TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
MECHANICS | MECHANIKA
4-M/2016

NORBERT RADEK*, MIECZYSŁAW SCENDO**

LASER BEAM WELDING OF DC04 STEEL

LASEROWE SPAWANIE STALI DC04

Abstract

This paper discusses the effect of selected parameters of laser welding on mechanical properties of welds. Two parameters were analysed: the welding speed and the laser power. The properties of the material in the fusion zone and the heat affected zone were determined by hardness tests and microscopic analysis. The results indicate welds produced at different welding parameters have similar properties.

Keywords: laser welding, *fusion zone*, *properties*

Streszczenie

W artykule przestawiono badania wpływu wybranych parametrów spawania laserowego na własności mechaniczne spoiny. Badano wpływ dwóch parametrów: prędkość posuw oraz moc wiązki. Na badania własności spoiny oraz stref do nich przyległych składały się pomiary twardości oraz obserwacje mikroskopowe. Przeprowadzone badania wykazują, że spoiny otrzymane przy różnych parametrach spawania charakteryzują się zbliżonymi własnościami.

Słowa kluczowe: spawanie laserowe, *spoina*, *własności*

DOI: 10.4467/2353737XCT.16.231.5980

---

* D.Sc. Ph.D. Eng. Norbert Radek, Assoc. Prof., Centre for Laser Technologies of Metals, Faculty of Mechatronics and Machine Design, Kielce University of Technology.

** D.Sc. Ph.D. Mieczysław Scendo, prof. UJK, Institute of Chemistry, Faculty of Mathematics and Natural Sciences, Jan Kochanowski University in Kielce.

1. Introduction

The process of laser beam welding involves melting the edges of metals to be joined with a focused beam of radiation at a power density of $10^4 \div 10^6$ W/mm^2 [1]. The development of lasers with a high input power made it possible to join thick plates by directly melting the adjacent edges with no need to chamfer them or use time-consuming filling of the bevel groove. This method of fusion is also used in electron beam welding but the process has numerous disadvantages, for example, the necessity to place the elements to be welded in vacuum, the necessity to remove random magnetic fields as well as the necessity to protect the workpiece against X-ray radiation occurring during high-voltage electron beam welding [2].

The process of laser welding has the following advantages:

- high purity of the process (dependent on the surface preparation and gas purity),
- joining difficult to weld materials,
- easy automation,
- welding with high precision (e.g. joining thin and thick elements),
- high speed of the welding process,
- one source of radiation for several welding stations,
- welding performed under atmospheric pressure (by contrast, electron beam welding is performed in vacuum),
- high power density (in the case of deep welding), and as a result, small distortions,
- narrow heat affected zone.

2. Materials and methods

The specimens to be tested were cut from a steel sheet 0.8 mm in thickness. As a material resistant to aging, DC04 steel is used extensively in high-performance applications including deep drawing and drawing, and in the transport industry. DC04 steel is characterised by good weldability which means that no special preparation of the work is needed. Table 1 shows the chemical composition of DC04 steel, respectively.

Table 1

Chemical composition of DC04 steel [3]

Steel grade	Maximum content [%]				
	C	Mn	P	S	Ti
DC04	0.08	0.40	0.030	0.030	0

The analysis of the properties of the joints produced by laser welding involved examining their microstructure and measuring their hardness.

The microstructural observations were conducted using a Joel JSM-5400 scanning electron microscope. The hardness was measured with a NEXUS 4304 tester at a load of 1 kG applied for 10 s.

3. Selection of laser welding parameters

The welding tests were conducted by changing two parameters: the laser power and the welding speed. According to the literature [4, 7], these two parameters have the greatest influence on the quality of welds.

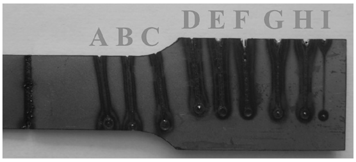

Fig. 1. View of the reference specimen with laser pass lines imitating welds

Figure 1 shows a specimen with laser pass lines imitating welds, whereas Table 2 provides the parameters of laser welding used during the tests. The macroscopic analysis of the laser pass lines and the phenomena accompanying the welding process helped select the main parameters of laser welding: the laser power and the welding speed.

Table 2

Values of the main process parameters

Number of the laser pass line	Laser power P [kW]	Welding speed v [m/min]
A	1.5	3
B	1.8	3
C	2	3
D	2.5	3
E	2	2
F	2	2.5
G	2	3.5
H	2	4
I	2	5

The laser pass lines A-D were formed at a welding speed of 3 m/min and the initial power of 1.5 kW gradually increased to 2.5 kW. When the pass line was produced at a power of 1.5 kW, plasma was not present. At a power of 1.8 kW, a small plasma cloud was observed, but its influence on the welding process was negligible. When the laser pass line was formed at a power of 2 kW or 2.5 kW, a positive effect of the plasma cloud was observed. After the macroscopic examinations of the laser pass lines, it was assumed that the tests would be conducted at a laser power of 2 kW. During the next five tests, the laser pass lines E-I were produced by changing the welding speed from 2 m/min to 5 m/min, with the laser power being constant (P = 2 kW). It was found that when the welding speed was 5 m/min, the weld penetration was incomplete (pass line I). The experimental data was analysed to select the laser welding parameters:

- laser power $P = 2$ kW;
- welding speed v: 2 m/min; 2.5 m/min; 3 m/min; 3.5 m/min; 4 m/min;
- shielding gas: argon $Q = 10$ l/min.
- preheat time $t = 5$ s;
- pulse repetition rate $f = 30\,000$ Hz;
- nozzle-workpiece distance $\otimes f = 0$ mm.

The tests were conducted for five series of laser welded specimens and one series of unwelded specimens, where the base metal was DC04 steel. There were three specimens in each series numbered from 0 (base metal) to 5 (where $v = 4$ m/min).

4. Results and discussion

The microstructure of the welded joints was analysed using a Joel JSM-5400 scanning electron microscope.

The microscopic examinations of the welded joints were performed on polished metallographic specimens in the plane perpendicular to the weld, which enabled observation of the fusion zone and the heat affected zone. It was also possible to analyse the structures formed and to measure the width of the heat affected zone (HAZ).

The aim of the analysis was to compare the resulting microstructures of the welded joints and to determine how variable values of the welding speed affect the shape of the weld.

The laser welding process is characterised by very high heating and cooling rates, which leads to the narrowing of the width of both the fusion zone and the heat-affected zone.

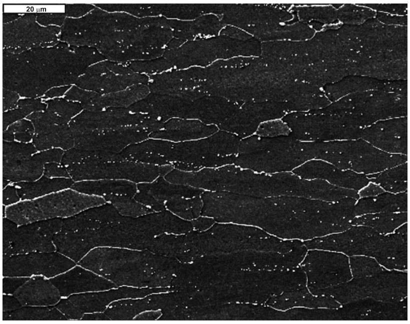

Fig. 2. Ferritic-pearlitic microstructure of the base metal (×1000 magnification)

Figure 2 shows an image of the microstructure of the base metal. The results suggest that the base metal had a coarse-grained ferrite-pearlite structure. From Fig. 2 it is clear that the grains are arranged in bands, which indicates that the production of steel sheets (DC04 steel) involved rolling. The analysis of a specimen of series 1 showed that the material in the HAZ had a fine-grained ferritic-pearlitic microstructure with visible metallic precipitates in the pearlite grains.

For a specimen of series 1, a Widmanstätten pattern was observed in the fusion zone (Fig. 3). It contains plate-shaped ferrite precipitates running at 60° and 120°. The occurrence of the Widmanstätten structure indicates that the steel was overheated, which caused a decrease in the mechanical properties of the weld.

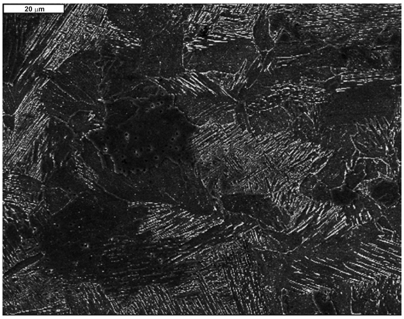

Fig. 3. Widmanstätten structure in the fusion zone (×1000 magnification)

The microscopic examinations were performed to determine the influence of different welding speeds on the microstructure and shape of the welds. It was found that the welding speed affected the weld shape and the penetration depth. The higher the welding speed the smaller the penetration depth and the more narrow the fusion zone; there was also a change in the direction of the fusion line resulting from a change in the weld shape from mushroom-like to triangular (Fig. 4). When the welding speed was too low, the width of the fusion zone and the width of the heat affected zone increased.

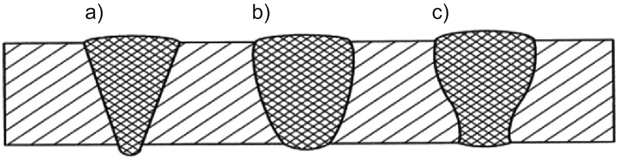

Fig. 4. Weld shapes after laser welding: a) triangular, b) and c) mushroom-shaped

The hardness of the material was measured by means of the Vickers method. The indentations were made in all the specimens of series 1–5 prepared as metallographic specimens. The measurements were taken on surfaces perpendicular to the three zones: the fusion zone (at the face), the heat affected zone and the base metal.

The values of the hardness in the base metal zone obtained for all the specimens were comparable. It can be assumed that the specimens had a similar structure with no microdefects that would contribute to the weakening of the material. The average hardness in the base metal zone for all the specimens of series 1–5 was 105 HV1.

The analysis of the hardness of the material in the heat affected zone indicates that the highest values were reported for a welding speed of 3.5 m/min (a series 4 specimen). The average hardness in the HAZ obtained for that specimen was 184 HV1. For the specimens of series 1–5, the average hardness in the HAZ was 38% higher than the average hardness in the base metal zone.

The highest hardness at the weld face was reported for a specimen of series 4; the average value was 256 HV1. The lowest hardness in the fusion zone was reported for a specimen of series 3 ($v = 3$ m/min); the average hardness for that specimen was 236 HV1. The phase transitions that occurred in the heated material during its rapid cooling contributed to material hardening both in the fusion zone and the heat affected zone. The phase transitions were responsible for the formation of martensite-like and ferrite-bainite structures, which improved material hardness. The average hardness in the fusion zone was 31% higher than that in the heat affected zone.

5. Summary

The following are the conclusions drawn from the experimental data:

1. The shape and thickness of the welds as well as the width of the heat affected zone are dependent on the welding speed.
2. The hardness measurement results confirm that the welded specimens are not homogeneous but very complex in structure.
3. An increase in the welding speed caused visible, irreversible structural changes in the fusion zone and the heat affected zone, which were attributable to high heating and cooling rates. The changes included refinement of the grain structure and higher hardness.

References

[1] Radek N., *Laboratorium wiązkowych technologii obróbki materiałów*, Wyd. Politechniki Świętokrzyskiej, Skrypt, Nr 456, Kielce 2013 [in Polish].

[2] Szczeciński Z., *Spawanie wiązką promieniowania laserowego*, Przegląd Spawalnictwa, vol. 9–10, 1985, 12-17 [in Polish].

[3] Ruukki catalogue, http://www1.ruukki.pl/~/media/Poland/Files/metals-coldrolled/karty-produkty/Ruukki-zimnowalcowane-Stale-przeznaczone-do-formowania.pdf [date of acc. 10.06.2016].

[4] Chen S., Huanga J., Xiaa J., Zhaoa X., Lin S., *Influence of processing parameters on the characteristics of stainless steel/copper laser welding*, J Mat. Proc. Tech., vol. 222, 2015, 43-51.

[5] Kuryntsev S.V., Gilmutdinov A.Kh., *Welding of stainless steel using defocused laser beam*, J. Constructional Steel Res., vol. 114, 2015, 305-313.

[6] Hayashi T., Matsubayashi K., Katayama S., Abe N., Matsunawa A., Ohmori A., *Reduction mechanism of porosity in tandem twin-spot laser welding of stainless steel*, Weld. Int., vol. 17, 2003, 12-19.

[7] Torkamany M.J., Ghaini F.M., Poursalehi R., *An insight to the mechanism of weld penetration in dissimilar pulsed laser welding of niobium and Ti–6Al–4V*, Optics & Laser Technology, vol. 79, 2016, 100-107.