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Assessment of the Structure and Properties of Manually Laser-Beam-Welded Joints of Steel DOCOL 1200M

Abstract: The research work aimed to determine the effect of manual laser beam welding process parameters on the properties of butt joints made of 1.8 mm thick steel DOCOL 1200M. The test joints were subjected to non-destructive (visual and penetrant) tests as well as destructive tests including static tensile tests, bend tests, hardness measurements as well as macro and microscopic metallographic tests. The optimisation of welding process parameters enabled the obtainment of joints satisfying both visual and strength-related quality requirements. The tests revealed that the use of the so-called continuous-wave laser beam helped minimise the number of welding imperfections. As a result of the laser beam welding process, the hardness in the heat affected zone (HAZ) decreased to approximately 260 HV, if compared to that of 360 HV in the base material and 370 HV in the weld.

Key words: laser beam, manual welding, steel Docol 1200M, martensitic structure

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1. Introduction

Over the past decade, the automotive industry has been faced with many challenges. The demand for a large number of motor vehicles and changing standards applying to them have led to increased material consumption and the need to obtain increasingly favourable material properties. Cars contain steel, plastics, ceramics and even natural materials such as wood or leather (in vehicle interiors) [1–5]. For many years, cars have been manufactured as self-supporting structures, i.e. without a separate load-carrying element, such as a frame used in off-road vehicles, delivery vans and lorries. In the past, the fabrication of the so-called BIW (Body in White), i.e. the uncovered car body (structural elements of the body without panelling) consisting of stringers, thresholds, pillars A, B and C involved the use of unalloyed steels, where mechanical properties were improved by increasing related cross-sections [4–7]. Safety and environmental issues forced manufacturers to rapidly develop materials used in the automotive industry. One of the solutions increasing passenger safety and reducing vehicle weight is connected with the obtainment of advanced high-strength steels (AHSS). Their mechanical properties make it possible to improve safety without the necessity of using larger cross-sections of structural elements, i.e. without increasing the weight. In addition, the use of the above-named steels even enables the reduction of weight [6–9].

Laser beam welding can enable the joining of elements without reducing their mechanical properties. Such an advantage is possible due to very short thermal cycles, which, in turn, result from the high concentration of light energy in a small area and the use of appropriate shielding gas. Manual laser beam welding can be used in post-accident repairs of motor vehicles [10–13].

2. Tests

The research work aimed to determine the effect of manual laser beam welding process parameters on the properties of butt joints made of 1.8 mm thick steel DOCOL 1200M DOCOL (i.e. advanced high-strength steel). In the carmaking industry, steel DOCOL 1200M is used primarily in the fabrication of anti-intrusion bars, bumpers and structural elements of vehicles. This martensitic steel is one of the most robust cold-rolled high-strength steel grades The chemical composition and the mechanical properties of steel DOCOL 1200M are presented in Table 1, whereas its structure is presented in Figure 1.

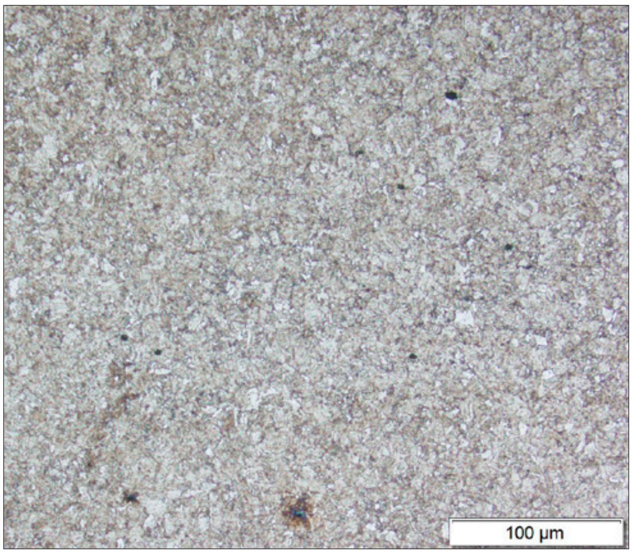

Fig. 1. Microstructure of steel DOCOL 1200M

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Table 1. Chemical composition and mechanical properties of martensitic steel DOCOL 1200M

Chemical element content [wt%]											
C	**Si**	**Mn**	**P**	**S**	**Al**	**Nb**	**V**	**Ni**	**Cr**	**N**	**Ce***
0.113	0.22	1.58	0.01	0.002	0.035	0.016	0.01	0.04	0.04	0.006	0.39

Mechanical properties		
Tensile strength R_m [MPa]	**Yield point R_e [MPa]**	**Elongation A_{80} [%]**
1260	1060	5

* Ce – carbon equivalent

Table 2. Welding process parameters

Joint	Welding programme	Mode	Laser power [W]	Welding rate [mm/s]
B1	F2	Pulse	650	8
B2	E2	Continuous wave	700	7.4
B3	E2	Continuous wave	650	7.1

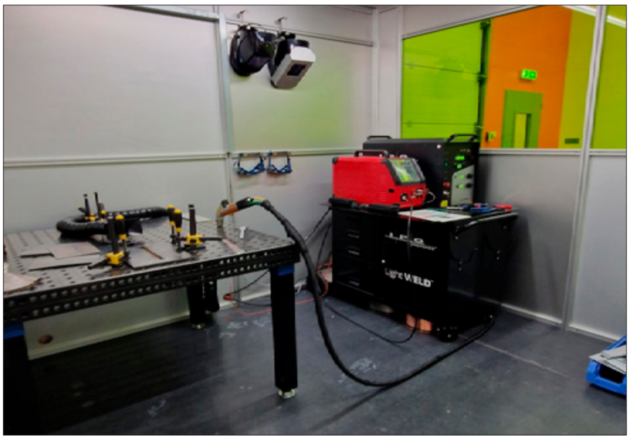

Fig. 2. Laser beam welding station

3. Test joints

The test joints were made in cooperation with the IPG Photonics company from Gliwice. The tests were performed using a LightWeld XC laser (Fig. 2). The diameter of the optical fibre connecting the resonator with the process head amounted to 50 µm. The optical system used in the tests enabled the threefold magnification and, consequently, the obtainment of the laser beam focus having a diameter of 150 µm. The working distance was adjusted by the welding torch, which was in direct contact with the surface of the element subjected to welding, thus constituting one of the safeguards against the unauthorised emission of the laser beam. In the standard setting, the position of the laser beam focus was on the surface of the material subjected to welding. The torch design enabled the manual change of its length and the setting of another position of the laser beam focus (in relation to the workpiece) within the range of +/- 10 mm. The welding tests were performed with the focus position on the surface of the welded element being $f = 0$ mm.

The shielding gas used in the tests was argon, fed at a constant flow rate (in relation to all specimens) of 19 l/min. The oscillation width amounted to 3 mm. The technological parameters used in the welding of individual joints are presented in Table 2.

The test welded joints are presented in Figure 3.

The test joints were subjected to the following tests:

- visual tests,
- penetrant tests,
- macroscopic metallographic tests,
- observations of the structure using light microscopy,
- strength tests,
- hardness measurements.

4. Analysis of test results

The visual tests were performed in accordance with the requirements specified in the PN-EN ISO 17637:2017-02, PN-EN ISO 13919-1:2020-04, PN-EN ISO 9712:2012 and PN-EN 13018:2016- 04 standards, using an illuminance of 700 lx. All of the joints were characterised by heat-process-triggered discolouration. Additional observation results are discussed below:

- Joint B1:
  - Face: few surface pores (along the entire length), slight angular misalignment.
  - Root: few areas with the lack of full penetration (along the entire length).

Result: joint B1 satisfied the requirements of quality level D in accordance with the PN-EN ISO 13919-1:2020-04 standard.

- Joint B2:
  - Face: slight (0.15 mm deep) incompletely filled groove 15 mm away from the left side, slight angular misalignment.
  - Root: 70 mm away from the left side – visible root concavity not exceeding 0.2 mm.

Result: joint B2 satisfied the requirements of quality level C in accordance with the PN-EN ISO 13919-1:2020-04 standard.

- Joint B3:
  - Face: along 124 mm and along 140 mm from the left side – visible incompletely filled grooves not exceeding 0.18 mm.
  - Root: lack of imperfections.

Result: joint B3 satisfied the requirements of quality level C in accordance with the PN-EN ISO 13919-1:2020-04 standard.

The penetrant test, based on related standards, i.e. PN-EN ISO 3452-1:2021-12, PN-EN ISO 23277:2015-05, PN-EN ISO 17635:2017-02, PN-EN ISO 9712:2012, PN-EN ISO 13919-1:2020-04, revealed that all the joints satisfied the criteria of acceptance level 1, corresponding to quality level B in accordance with the PN-EN ISO 23277:2015-05 standard.

Joint B3 after the penetrant test is presented in Fig. 4.

The macroscopic tests revealed that the base material, heat affected zone (HAZ) and the weld did not contain any

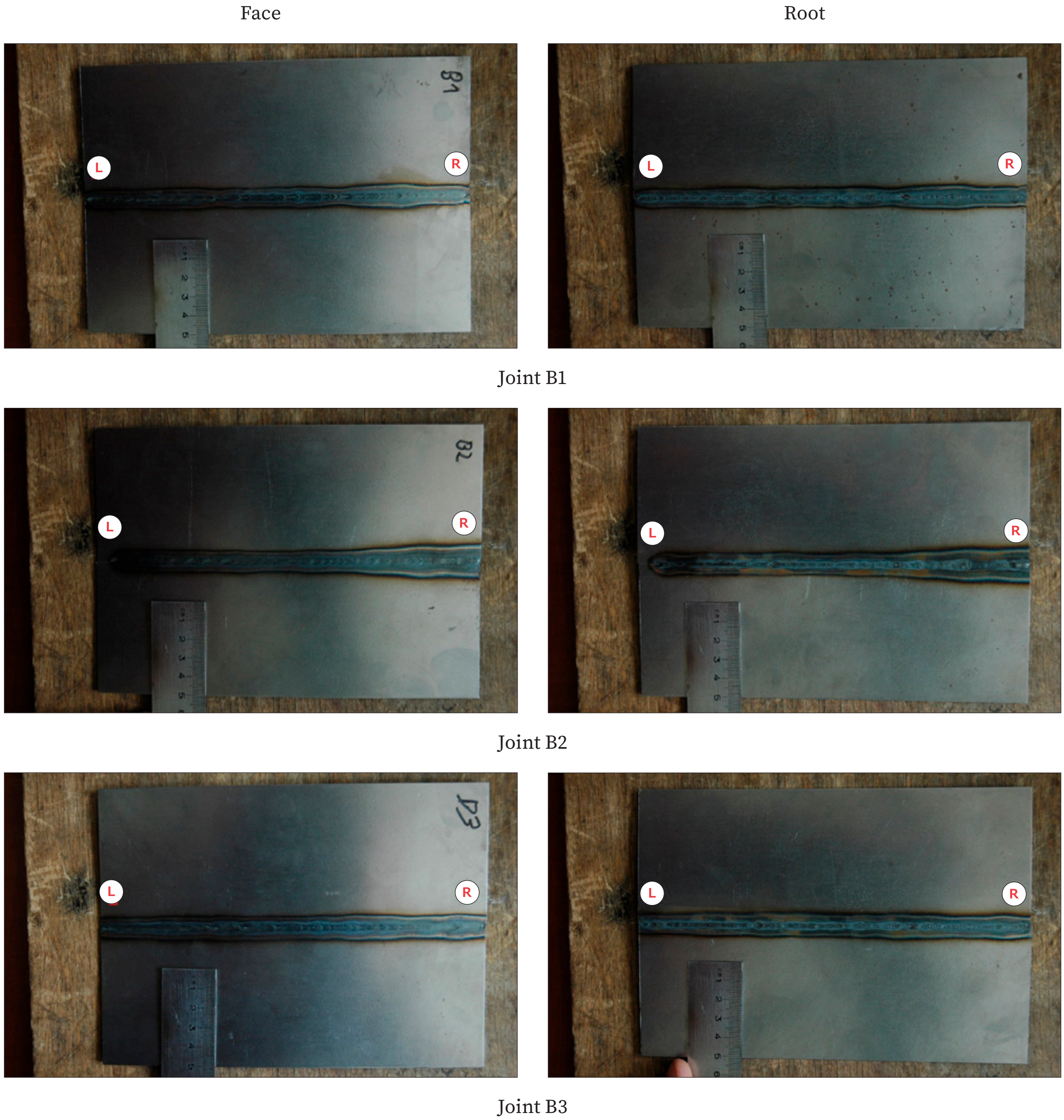

Fig. 3. Joints welded using various parameters

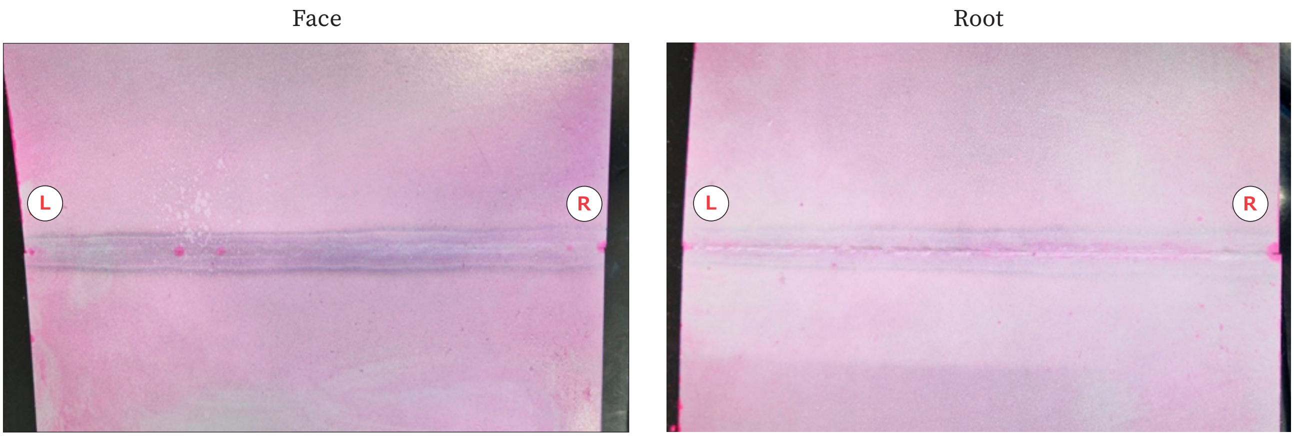

Fig. 4. Joint B3 after the penetrant test

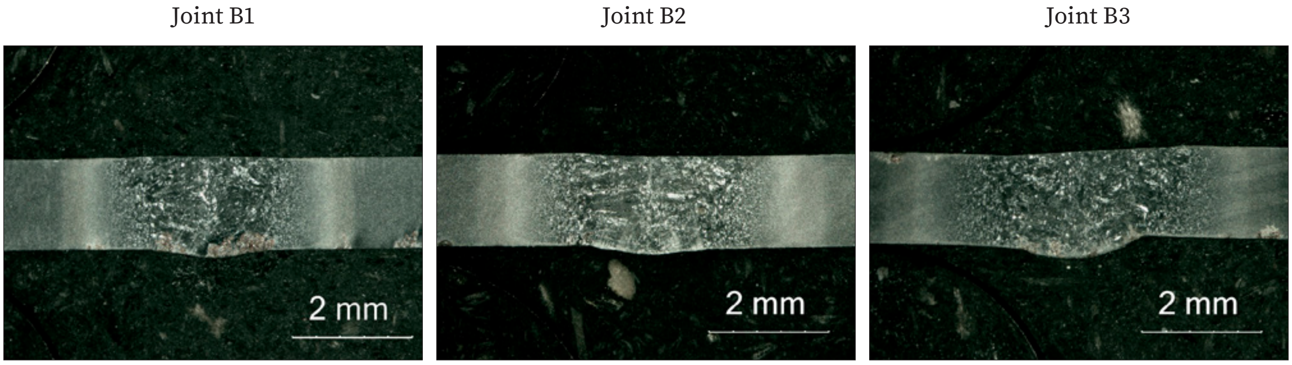

Fig. 5. Macrostructure of the test joints

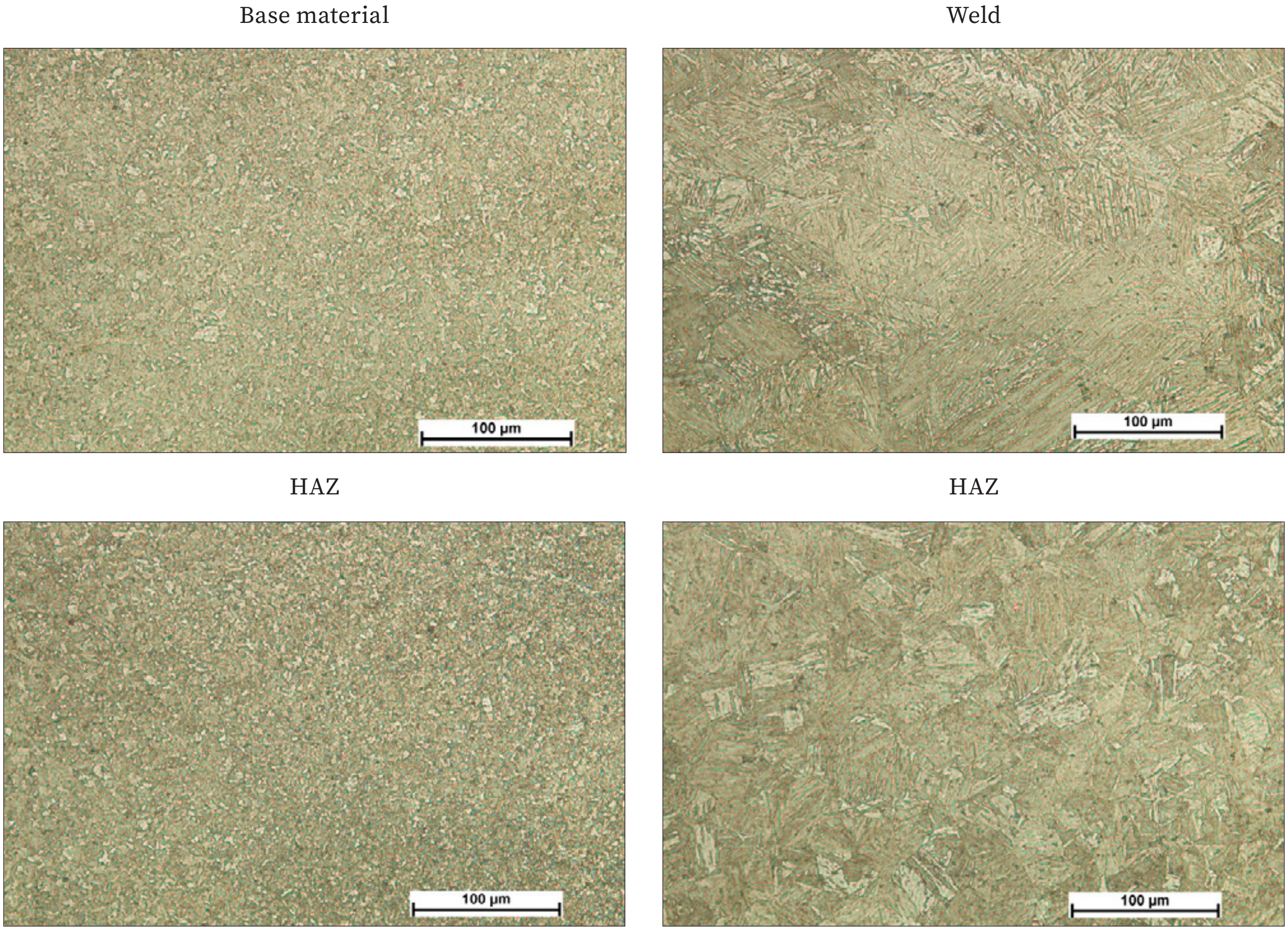

Fig. 6. Microstructure of joint B3

welding imperfections. The test joints were characterised by proper geometry (Fig. 5).

The microscopic metallographic tests revealed that the weld and the base material were characterised by the martensitic structure with variously sized aciculae. In turn, in the HAZ, it was possible to observe a tempered martensite structure, resulting from the effect of the welding thermal cycle (Fig. 6).

The analysis of hardness measurement results revealed that the hardest area in each of the test joints was the weld (370 HV). The heat affected zone (HAZ) softened and its hardness dropped to 260 HV. The hardness of the base material amounted to 350 HV (Fig. 7).

The face bend test (FBB) and the root bend test (RBB) revealed that the joints were characterised by good plasticity; none of the joints cracked. However, it was also possible to observe a non-uniform bend (the so-called springing) resulting from the formation of the tempered area, triggered by the welding thermal cycle (Fig. 8).

The static tensile test revealed that all the joints were characterised by a similar (mean) tensile strength of 1043 MPa and a similar (mean) elongation of 5.8 % (Fig. 9). The tensile strength values turned out to be lower than those declared by the manufacturer (approximately 1300 MPa), which could be ascribed to the longer effect of the heat source during manual welding.

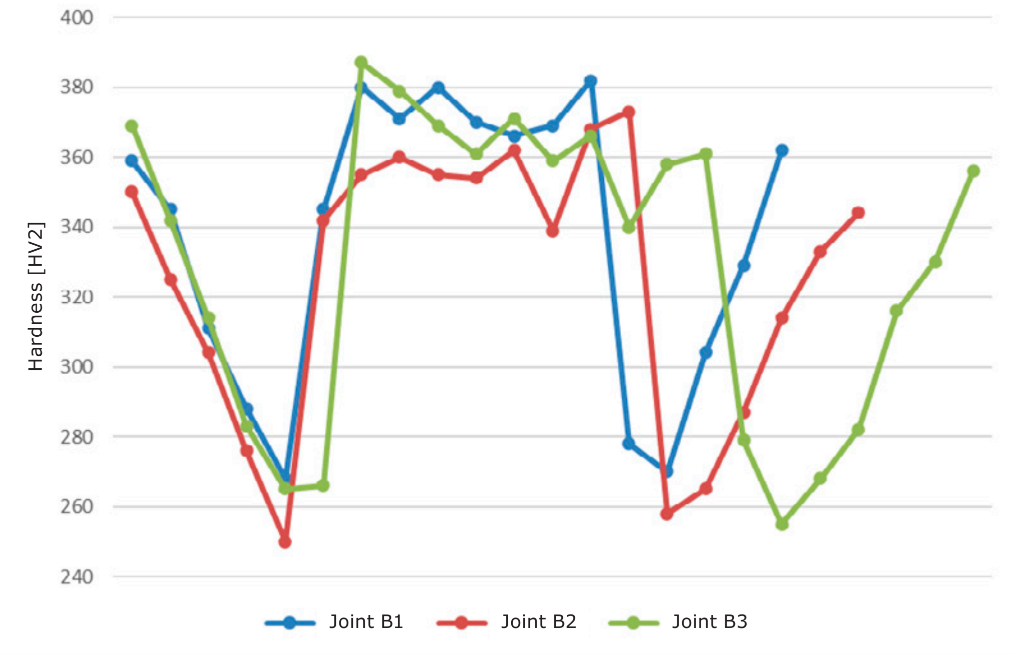

Fig. 7. Hardness distribution in the test joints

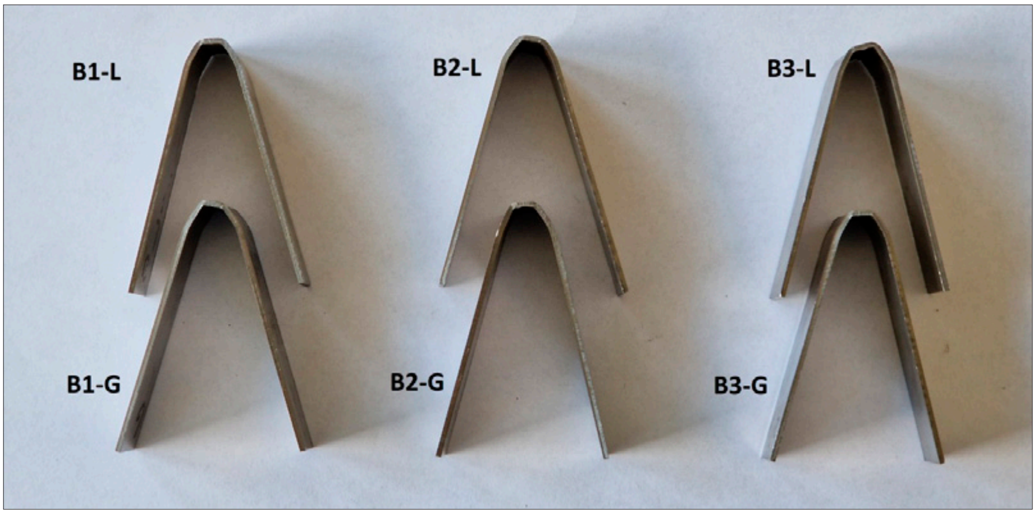

Fig. 8. Welded joints after the bend test

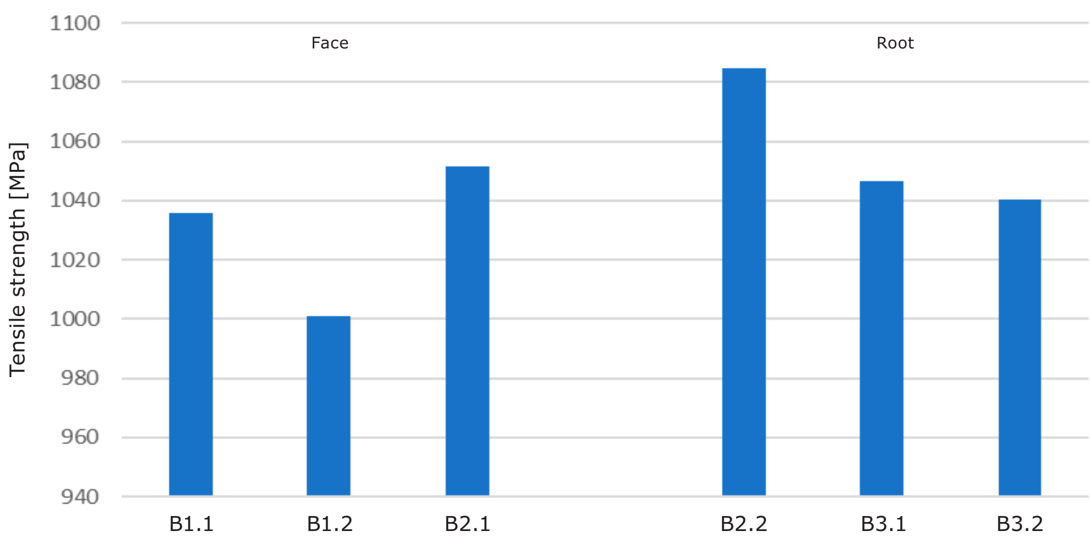

Fig. 9. Tensile strength of the test welded joints

5. Conclusions

The analysis of the test results led to the formulation of the conclusions presented below:

- The manual laser beam welding of car body sheets made of steel DOCOL 1200M guarantees the obtainment of favourable mechanical properties of joints.
- The use of the continuous-wave laser beam mode made it possible to minimise the number of welding imperfections (was revealed in the non-destructive tests).
- The manual laser beam welding process led to the softening of the HAZ, the hardness of which dropped to approximately 260 HV in comparison with that of the base material amounting to 360 HV and a weld hardness of 370 HV.
- An increase in the welding rate was responsible for the widening of the weld and the reduction of its hardness.

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