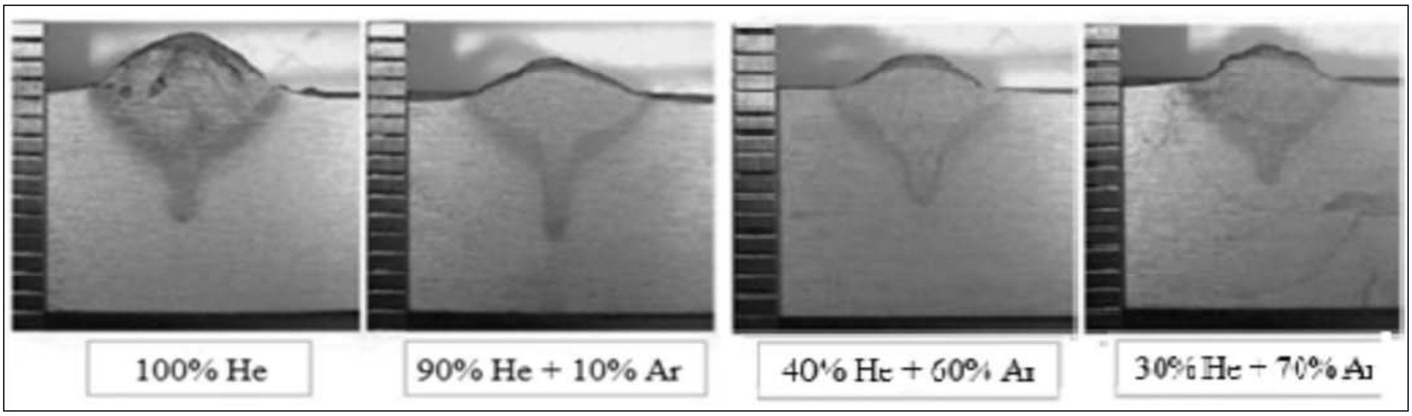


Figure 6. *Cross-section of hybrid weld performed with different ratios of inert shielding gas [9]*

Slika 6. *Poprečni presek hibridnog zavara izvedenog sa različitim odnosima inertnog zaštitnog gasa [9]*

In terms of welding speed, it can be concluded that, in HLAW, by increasing the welding speed, other welding parameters should be adjusted, especially the wire feed speed, thus obtaining the required welding geometry [5]. Moreover, increasing the welding speed decreases the amount of heat input, resulting in increased weld hardness, decreased weld ductility and weld penetration [30].

Salminen's results [30] clearly show the influence of the wire feed rate on the geometric characteristics of the weld, such as the size of the weld bead the amount of deposited material, and the occurrence of defects. During the hybrid welding of structural steel in quality AH36, increasing the wire feed rate results in increased weld penetration until a full penetration is achieved, and then the higher wire feed rate contributes to a larger weld width in the top and bottom zones.

The laser source power is the primary heat source in HLAW that influences the efficiency of the whole process [3]. Therefore, the ratio of the power of the two heat sources should be considered and obtained by dividing the laser power with the arc power [16, 17]. In HLAW increasing of the power ratio leads to a narrow weld width, reducing the tendency of grain growth and modifies the microstructure of fusion zone, while with its reduction, we have a larger heat affected zone of heat, due to a wider distribution of the heat flux (Table3) [17].

Table 3. *Influence of the HLAW parameters on the weld bead*

Tabela 3. *Uticaj parametara HLAW na metal šava*

Welding parameteres	Penetration		Deposition		Face bead width		Root bead width	
	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease
Welding speed	Decrease	Increase	Decrease	Increase	Decrease	Increase	Decrease	Increase
Laser power	Increase	Decrease	No effect	No effect	Minor effect	Minor effect	Minor effect	Minor effect
Arc current	Increase	Decrease	Minor effect	Minor effect	Decrease	Increase	Increase	Decrease
Wire feed rate	Minor effect	Minor effect	Increase	Decrease	Minor effect	Minor effect	No effect	No effect
Arc voltage	No effect	No effect	No effect	No effect	Increase	Decrease	No effect	No effect
Process orientation	Minor effect	Minor effect	No effect	No effect	Laser leading	Arc leding	Minor effect	Minor effect

According to Nielsen's research [31] in the previous point presented, it can be concluded that the proper gap width selection and edge preparations directly affect the effectiveness and efficiency of the entire welding process. Special consideration should be given to laser beam power, wire feed rate, and welding speed in the selection of joint gab and edge preparation.

4. Conclusions

The effectiveness of hybrid laser arc welding in contrast of the individual LBW and GMAW processes is based on the combination of their advantages, such as: higher welding speed, increased productivity, deeper penetration, stable process, better gap bridging ability, less heat input and high flexibility. However, there are drawbacks, due to combination of two heat sources in a single welding process leads to an increased number of parameters that need to be synchronized and optimized to obtain a perfect weld.

According to the performed analysis, is can be concluded that primary parameters of hybrid laser arc welding of structural steel are the laser power, arc power, welding speed, layout of the heat sources, focal positioning, working angle of electrode, shielding gas type, wire feed rate and preparation of the weld joint.

In HLAW, the efficiency and weld penetration depend on the laser source that directly affects the heat sources distance and the type of shielding gas and subsequently affects the process stability and weld geometry and its mechanical properties. In addition, the laser beam focal positioning should be considered, with a negative value just below the work material surface, the best results can be achieved. The arc power and the electrode's angle directly affect the process stability, droplet transfer mood and weld bead geometry. It is recommended

4. Zaključci

Efikasnost hibridnog laserskog zavarivanja za razliku od pojedinačnih LBW i GMAW procesa zasniva se na kombinaciji njihovih prednosti, kao što su: veća brzina zavarivanja, povećana produktivnost, dublje prodiranje, stabilan proces, bolja sposobnost premošćavanja zazora, manji unos toplote i visoka fleksibilnost. Međutim, postoje nedostaci, jer kombinacija dva izvora toplote u jednom procesu zavarivanja dovodi do povećanog broja parametara koje je potrebno sinhronizovati i optimizovati da bi se dobio savršen zavareni spoj.

Na osnovu izvršene analize, može se zaključiti da su primarni parametri hibridnog laserskog zavarivanja konstrukcionog čelika su snaga lasera, snaga luka, brzina zavarivanja, raspored izvora toplote, fokusno pozicioniranje, radni ugao elektrode, vrsta zaštitnog gasa, brzina dodavanja žice i priprema zavarenog spoja.

U HLAW, efikasnost i penetracija šava zavise od izvora lasera, koji direktno utiče na udaljenost izvora toplote i vrstu zaštitnog gasa i posledično utiče na stabilnost procesa i geometriju zavara i njegove mehaničke osobine. Pored toga, treba uzeti u obzir i fokusno pozicioniranje laserskog zraka, sa negativnom vrednošću neposredno ispod površine radnog materijala, mogu se postići najbolji rezultati. Snaga luka i ugao elektrode direktno utiču na stabilnost procesa, način prenosa kapljica i geometriju zrna zavarivanja. Preporučuje se da the electrode's angle to be greater than >70°, and pulsed/spray-arc is preferred in relation to short/globular-arc due to the lower turbulence of the molten droplets. The shielding gas should be an inert gas mixture with a high percentage of helium more than 50% with the aim to reduce the effect of plasma absorption and small amounts of oxygen less than 5% to improve the metal transfer mode. The ratio between the welding speed and filler wire feeding is another parameter that affects the entire process stability as well as on the weld shape. Higher welding speed with the constant wire feed rate cause faster heat up and cooling cycle of the work material which may result in metallurgical defects in the weld and HAZ. The main advantage of HLAW is the better gap bridging ability for thicknesses up to 10mm in one pass, without additional preparation of the weld joint preparation.

Based on the presented, the general influence of the HLAW parameters on the structural steel can be concluded, while for the detailed influence, especially for welding of thicker structural steel elements, additional experiment research should be performed.

ugao elektrode bude veći od >70°, a pulsni/sprej-luk je poželjniji u odnosu na kratki/globularni luk zbog niže turbulencije rastopljenih kapljica. Zaštitni gas treba da bude mešavina inertnog gasa sa visokim procentom helijuma više od 50% sa ciljem da se smanji efekat apsorpcije plazme i male količine kiseonika manje od 5% radi poboljšanja načina prenosa metala. Odnos između brzine zavarivanja i dodavanja žice za punjenje je još jedan parametar koji utiče na stabilnost celokupnog procesa kao i na oblik šava. Veća brzina zavarivanja sa konstantnom brzinom dodavanja žice uzrokuje brži ciklus zagrevanja i hlađenja radnog materijala što može dovesti do metalurških defekata u šavu i ZUTu. Glavna prednost HLAW-a je bolja sposobnost premošćavanja zazora za debljine do 10 mm u jednom prolazu, bez dodatne pripreme žljeba zavarenog spoja.

Na osnovu prikazanog može se zaključiti opšti uticaj parametara HLAW na konstrukcioni čelik, dok za detaljniji uticaj, posebno za zavarivanje debljih čeličnih konstrukcionih elemenata, treba izvršiti dodatna eksperimentalna istraživanja.

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