THE IMPACT OF WELDING WIRE ON THE MECHANICAL PROPERTIES OF WELDED JOINTS

Magdalena Mazur[1,*], Robert Ulewicz[1], Otakar Bokůvka[2]

[1] Czestochowa University of Technology, Institute of Production Engineering, al. Dąbrowskiego 69, 42-201 Częstochowa, Poland
[2] Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic

[*] corresponding author: e-mail: mazur.m@zim.pcz.pl

Resume

This paper presents results of the mechanical properties of Hardox 450 steel welded joints. These welded joints were made in accordance with welding procedure specifications (WPS), which was prepared and applied in the Wielton company. Fillers were provided by welding wires with two different diameters. The welding wire was G4Sil with diameter of 1.0 mm and 1.2 mm. The aim of this study was to examine whether the thickness of the welding wire has a direct effect on the properties of welded joints. Test specimens were made in similar parameters of the welding process. Then they were subjected to macroscopic examination, tensile strength, impact strength and hardness test were performed on the specimens.

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1. Introduction

Increased competition in the market of semitrailers forces manufacturers to design new solutions and use new materials. By analysis of the products of leading manufacturers of semitrailers including products of Wielton S.A. company, a tendency to use steel characterized by increased resistance to abrasion such as steel Hardox is observed. These steels are easily weldable and can also provide solutions how to reduce the weight of the trailer. All these actions are aimed to increase the technical object life time [1]. Based on research which are realized by Wielton S.A. it can be formed a list of requirements for materials, which are used for construction of semitrailers with particular emphasis on the requirements posed by the construction. Such materials must have features: very high wear resistance, the ability to transfer variable workloads, uniform properties throughout the cross-section of the element, as well as weldability, and ease of cold forming. Hardox steels are produced in six different types. Change the sheets on Hardox 400 to sheet Hardox 450 allows you to create lighter structures or extend the period of exploitation and sometimes both of these advantages occur together. After the change to Hardox 450 it is possible to use thinner sheet of metal in the design provided that there does not occur a significant decrease in fatigue strength, stability of the whole structure [2, 3].

A responsible choice of a suitable grade of structural steel used for components of machines and structures requires knowledge of the mechanical properties as well as fatigue properties of these steels. The study presents the initial results of investigations of properties of welded joints made of Hardox 450 steel according to the technical procedures recommended by the manufacturer. The steel is used for the parts of semitrailers, railroad cars, agricultural machines etc [4]. Investigations of weld properties made using welding wires of different diameters were aimed to find whether modification of this part of the welding process might significantly affect the properties of welded joints.

2. Preparation Procedure

Two 8 mm sheet metal specimens of Hardox 450 steel were prepared according to the Technological Welding Manual used in Wielton. The analysis was carried out for a V-shaped weld joint, welded in 4 passes by the method of metal active gas welding (MAG) [5]. The purpose of the analysis was to determine the mechanical properties of weld joints made in Wielton. The Welding Manual was developed in Wielton's engineering division based on the manufacturer's material specifications (filler, heat input).

In order to obtain the joint, the two 8 mm thick sheets of Hardox 450 steel were welded according to the diagram (Fig. 1). PF position (vertical from bottom to top) was used during welding [6].

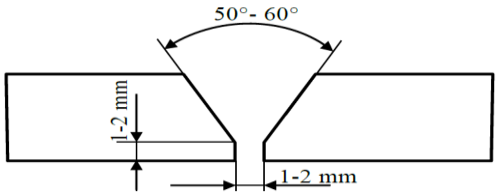

Fig. 1. Weld diagram.

For preparation of specimens it was used a material of which the chemical composition and mechanical properties are shown in Table 1. Properties shown in the table are specified by the manufacturer.

Fillers were provided by welding wires with two different diameters. The welding wire was G4Sil-DIN EN ISO 14341 with diameter of 1.0 mm and 1.2 mm. Equal value of heat input was used for both diameters of fillers. The shielding gas was a mix M21 (PN EN 439).

All the specimens were prepared by means of a conventional welding technique MAG. The parameters of welding process of the specimens are specified in the Table 2. Welded joints, made with the use of 1.0 diameter wire are marked 1225-1, and the specimens of 1.2 wire are mark 1225-2.

Table 1

Chemical composition and mechanical properties of used materials.

Chemical composition of the based material (at. %)											
Steel	C	Si	Mn	P	S	Al	Mo	Nb	V	CE	CET
Hardox 450 (8 mm)	0.16	0.45	1.36	0.01	0.001	0.034	0.012	0.011	0.010	0.41	0.30

Mechanical properties					
Material	**Yeld point R_e (MPa)**	**Tensile strength R_m (MPa)**	**Elogation A5 (%)**	**Hardness HB**	**Impact strength (J)**
steel Hardox 450	1250	1450	8	425 - 475	25J (-40°C)
Welding wire G4Sil	525	595	26	--	70 (-30 °C)

Table 2

Parameters of welding processes.

Welded joint	Direction of welding	DATA ON WELDING PROCESSES							
		Wire/Ø	**Transition T_0**	**Heat input Q (kJ/mm)**	**$T_{8/5}$ (s)**	**U (V)**	**I (A)**	**Speed (cm / min)**	**Gas**
1225 -1	L	G4Si1 /1.0	30 30 30 30	0.83 0.83 0.83 0.83	11.5 11.5 11.5 11.5	20 20 20 20	130 130 130 130	15 15 15 15	M21
1225 – 2	L	G4Si1 /1.2	30 30 30 30	0.83 0.83 0.83 0.83	11.5 11.5 11.5 11.5	20 20 20 20	130 130 130 130	15 15 15 15	M21

Table 3

Mechanical properties of welded joints.

Welded joint	Direction of welding	TENSILE STRENGTH TESTING							
		Direction	**$R_{p0.2}$ (MPa)**	**R_m (MPa)**	**A5 (%)**	**A80 (%)**	**Reinforcement**	**The crack point**	**wire Ø (mm)**
1225 - 1	L	T	580	682	5.3	6.1	No	Weld	1.0
1225 - 1	L	T	599	766	5.7	6.6	Yes	Weld toe	1.0
1225 - 2	L	T	564	688	6.2	7.1	No	Weld	1.2
1225 - 2	L	T	600	772	6.8	7.9	Yes	Weld toe	1.2

3. Testing results and discussion

Based on visual and macroscopic examinations of tested weld joints, the quality of the obtained welded joints was evaluated according to PN-EN ISO 5817 standard. With regard to the results, both types of welded joints met the requirements of B welding class (high requirements). In order to detect cracks on the surface or inside the joint, the specimens were subjected to X-ray non-destructive testing (NDT) [2, 7]. The NDT analysis did not reveal cracks or cavities and they excluded the lack of fusion. The examinations showed only excessive penetration (welding incompatibility 504). However, the measurements demonstrated that it was within tolerance limits of the standard.

3.1 Tensile strength testing

Tensile strength testing was carried out on two types of welded joints. One type was so called “reinforced welds”, where no additional operations such as grinding are carried out after welding. The second type, so called not reinforced were grinded after the welding so the surface of the weld metal was coplanar with the surface of the welded sheet metal. Not treated (reinforced) welds have usually higher tensile strength then the grinded ones.

The tensile tests were carried out in a way that the loading force was aligned perpendicularly to welding direction. The results of the tensile tests are presented in Table 3.

The term crack point means the place (area) where the crack is located. The data contained in Table 3 show that, all the cracks were found either in the weld or at the weld toe. The tested welded joints were welded with the material with lower strength than the strength of the base material. For this reason, it seems to be obvious that the defects occurred in the weld metal or at the weld toe. The microstructure in this area (weld metal and the area around the weld toe/HAZ [heat-affected zone]) was also more sensitive to stress [8]. Table 3 shows that tensile strength of joints was much lower than the strength of the base material (the respective values were 1250 MPa for $R_{p0.2}$ and 1450 MPa for R_m). It can also be observed that the tensile strength and yield point of welded joints are also higher than for the filler metal. The increase in strength, compared to filler strength results from mixing of the base material with the filler metal during the welding process.

Although, percentage of base material in the weld metal is insignificant, it contributes to improvement in mechanical properties.

Elongation of all welded joints is much lower than of the filler metal. However, when comparing elongation of both weld joints with the specific values for elongation of base material, one can observe that reduction in elongation is not as significant. In Figure 2 are summarised results of mechanical properties of welded joints welded with filler with diameter of 1.0 mm and 1.2 mm.

Comparison of the results obtained for the treated specimens with the non-treated specimens (reinforced) shows that mechanical properties (R_m and $R_{p0.2}$) are higher for those with reinforcement. This is caused by the fact that the cross-section is larger in the reinforced specimens when compared to the processed ones. However, no significant difference in mechanical properties (R_m or $R_{p0.2}$) was observed between joints, which were welded with wire with diameter of 1.0 mm or 1.2 mm. Only an insignificant increase in elongation is observed for the welded joint 1225-2 (welded with the wire with the diameter of 1.2 mm) compared to the weld joint 1225-1. This difference in elongation is not significant and is probably just a result of the measurement scatter. At present, there is no information about the influence of welding wire diameter on mechanical properties of welds in Hardox steels. All the parameters (current intensity, voltage and welding speed) are the same for both welded joints and the level of heat input is also kept constant; the only difference is the change of the wire diameter. Welds examinations results presented in this paper show that mechanical properties do not depend on diameter of wire use.

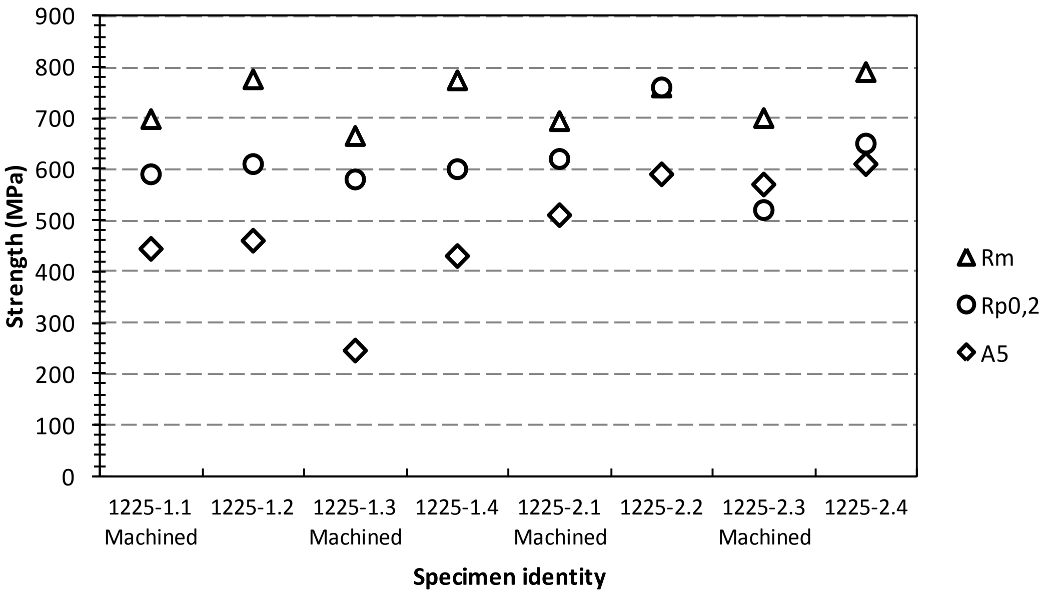

Fig. 2. Mechanical properties of studied weld joints.

3.2 Impact strength

Another examination carried out for the specimens was impact strength testing. Charpy V-notch specimens with dimensions of 10 x 6 mm (surface area of 48 mm^2) were prepared for the tests. The locations of notches with relation to the weld joint are presented in Fig. 3. The specimens were positioned perpendicularly to the welding direction. The specimens prepared in such manner were used in this study. Impact strength testing was carried out at the temperature of -40^{o}C to study the properties of the welded joints in the conditions of brittle fracture. This temperature has been chosen according to producer's standards (for this type of truck components).

Impact ductility is an essential parameter from the standpoint of the design process. According to the manufacturer, the specific value of impact strength for Hardox 450 steel is 25 J at -40^{o}C, which means 32 J/cm^2 at -40^{o}C (for the base material) [9, 10, 11]. The obtained results of impact strength for the weld joints analysed in the study are presented in Fig. 4.

As can be observed from Fig. 4, wire diameter does not affect impact strength for any of the four locations of the notch. All of them show high values of impact strength. The lowest impact strength was found for the weld metal (WM) and then for the fusion line (FL). Impact ductility increases with the distance from the weld metal towards the base material.

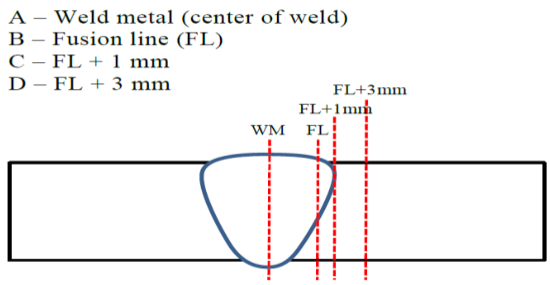

Fig. 3. Position of Charpy specimens used in the study.
(full colour version available online)

Comparison of impact ductility for the weld metal (WM) with the specific impact ductility of the filler (70 J for -30 ^{o}C – according to manufacturer's data) shows considerably higher impact ductility for the studied joints compared to the filler material. A very high impact strength joint is a result of using the G4Si1 welding wire and specific welding parameters.

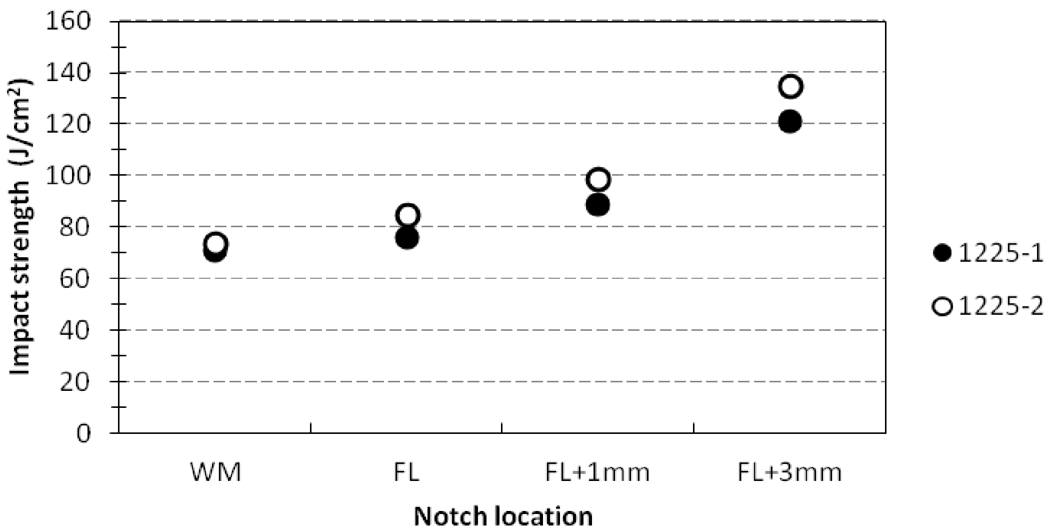

Fig. 4.Impact ductility of the weld joints tested at the temperature of -40^{o}C.

3.3 Hardness testing

Another stage of the examinations was hardness testing, carried out transversely to welding direction. Two sets of measurements were done at the distance of ca. 1.0 mm from the upper surface (black curve marked "surface") and 1.0 from the lower surface (white curve marked "root"). The result of hardness testing in the area of weld for the joint 1225-1 (wire diameter of 1.0 mm) are presented in Fig. 5, whereas Fig. 6 illustrates the results for the joint 1225-2 (wire diameter of 1.2 mm).

Analysis of the Figures 5 and 6 showed that hardness profiles are identical for both diameters of the fillers used for welding. Obviously, this is connected with the fact that the base and filler material in both cases was the same. Moreover, the level of heat input was also the same. Therefore, the hardness curves for both joints are identical. Testing of both upper and lower surface of the specimen showed a decrease in hardness from base material towards the heat-affected zone in the base material.

The fusion zone in both cases is characterized by the increased hardness, the exception is only for the profile on the specimen's surface (with 6 mm and 22 mm). After the sharp increase in the hardness, a rapid decrease in the weld metal zone can be observed. The increase in the hardness followed by the decrease occurs as a result of tempering of the material around the welded joint [12]. After the hardness decline, the values are increasing until they reach the hardness of the base material.

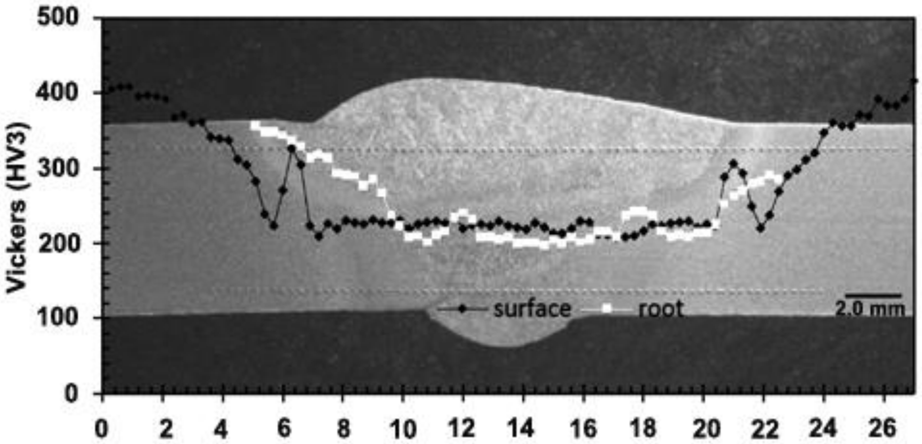

Fig. 5. Hardness profile for 1225-1 weld joint (wire diameter 1.0 mm).

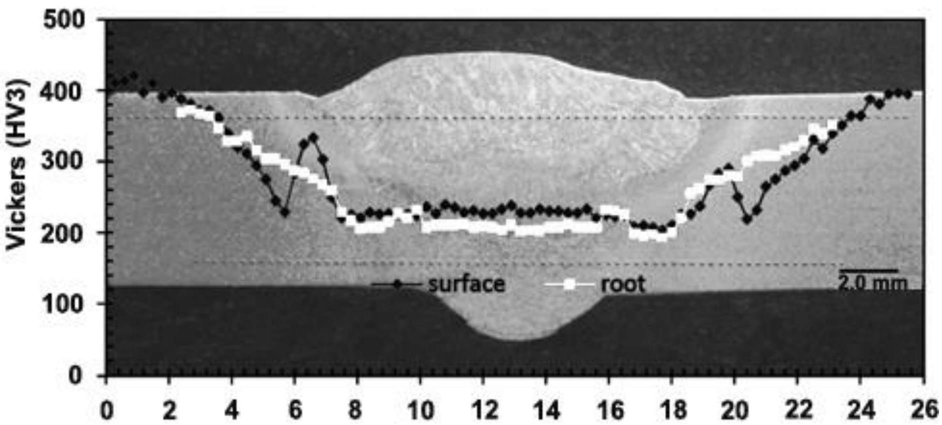

Fig. 6. Hardness profile for 1225-2 weld joint (wire diameter 1.2 mm).

4. Conclusions

The aim of this study was to examine whether the thickness of the welding wire has a direct effect on the properties of welded joints. The experimental study presented in this paper leads to the following conclusions:

- Both welded joints met the requirements of quality level B according to EN ISO 5817, which means no cavities and lack of fusion were found.
- According the construction standard the strength of both welded joints is fully acceptable in consideration of used filler metal. Obviously, comparison of strength properties with typical values for the base material shows a relatively high difference (of the order of 730-770MPa).
- Hardness profile for the whole weld is as expected i.e. hardness is reduced due to the contribution of heat input which causes tempering of the base material.
- An increase in the hardness in the fusion zone can be observed, probably due the higher cooling rate after melting the material during the welding process.
- Impact ductility is very high. The lowest impact ductility was found in the weld metal, but it is equal or greater than the typical impact ductility of the filler.

References

[1] WIELTON S.A.: Materiały informacyjne (Company information materials), Wieluń 2011 (in Polish).

[2] M. Mazur, R. Ulewicz, P. Szataniak: In: SEMDOK 2011. 16th International of PhD. Students' Seminar. University of Žilina, EDIS 2011, pp. 45-48.

[3] G. Pękalski, K. Haimann, Ł. Konat: Badania materiałowe stali Hardox 400 i stali Hardox 500 (*Materials research of Hardox 400 steel and Hardox 500 steel*). The report of the Institute of Materials Science and Applied Mechanics SPR 10/2005 series (*in Polish*).

[4] R. Ulewicz, M. Mazur, O. Bokůvka: In: Advanced Manufacturing and Repairing Technologies in Vehicle Industry. 30th International Colloquium on Advanced Manufacturing and Repairing Technologies in Vehicle Industry. Budapest 2013, pp. 61-66.

[5] W. Ptak, A.Tabor: Metody oceny jakości wyrobów metalowych. Inżynieria produkcji spawalniczej (*Quality assessment methods of metal products. Engineering of welding production*). Wydawnictwo Politechniki Karkowskiej, Kraków 2008 (*in Polish*).

[6] S. Karpiński, J. Moszumański, K. Radwan-Wiatrowski: Laboratorium z podstaw spawalnictwa (*Laboratory of the basics welding technology*). Politechnika Koszalińska, Koszalin 2004 (*in Polish*).

[7] J. Schijve: Fatigue of Structures and Materials. Kluwer Academic Publishers, Dordrecht – Boston – London 2001.

[8] S. Borkowski, M. Mazur, R. Ulewicz: In: Degradácia konštrukčných materiálov 2011. XII vedecká konferencja so zahraničnou účasťou. (Degradation of construction materials 2011. XII scientific conference with forein participants), University of Žilina, EDIS 2011, pp. 21-24.

[9] M. Mazur, R. Ulewicz: In: IV Międzywydziałowe Seminarium Kół Naukowych Politechniki Częstochowskiej. Materiały konferencyjne (IV Interdisciplinary Seminar for Student Scientific Groups Technical University of Czestochowa. Proceedings), Ed: A. Szarek, G. Stradomski, Częstochowa 2011, pp. 135-140.

[10] R. Mintách, F. Nový, O. Bokůvka, M. Chalupová: Mater. Eng. - Mater. Inz. 19(1) (2012) 22-28.

[11] E. Schmidová, P. Hanus: Mater. Eng. - Mater. Inz.19(4) (2012) 149-156.

[12] P. Skočovský, O.Bokůvka, R. Konečná, E. Tillová: Náuka o materiáli pre odbory strojnícke. (*Material science for mechanical engineering*), EDIS, Žilina 2008 (*in Slovak*).