Forging the Future: Pioneering Approaches in Business, Management and Economics Engineering to Overcome Emerging Global Challenges - 2024

https://doi.org/10.24867/FUTURE-BME-2024-075 Original scientific paper

INFLUENCE OF LASER WELDING SPEED ON WELD WIDTH, PENETRATION, REINFORCEMENT AND HEAT AFFECTED ZONE

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Abstract

Laser welding is an emerging eco-friendly technology that has a significant potential in industrial applications. Compared to arc welding, laser welding is quicker, more efficient, less energy demanding, more user friendly, while the cost of the equipment has dropped in recent years. In this paper, an attempt was made to determine the dimensions of the weld, weld metal and heat affected zone in order to better understand phenomenons that occur in the process. It was found that the increasing in welding speed has a strong influence on the penetration, reinforcement and heat affected zone, while the width of the weld was not affected. Furthermore, in some specimens, gas inclusions or pores were observed within the weld. There is a strong tendency of the gases to escape, which is evident from the apparent underfill defect in some specimens, that was followed by crystallisation.

Key words: *sustainable welding, laser welding, weld dimensions, welding speed.*

1. Introduction

Welding is a joining process that utilises heat and/or pressure. The most widely used welding processes are fusion processes that impart melting to the base material, making the welding relatively quick and productive, while maintaining a low cost of the equipment. However, there are numerous drawbacks to this principle, beginning with problems related to overheating, microstructural changes like segregation, heat affected zone, distorsion, etc. Of these, the most widely used

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are processes that utilise arc welding heat sources like shielded metal arc welding (SMAW), gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW). However, recently, laser heat sources emerged in the welding technology (Messler, 2004). Laser welding joins materials using a concentrated heat source from a laser beam, enabling precise, deep welds at high speeds. It accommodates various materials (metals, polymers, ceramics composites) and thicknesses ranging from 0.01 mm to 50 mm plates (Science, 2013) (Antolić, 2016). Laser welding's narrow weld zone suits thin sheets and small parts. While not replacing traditional methods, laser tech offers efficiency in difficult-to-work materials and high-speed applications. Its uses span industries like machinery, automotive, electronics, non-metallic sectors, and medicine (Gostimirović, 2012). Laser welding is concentrated, so it applies less heat. This leads to smaller weld zones and less material consumption. Laser welding has some advantages for the environment. Reduced heat input and quicker processing lead to lower energy usage. They also result in a smaller carbon footprint. A more sustainable production process benefits from decreased post-processing waste and consumable usage (S3Dht).

In this paper, an attempt was made to determine the influence of welding speed on weld dimensions, to better understand the effect of laser beam on structural steel.

2. Experimental part

The material selected for testing was S355 steel. The samples were plates of rectangular shape with dimensions of 150 x 50 x 3mm, cut by laser. The chemical composition of the material is provided in the Table 1.

Table 1. Chemical composition of the S355 steel

%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Mo	%Fe
0.16	0.31	0.78	0.014	0.015	0.63	0.15	0.03	balance

Steel S355 belongs to the group of structural steels. The application of this group of steels is very extensive because they provide an excellent combination of good weldability, strength and toughness. Structural steels are highly adaptable to various purposes and are often the first choice in engineering practice.

Before welding, samples underwent visual inspection, dimension measurement, and impurity removal with abrasive cloth. A degreasing agent wipes were used to remove chemical contaminants. This preparation is vital to prevent impurities from affecting laser beam absorption and lowering weld quality. To conserve material, passes were made parallel within one sample instead of changing for each parameter variation. Laser welding's concentrated energy input minimally impacts the surrounding material, so parallel passes didn't affect adjacent ones. Welding, or to be more accurate, laser remelting was done by the following equipment:

1. Welding Machine: Gweike LW1500H with a 1500W laser power and AU3TECH-HW970 welding head.

2. Welding Table: 1000mm x 2000mm, equipped with perforated steel plates for effective sample clamping.
3. Welding Tractor: GECKO Battery tractor for linear welding, offering movement of the welding head with various welding speeds in both directions.
4. Clamps and Hand Tools: Various tools secure and manipulate workpieces during welding.
5. Protective Gear: Includes a welding mask and gloves for operator safety, providing shielding from irradiation and heat. Masks protect against UV and infrared radiation, while gloves guard against heat and splatter. Proper gear ensures safety in laser welding.

Figure 1. Experimental setup: a) welding tractor; b) welding device

The HW970 welding head was securely mounted on the welding tractor, ensuring stability during the process. After conducting trial passes to align the movement direction, the welding process commenced with the following parameters:

- Laser Power: 1500W,
- Beam Width: 3 mm
- Material Distance from Nozzle Tip: 5 mm
- Shielding Gas: Argon
- Gas Flow Rate: 20 l/min
- Welding Speed: 20-110 cm/min
- Pre- and post-time: 100 ms
- Laser Mode: Continuous

The passes were conducted consecutively with variations in the tractor movement speed following this sequence: 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 cm/min. A total of 10 passes were executed, Figure 2.

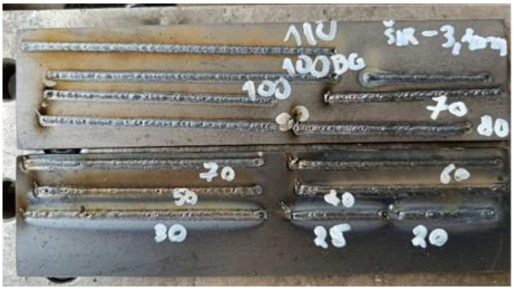


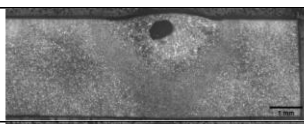
Figure 2. Welding/remelting passes

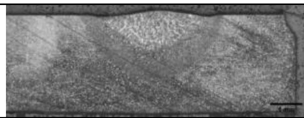
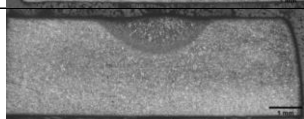
Struers-Discotom device was used for cutting the segments from the plates, with intensive water cooling to prevent heat-induced changes in microstructure. Samples were subsequently encapsulated using a STEUERS Prontopress device, shaping them into discs with melted polyethylene granules as a filler. Finally, each sample was engraved with a number. After wards, samples were ground for microscopy by Struers-Knuth Rotor device (with SiC abrasive papers) and finally polished with a Struers DP-U2 using diamond suspensions. Surface chemical etching is then applied to reveal the microstructure, by Nital (3% HNO_3 in ethanol). Welds were examined by Leeitz Orthoplan light microscope with a camera and measurement scale to study weld dimensions.

3. Results and discussion

Panoramic photographs of the cross-section of the welded joint are provided in Table 2. In Samples 1, 6 and 10, welding defects were observed, in form of gas inclusion/porosity (Sample 1), underfill as a result of gas inclusion collapse (Sample 6) and both (Sample 10). Usually, porosity is the result of solidification kinetics, where quick crystallisation occurs and the gas becomes trapped within the material. Underfill is in this case also related to porosity, where the gas from the pore escapes from the weld metal, which is followed by the immediate solidification.

Table 2. Weld macro images

Sample number	Welding speed	Picture
1.	20 cm/min	
2.	25 cm/min	

Sample number	Welding speed	Picture
3.	30 cm/min	
4.	40 cm/min	
5.	50 cm/min	
6.	60 cm/min	
7.	70 cm/min	
8.	80 cm/min	
9.	90 cm/min	
10.	100 cm/min	

The measurement results of the width, penetration depth, reinforcement, and heat-affected zone width of the welded joint samples are provided in Figures 3 - 6.

The table clearly shows a tendency of decreasing certain characteristic dimensions with increasing welding speed. Based on the table, diagrams have been created to visualize, or rather, to simplify the observation of dimension changes.

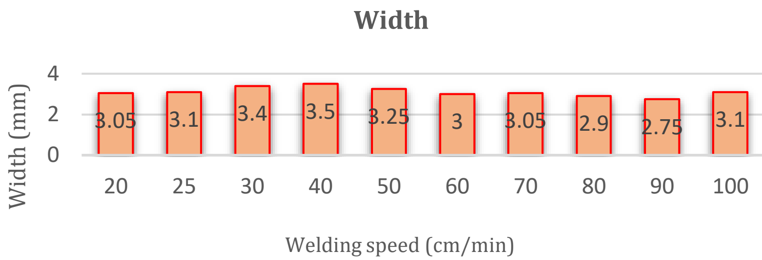


Figure 3. Weld width vs welding speed

The width of the welded joint increases up to a speed of 40 cm/min, then decreases until the final speed of 100 cm/min, when the width increases to approximately the initial value. Nevertheless, the differences are fairly small. The range of measured dimensions indicates that the welding speed does not have a direct impact on the width of the welded joint, as no consistent pattern can be found.

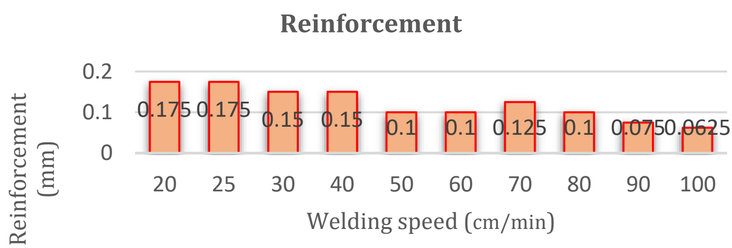


Figure 4. Weld reinforcement vs welding speed

The values of the reinforcement were obtained as the average measurement in several different positions. A decrease in the reinforcement is noticeable with increasing welding speed. Based on the results shown in Figure 4, it can be noted that there are pores on samples 1 and 10, likely due to the penetration of shielding gas or even atmospheric gases. Samples 6 and 10 exhibit surface depressions as a result of gas escaping to the surface, which certainly affects the reinforcement.

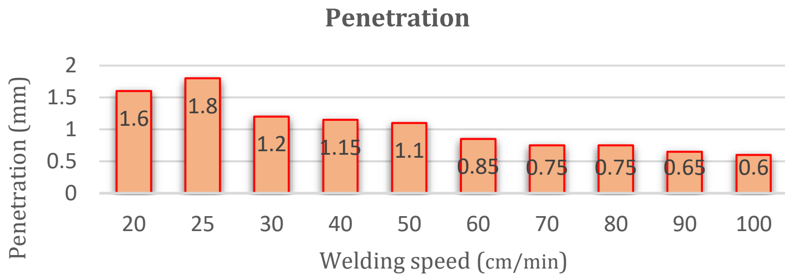


Figure 5. Penetration vs welding speed

The penetration decreases as welding speed increases, as with the reinforcement, however, penetration exhibits a wider range of dimensions. For example, there is a 1.2 mm difference in fusion zone depth between sample 2 at 25 cm/min and sample 10 at 100 cm/min. The reason for the smaller penetration in sample 1 compared to sample 2 is unclear, possibly due to a pore inside the weld on this particular section that was tested.

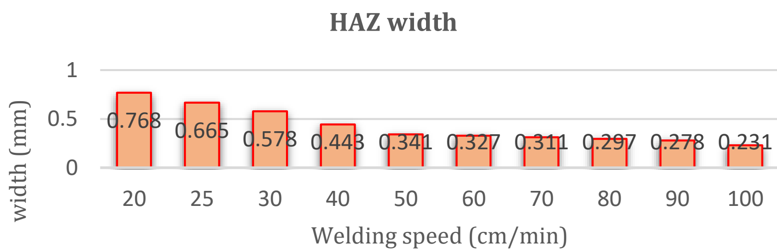


Figure 6. HAZ width vs welding speed

The widest HAZ was obtained in sample 1 at 20 cm/min. Speed increases lead to a steep decrease until 50 cm/min, with further increases gradually reducing the HAZ width. Analysis suggests the HAZ width correlates with heat input, with speed having a significant effect.

4. Conclusions

Laser welding offers versatility and adaptability across various applications, boasting simplicity, high productivity, and precision compared to conventional methods. Its high power density allows for swift welding speeds, affecting a small area around the joint with minimal base material deformations, ideal for thin materials. Operator training is notably fast, vital given the shortage of skilled welders. However, high initial and upkeep costs pose challenges. Yet, ongoing advancements promise a more cost-effective alternative to traditional methods. To fully implement laser welding, understanding the influence on parameters is crucial.

Analysis of results reveals a clear link between welding speed and joint dimensions, which can be summarized as follows:

- Speed notably impacts fusion and heat-affected zones, causing a decrease in dimensions.
- Reinforcement shows deviations but generally decreases with higher welding speed.
- The effect of welding speed on weld width remains inconclusive based on this experiment, suggesting no direct influence.

Porosity has a significant impact on the quality and weld dimensions. Although pores, that is, gas inclusions have a strong tendency to escape the weld metal, the quick and subsequent crystallization causes the occurence of underfill in the weld metal.

Funding

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project “Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad” (No. 01-3394/1).

Acknowledgement

The authors gratefully acknowledge research support by the project entitled “Interdisciplinarity in Materials Science and Joining Technologies” from the Department of Production Engineering, Faculty of Technical Sciences Novi Sad, Serbia.

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