Nonconventional Technologies Review
Romania, June, 2025

INFLUENCE OF WELDING PARAMETERS ON WELD BEAD GEOMETRY IN LASER BEAM WELDING OF CARBON STEEL ST 37

Sandor Ravai-Nagy [1,2], Aurel Mihail Ţîţu [3], Gheorghe Ioan Pop [4], Alina Bianca Pop [5] and Péter Kósa[6]
[1] Technical University of Cluj-Napoca, Faculty of Engineering, V. Babes Str. 62A, 430083 Baia Mare, Romania,
sandor.ravai@imtech.utcluj.ro
[2] University of Nyíregyháza, Institute of Technical and Agricultural Sciences, Sóstói Str. 31/b, 4400 Nyíregyháza, Hungary,
nagy.sandor@nye.hu
[3] Lucian Blaga University of Sibiu, 10, Victoriei Street, Sibiu, România, e-mail: mihail.titu@ulbsibiu.ro
[4] S.C. Universal Alloy Corporation Europe S.R.L., Dumbravița 244A, 437145 Maramures, Romania,
popghitza@gmail.com
[5] Technical University of Cluj-Napoca, North University Center of Baia Mare, 62A, Victor Babeș Street, Baia Mare, Romania,
e-mail: bianca.bontiu@gmail.com
[6] University of Nyíregyháza, Institute of Technical and Agricultural Sciences, Sóstói Str. 31/b, 4400 Nyíregyháza, Hungary,
kosa.peter@nye.hu

ABSTRACT: Laser beam welding (LBW) is a non-conventional joining technology widely used in industry due to its advantages, such as a small heat-affected zone (HAZ) and high precision. Welding quality is influenced by several parameters, including welding speed, shielding gas flow rate, and the distance between the components being welded. This study aims to investigate the influence of welding parameters on weld bead geometry and HAZ in the laser beam welding of carbon steel St 37, without filler material. The paper demonstrates the importance of optimizing welding parameters to achieve a high-quality weld in carbon steel St 37. Laser welding experiments were conducted using an XT Laser 1.5kW Handheld Fiber Laser Welding Machine, mounted on a monoaxial automatic displacement device. Welding parameters such as welding speed, argon flow rate, and distance between the welded plates were varied, while keeping other parameters constant. The dimensions of the welded bead and HAZ were measured on cross-sections of the welded specimens. The experimental results showed that the dimensions of the weld bead and HAZ increase with decreasing welding speed and increasing argon flow rate. The distance between the welded plates negatively influences the shape of the bead; an excessive distance leads to a concave bead profile with reduced mechanical strength. These findings emphasize the need for precise control of welding parameters to achieve high-quality joints.

KEYWORDS: Laser welding, Carbon steel St 37, Welding parameters, Bead size, Heat-affected zone (HAZ), Manual laser

1. INTRODUCTION

Laser beam welding (LBW) is a non-conventional joining technology that uses a focused laser beam to melt and join materials [1,2]. This method has gained significant popularity in various industries, from automotive to aerospace, due to its numerous advantages. These include a small heat-affected zone (HAZ), high welding speed, high precision, minimal distortion, and the ability to weld materials that are difficult to join by conventional methods [3,4]. However, LBW also has drawbacks, such as the high initial cost of the equipment and the need for precise control of welding parameters to achieve optimal results [5].

Control of welding parameters, such as laser power, welding speed, shielding gas flow rate, and focal distance, is crucial to achieving a high-quality weld [6]. Variation of these parameters can significantly influence weld bead geometry, mechanical properties of the joint, and HAZ size [7].

In recent years, significant progress has been made in the field of LBW, including the development of higher power and more efficient lasers, advanced control systems, and new welding techniques [8,9]. However, there is still a continuous need for research to optimize the welding process and extend the applicability of LBW to new materials and configurations [10,11].

Despite the numerous existing studies on laser beam welding, there is still a lack of detailed information regarding the influence of welding parameters on weld bead geometry and HAZ in the case of carbon steel St 37, a widely used material in industry [12,13]. Most studies focus on alloy steels or more exotic materials [14-16].

A significant gap identified in the literature is the lack of a systematic analysis of the influence of specific welding parameters (welding speed, gas flow rate, distance between components) on handheld laser welding of carbon steel St 37 without filler material.

This study makes an original contribution by systematically investigating the influence of welding parameters on weld bead geometry and HAZ in the handheld laser welding of carbon steel St 37 without filler material. Emphasis is placed on correlating the specific parameters of the equipment used with the characteristics of the weld bead.

The main research objectives involve:

- Determining the influence of welding speed on bead size and HAZ.
- Evaluation of the effect of argon flow rate on bead geometry.
- Analysis of the impact of the distance between welding tables on welding quality.
- - Establishing correlations between welding parameters and welding bead characteristics.

2. MATERIALS AND METHODS

2.1 The parent material

The material used in the experiments was carbon steel St 37, a low-carbon, non-alloy steel widely used in construction and general industrial applications. The chemical composition of St 37 steel is presented in Table 1.

Table 1. Table 1. Chemical composition of steel St 37

Element	C (%)	Mn (%)	Si (%)	P (%)	S (%)
Maximum admissible content	0.2	1.5	0.5	0.05	0.05

2.2 2.2 Welding equipment

Welding was performed using an XT Laser 1.5kW Handheld Fiber Laser Welding Machine mounted on a mono-axial automatic traversing device. This device enables the welding torch to move at a constant and adjustable speed, eliminating the speed variations typical of manual welding. Additionally, the device allows for adjustment of the distance between the torch and the workpieces, thus influencing the position of the laser focus relative to the material surface.

2.3 Welding parameters

The experiments varied the following welding parameters:

- **Welding speed:** Different welding speeds were used, ranging from 108.75 mm/min to 290 mm/min, by programming the mono-axial traversing device.
- **Argon flow rate:** Argon flow rates of 11 l/min, 13 l/min, and 16 l/min were tested.
- **Distance between the welded plates:** The distance between the plates varied from 0 mm to 0.6 mm.
- **Laser focal position:** The laser focus was positioned 2 mm above and 2 mm below the material surface.

The other welding parameters were kept constant, as shown in Table 2.

Table 2. Welding parameters

No.	Parameter Name	Unit of measurement	Value
1	Sheet Thickness	mm	8
2	Pick power	%	90
3	Weave Speed	%	100
4	Per-flow Gas	sec	0.2
5	Post-flow Gas	sec	0.2
6	Rise time	sec	0
7	Decay time	sec	0.15
8	Modulation Freq	Hz	2000
9	Duty cycle	%	99
10	Laser Frequency	Hz	10
11	Laser Pulse Duration	m sec	10

2.4 Specimen preparation

Prior to welding, the St 37 steel sheets were mechanically cleaned by grinding to a bright metallic finish using a hand-held grinder and a Klingspor A24 abrasive disc. This operation was necessary to remove oxides, impurities, and other contaminants from the sheet surfaces, ensuring a high-quality weld.

2.5 Bead size measurement and HAZ

After welding, the specimens were sectioned perpendicular to the welding bead direction. The sectioned surfaces were polished and etched with acid to reveal the heat-affected zone (HAZ) and the grain structure of the weld bead. The dimensions of the weld bead (width - B, penetration - p) and HAZ were measured from images of the cross-sections using an optical microscope. Figure 1 illustrates the measured dimensions.

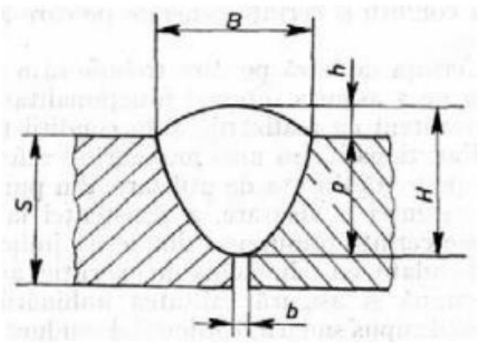

Figure 1. Weld bead dimensions

3. 3. RESULTS AND DISCUSSIONS

3.1 Presentation of experimental results

Table 3 presents the dimensions of the weld bead (width - B, penetration - p) and the heat-affected zone (HAZ) for each weld produced, as a function of the welding parameters used. Images of the weld cross-sections are shown in Figures 2-10.

Table 3. Weld bead dimensions

Bead no.	Width B (mm)	Penetration p (mm)	Weld Bead Area (mm^2)	HAZ size (mm)	Gap width S (mm)	Argon flow rate (l/min)	Welding speed (mm/min)	Laser focal position
1	2.02	0.93	1.879	0.5	0	11	290	2
2	1.54	1.02	1.571	0.47	0	13	290	2
3	2.93	2.33	6.827	0.41	0	13	217.5	2
3	2.22	2.86	6.349	0.31	0	13	217.5	2
6	2.78	2.55	7.098	0.45	0	13	151.3	2
6	2.85	2.18	6.213	0.8	0	16	151.3	2
7	3.4	2.37	8.058	0.4	0	13	108.75	2
8	3.26	2.23	7.27	0.71	0	16	108.75	2
9	3.54	2.3	8.142	0.58	0	16	124.14	-2
10	3.26	1.9	6.194	0.72	0.2	16	124.14	-2
11	3.07	2.71	8.32	0.3	0.4	16	124.14	-2
12	3.42	2.22	7.592	0.45	0.6	16	124.14	-2

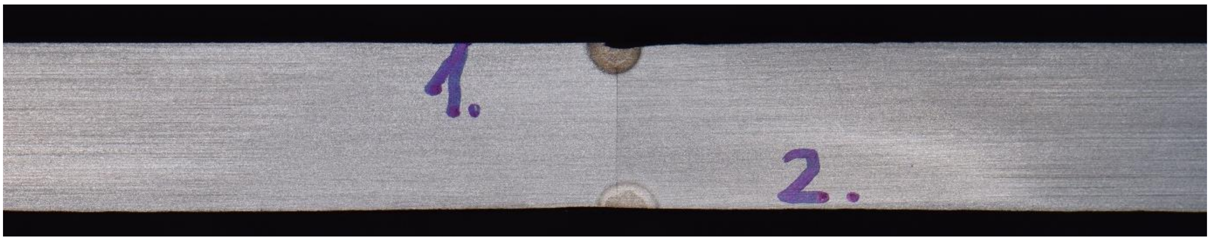

Figure 2. Weld beads one and two from Table 3.

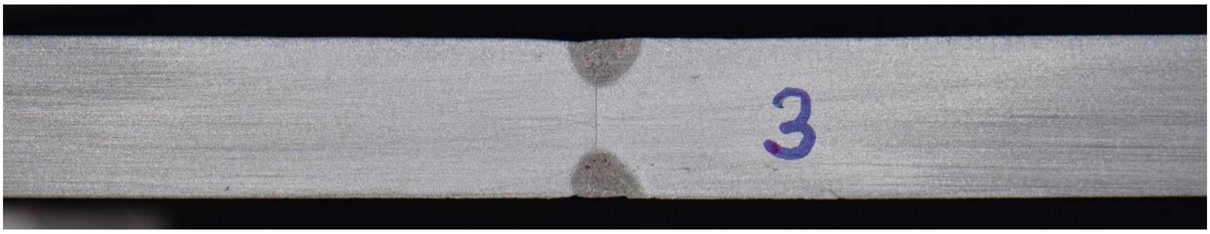

Figure 3. Weld bead three from Table 3.

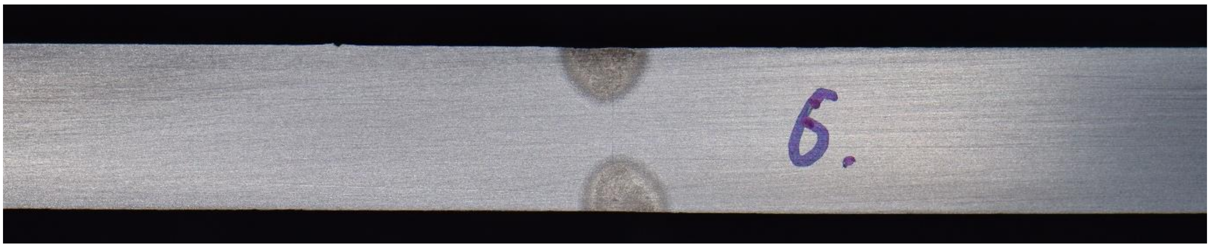

Figure 4. Weld bead six from Table 3.

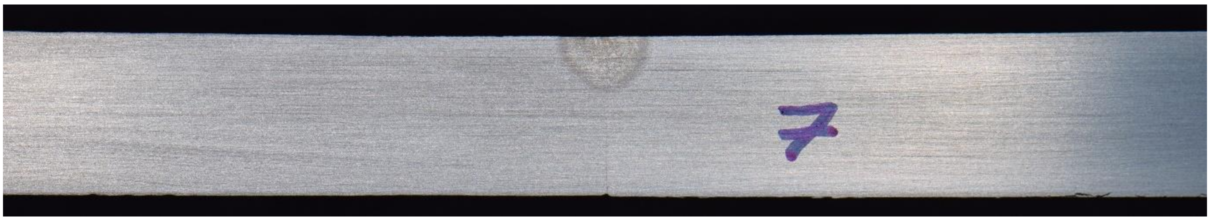

Figure 5. Weld bead seven from Table 3.

Figure 6. Weld bead eight from Table 3.

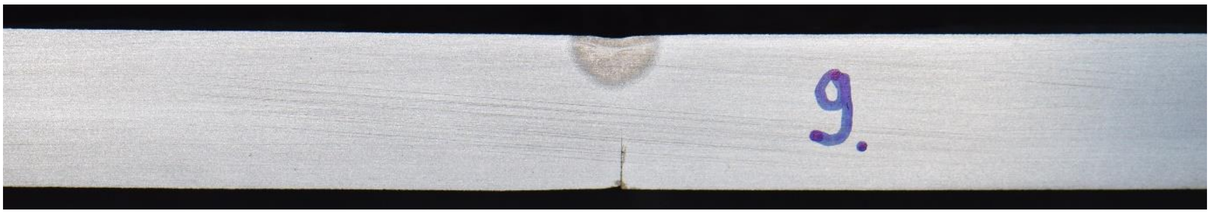

Figure 7. Weld bead nine from Table 3.

Figure 8. Weld bead ten from Table 3.

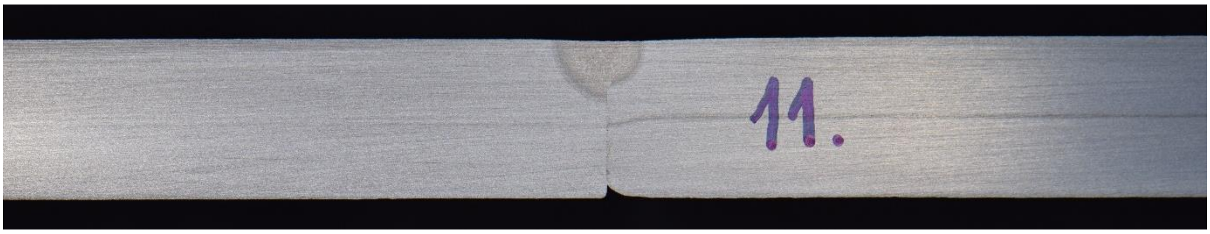

Figure 9. Weld bead eleven from Table 3.

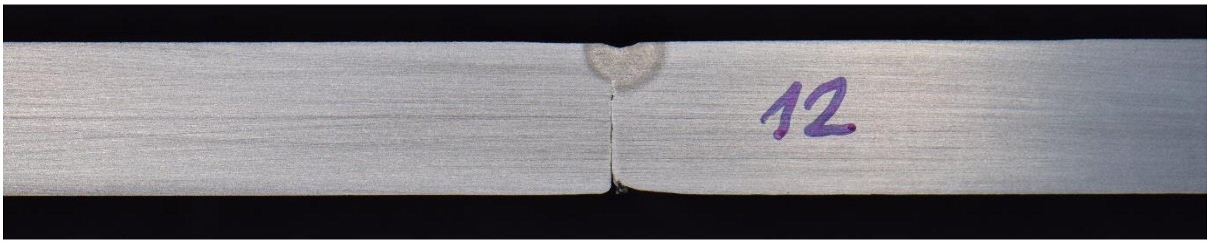

Figure 10. Weld bead twelve from Table 3.

3.2 Parameters influence analysis

Welding speed: An increase in welding bead dimensions and HAZ size is observed with decreasing welding speed. This phenomenon is since, at lower speeds, laser energy is applied for a longer period to the same area, leading to deeper melting and a larger heat-affected zone.

Argon flow rate: Increasing the argon flow rate has a negative effect on the weld bead cross-section, likely due to faster cooling of the molten weld pool. For instance, an increase in flow rate from 13 l/min to 16 l/min reduces the weld bead cross-section by approximately 10-15%.

Distance between plates: An excessive distance between the welded plates (≥ 0.6 mm) leads to a concave weld bead profile, with a reduced cross-section and potentially lower mechanical strength. This is attributed to the loss of laser beam focus and energy dispersion at larger distances.

Laser focal position: From the data presented, a clear conclusion cannot be drawn regarding the influence of laser focal position on weld bead dimensions and HAZ size. Further experiments are needed to investigate this aspect.

3.3 3.3 Discussing physical mechanisms

The results obtained can be explained by the physical mechanisms governing the laser beam welding process.

Laser energy absorption: The amount of laser energy absorbed by the material depends on the material properties, the laser wavelength, and the surface condition of the material. Higher energy absorption leads to deeper melting and a larger HAZ.

Thermal conductivity: The thermal conductivity of the material influences how heat dissipates within the material. Higher thermal conductivity results in a smaller HAZ, as heat is dissipated more rapidly.

Surface tension: The surface tension of the molten metal affects the shape of the welded bead. Higher surface tension leads to a narrower and taller bead.

Convection: Convection in the molten weld pool, influenced by the shielding gas flow rate, can affect heat transfer and bead formation. A higher gas flow rate can cool the molten weld pool faster, resulting in a reduced weld bead cross-section.

In conclusion, the experimental results highlight the importance of precise control of welding parameters to achieve high-quality joints in carbon steel St 37. Welding speed, argon flow rate, and the distance between the welded plates have a significant influence on weld bead geometry and HAZ dimensions.

4. CONCLUSIONS

This study investigated the influence of laser welding parameters on weld bead geometry and heat-affected zone (HAZ) size in carbon steel St 37, using an XT Laser 1.5kW Handheld Fiber Laser Welding Machine mounted on a mono-axial automatic traversing device.

The main conclusions of the study are:

- Welding bead dimensions and HAZ size increase with decreasing welding speed.
- Increasing the argon flow rate has a negative effect on the weld bead cross-section, likely due to faster cooling of the molten weld pool.
- Excessive distance between the welded plates (≥ 0.6 mm) leads to a concave weld bead profile, with a reduced cross-section and potentially lower mechanical strength.

These results emphasize the importance of optimizing welding parameters to achieve high-quality joints in carbon steel St 37. Proper selection of welding speed, argon flow rate, and the distance between the welded plates is crucial to ensure a weld with optimal dimensions and superior mechanical properties.

This study can be extended by investigating the following aspects:

- The influence of other welding parameters could be investigated, such as laser power, pulse frequency, and shielding gas composition, to gain a comprehensive understanding of their effects on weld quality.
- A detailed microstructural analysis of the weld bead and HAZ could be performed to better understand the weld formation mechanisms and correlate the microstructure with mechanical properties.
- Mechanical tests, such as tensile, impact, and fatigue tests, could be conducted to evaluate the performance of the welded joints under various loading conditions.
- A numerical model of the welding process could be developed to simulate the influence of welding parameters on weld bead geometry and the thermal properties of the material.
- Optimization techniques, such as genetic algorithms or neural networks, could be employed to determine the optimal set of welding parameters that maximize joint quality.

By addressing these research directions, we can contribute to a better understanding and optimization of the laser welding process of St 37 carbon steel, opening new opportunities for the application of this technology in various industrial fields.

5. REFERENCES

1. Arulvel, S., Jain, A., Kandasamy, J. and Singhal, M., Laser processing techniques for surface property enhancement: Focus on material advancement. *Surfaces and Interfaces*, *42*, p.103293 (2023).
2. Gonçalves, L.F., Duarte, F.M., Martins, C.I. and Paiva, M.C., Laser welding of thermoplastics: An overview on lasers, materials, processes and quality. *Infrared Physics & Technology*, *119*, p.103931 (2021)
3. Cai, W., Wang, J., Jiang, P., Cao, L., Mi, G. and Zhou, Q., Application of sensing techniques and

artificial intelligence-based methods to laser welding real-time monitoring: A critical review of recent literature. *Journal of Manufacturing systems*, *57*, pp.1-18 (2020).

4. Shin, Y.C., Wu, B., Lei, S., Cheng, G.J. and Lawrence Yao, Y., Overview of laser applications in manufacturing and materials processing in recent years. *Journal of Manufacturing Science and Engineering*, *142*(11), p.110818, (2020).
5. Slobodyan, M., Resistance, electron-and laser-beam welding of zirconium alloys for nuclear applications: a review. *Nuclear Engineering and Technology*, *53*(4), pp.1049-1078, (2021).
6. Mirak, A., Shams, B. and Bakhshi, S., Dissimilar welding of Inconel 713 superalloy and AISI 4140 steel using Nd: YAG pulse laser: An investigation on the microstructure and mechanical properties. *Optics & Laser Technology*, *152*, p.108143 (2022).
7. Gajbhiye, A.M., Sonawane, P.R., Karle, A.H. and Campli, S., Optimization of welding parameters for En8D and SAE1018 materials by Taguchi. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, pp.1-10 (2023).
8. Kumar, B., Bag, S., Paul, C.P., Das, C.R., Ravikumar, R. and Bindra, K.S., Influence of the mode of laser welding parameters on microstructural morphology in thin sheet Ti6Al4V alloy. *Optics & Laser Technology*, *131*, p.106456 (2020).
9. Haupt, W., Borges, L.G., Israel, C.L. and Riffel, K.C., Effects of laser welding on the mechanical properties and microstructure of AISI 304 stainless steel. *Lasers in Manufacturing and Materials Processing*, pp.1-18 (2024).
10. Errico, V., Campanelli, S.L., Angelastro, A., Mazzarisi, M. and Casalino, G., On the feasibility of AISI 304 stainless steel laser welding with metal powder. *Journal of Manufacturing Processes*, *56*, pp.96-105 (2020).
11. Omoniyi, P.O., Mahamood, R.M. and Akinlabi, E.T., Impact of process parameters of laser welding on the mechanical properties of Ti6Al4V: A review. *J. Chem. Technol. Metall*, *56*, pp.1074-1081 (2021).
12. Far, M.N.S., Farsibaf, M.M., Kolahan, F. and Elhami, S., Analyzing weld bead geometry and microstructure in ultrasonic-assisted activated flux TIG welding of ST37 steel. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, pp.1-14 (2024).
13. Vuherer, T., Milčić, M., Glodež, S., Milčić, D., Radović, L. and Kramberger, J., Fatigue and fracture behaviour of Friction Stir Welded AA-2024-T351 joints. *Theoretical and Applied Fracture Mechanics*, *114*, p.103027 (2021).
14. Wang, C.Y., Jiang, M.H., Wang, C.D., Liu, H.H., Zhao, D. and Chen, Z.L., Modeling three-dimensional rough surface and simulation of temperature and flow field in laser transmission welding. *Journal of Advanced Joining Processes*, *1*, p.100021 (2020).
15. Perka, A.K., John, M., Kuruveri, U.B. and Menezes, P.L., Advanced high-strength steels for automotive applications: arc and laser welding process, properties, and challenges. *Metals*, *12*(6), p.1051 (2022).
16. Deepak, J.R., Anirudh, R.P. and Sundar, S.S., Applications of lasers in industries and laser welding: A review. *Materials Today: Proceedings* (2023).