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# Investigation into technology for making spot resistance welded joints used in the construction of rail car body components

## Introduction

An increasing demand for the modernisation of railway rolling stock in Poland and other countries in the European Union is responsible for an increase in investments in the development of modern car structures [1]. For this reason, rolling stock manufacturers undertake activities aimed at the following:

- introduce new structural solutions adapted for material possibilities,
- use modern manufacturing technologies,
- optimise the use of materials,
- improve quality,
- reduce the weight of vehicles,
- reduce production costs.

One of the examples of such activities includes whole car structures as well as car body components (side walls, cabins, roofs, passage walls). The structural elements of these components are cut using a laser, and bent in order to obtain self-fixing sections enabling their precise fitting (the use of the so-called interlocking) (Fig. 1).

The use of interlocking makes it possible to reduce weight while maintaining appropriate rigidity and strength of the structure, re-

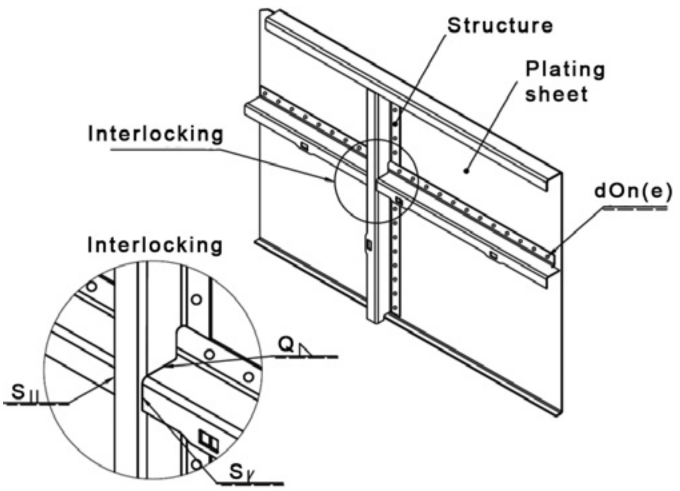


Fig. 1.Fragment of car side wall. Structure elements fixed by interlocking to each other and by spot resistance welding to plating

Fig. 2. Station for welding car body components produced by the ASPA company

Fig. 3. Station for welding car body components – the Bisiach & Carru company gantry

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Table 1. Results of shear tests of resistance welded joints made of X2CrNi12 steel sheets

| Thickness of sheets being joined [mm] | Maximum force obtained in tests [kN] | Maximum force required according to PN-EN 15085-3 [kN] | Measured weld diameter [mm] | Minimum diameter required according to PN-EN 15085-3 [mm] | Sample rupture manner during tests | Manner of rupture required according to PN-EN 15085-3 |
|---|---|---|---|---|---|---|
| 2,0 + 2,5 | 27,0 ÷ 30,3 | min 17,0 kN | 7,7 ÷ 8,4 | min 7,0 | in weld plane | by peeling or in weld plane |
| 2,0 + 3,0 | 31,1 ÷ 34,8 | | 9,2 ÷ 10,3 | | by peeling | |
| 2,0 + 4,0 | 31,0 ÷ 33,5 | | 8,2 ÷ 9,2 | | by peeling and in weld plane | |
| 2,5 + 2,5 | 27,0 ÷ 30,3 | min 22,0 kN | 8,1 ÷ 9,5 | min 8,0 | in weld plane | |
| 3,0 + 3,0 | 42,5 ÷ 47,6 | min 28,0 kN | 9,8 ÷ 10,6 | min 8,5 | in weld plane | |
| 3,0 + 4,0 | 38,6 ÷ 40,5 | | 9,7 ÷ 10,4 | | by peeling | |
| 3,0 + 6,0 | 51,5 ÷ 57,8 | | 10,2 ÷ 10,9 | | by peeling and in weld plane | |

duce assembly-related labour consumption and limit component straightening (or even eliminate it – depending on the method used for fixing the structure with plating), which, in consequence, makes it possible to reduce production costs. The elements of side wall structures, cabins or roofs are connected with the plating by, e.g. arc welding, laser welding (also hybrid welding), spot plasma and spot resistance welding. These processes are usually mechanised to a various extent (Fig. 2 and 3).

In the case of spot resistance welding, the determination of mechanical properties and the control of joint quality is carried out on the basis of standards PN-EN 15085 [2] and PN-EN ISO 15614-12 [3]. Spot resistance welded joints are allowed only for weld quality classes CP C1 to CP D according to PN-EN 15085 [2]. Spot welding is not allowed for weld quality classes CP A and CP B. Quite often, the plating of car body components and related elements of the structure of such components are made of steels of various thickness and grade. For this reason, spot resistance welding requires tests for each combination of connections.

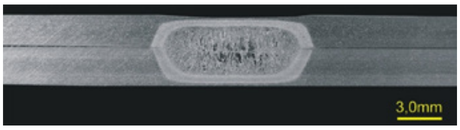
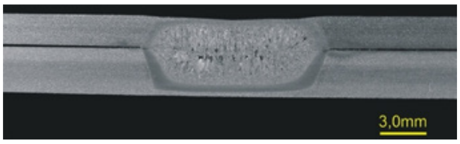
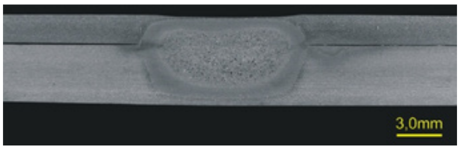
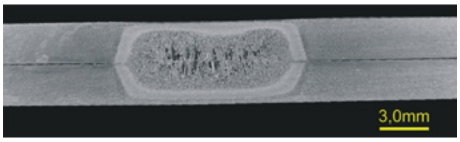
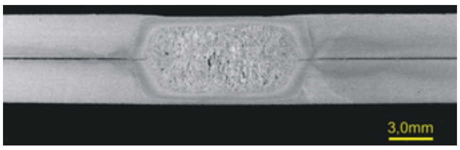
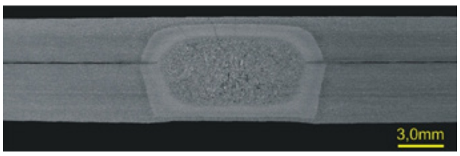
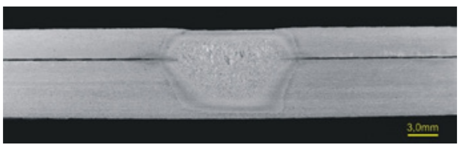
## Objective and scope of tests

The objective of the tests was to verify the quality and the mechanical properties of spot resistance welded joints made of sheets having thicknesses of 2.0 + 2.5 mm; 2.0 + 3.0 mm;

Table 2. Results of peeling tests of spot resistance welded joints made of X2CrNi12 steel sheets

| Thickness of sheets being joined [mm] | Measured weld diameter [mm] | Minimum diameter required according to PN-EN 15085-3 [mm] | Sample rupture manner during tests | Manner of rupture required according to PN-EN 15085-3 |
|---|---|---|---|---|
| 2,0 + 2,5 | 7,9 ÷ 8,5 | min 7,0 | by peeling and in weld plane | by peeling or in weld plane |
| 2,0 + 3,0 | 9,7 ÷ 10,0 | | by peeling | |
| 2,0 + 4,0 | 8,3 ÷ 9,0 | | by peeling | |
| 2,5 + 2,5 | 9,4 ÷ 10,3 | min 8,0 | by peeling | |
| 3,0 + 3,0 | 10,2 ÷ 11,5 | min 8,5 | by peeling | |
| 3,0 + 4,0 | 9,5 ÷ 10,1 | | by peeling | |
| 3,0 + 6,0 | 10,5 ÷ 11,4 | | by peeling | |

Table 3. Results of macroscopic metallographic tests of spot resistance welded joints made of X2CrNi12 steel sheets

| Thickness of joined sheets [mm] | Metallographic tests according to PN-EN 1321 |
|---|---|
| 2,0 + 2,5 |   etching: Adler etchant, weld diameter 8,2 mm, quality class CP C1 |
| 2,0 + 3,0 |   etching: Adler etchant, weld diameter 9,7 mm, quality class CP C1 |
| 2,0 + 4,0 |   etching: Adler etchant, weld diameter 8,9 mm, quality class CP C1 |
| 2,5 + 2,5 |   etching: Adler etchant, weld diameter 10,2 mm, quality class CP C1 |
| 3,0 + 3,0 |   etching: Adler etchant, weld diameter 10,3 mm, quality class CP C1 |
| 3,0 + 4,0 |   etching: Adler etchant, weld diameter 10,1 mm, quality class CP C1 |
| 3,0 + 6,0 |   etching: Adler etchant, weld diameter 10,3 mm, quality class CP C1 |

2.0 + 4.0 mm; 2.5 + 2.5 mm; 3.0 + 3.0 mm; 3.0 + 4.0 mm; 3.0 + 6.0 mm and made of ferritic corrosion-resistant steel X2CrNi12, according to PN-EN10088-1 [4]. Test joints were made using a flat electrode, from the external side of the plating sheet (from the external side of the car). The purpose of such an approach was to reduce the consumption of materials and labour at the car painting stage. The tests were carried out in accordance with the scope presented in standard PN-EN 15085 [2], extended by requirements contained in standard PN-EN ISO 15614-12 [3]. The scope of the tests included the following:

- visual inspection – involving 100% of joints (according to PN-EN ISO 17637 [5] ),
- shear tests (according to PN-EN ISO 14273 [6]) involving 11 samples,
- peeling test (according to PN-EN ISO 10447:2007 [7]) involving 11 samples,
- macroscopic metallographic tests (according to PN-EN 1321 [8]) involving 2 samples,
- hardness measurements (according to PN-EN ISO 14271 [9]) involving 1 sample.

## Course and results of tests

Overlap test joints were subjected to visual inspection. All the joints were assessed as representing the quality class CP C1. Afterwards, the joints were marked off in a manner making it possible to maintain the minimum width of the samples required for further tests. The samples were cut out mechanically. The examples of test sheets are presented in Figure 4.

Due to a significant number of samples, in order to maintain the clarity of this study, obtained results are presented in the form of the minimum and maximum scopes of values obtained for individual combinations of thicknesses.

A shear test was carried out using a testing machine. Measurements of weld diameters after peeling and shearing were carried out for each sample in two perpendicular directions. A similar approach was adopted during the peel test. The results of shear and peel tests are presented in Tables 1 and 2.

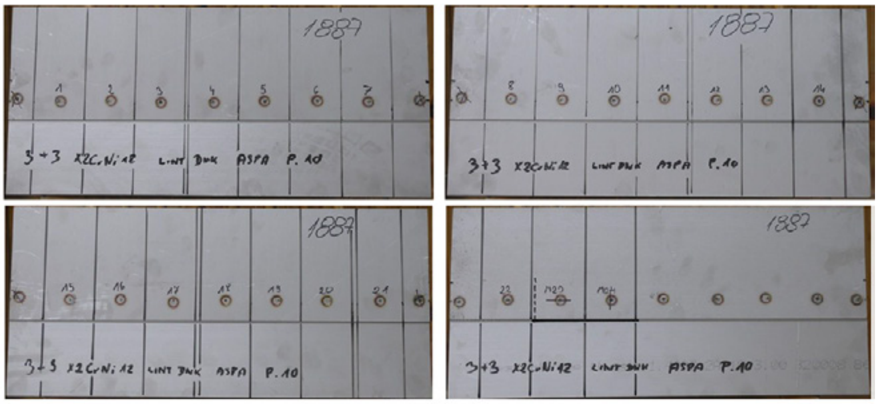


Fig. 4. Examples of test sheets with spot resistance welded joints made of 3.0 + 3.0 mm-thick steel X2CrNi12

The macro and microscopic metallographic tests were carried out in order to assess the quality of joints and their diameters in the interface of sheets being joined. The following assessment criteria were adopted: weld quality class CP C1, weld diameters required by standard PN-EN 15085 (presented in Tables 1 and 2 for individual combinations of connections) and the depth of weld nugget penetration in the material (min. 30%, max. 90% of a single sheet) (Fig. 5). The tests involved two joints of each combination. Table 3 presents 1 photograph for each set of samples. All the tested joints met the requirements of the aforesaid standard.

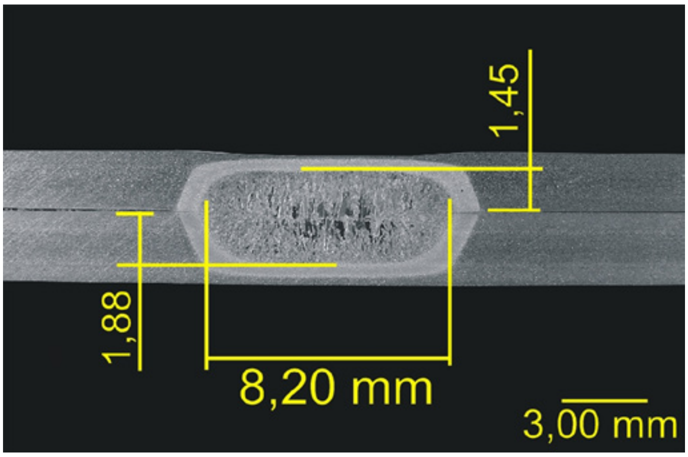
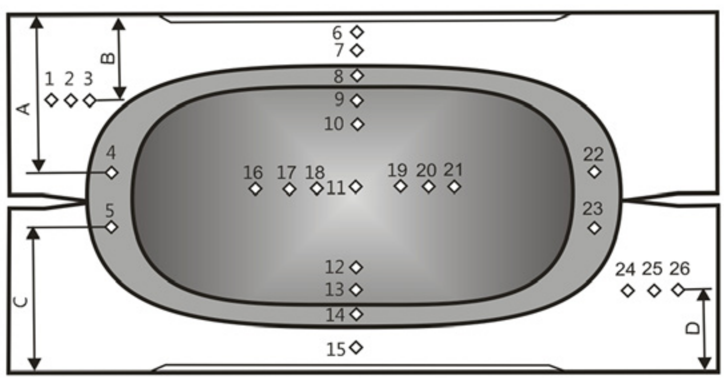



Fig. 5. Testing the depth of weld nugget penetration in material: steel X2CrNi12, the thickness of sheets being joined: 2.0 + 2.5 mm. Etchant: Adler.

Hardness measurements were carried out following the requirements of standard PN-EN ISO 14271 [9]) in accordance with the scheme presented in Table 4. The maximum hardness according to PN-EN ISO 15614-1 [10] should not exceed 380 HV. The results of

Table 4. Arrangement points at which the hardness of welded was measured




| Dimension | Welded joint [mm] | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2,0 +2,5 | 2,0 + 3,0 | 2,0 + 4,0 | 2,5 + 2,5 | 3,0 + 3,0 | 3,0 + 4,0 | 3,0 + 6,0 |
| A | 1,8 | 1,8 | 1,8 | 2,25 | 2,7 | 2,7 | 2,7 |
| B | 1,0 | 1,0 | 1,0 | 1,25 | 1,5 | 1,5 | 1,5 |
| C | 2,25 | 2,7 | 3,6 | 2,25 | 2,7 | 3,6 | 5,4 |
| D | 1,25 | 1,5 | 2,0 | 1,25 | 1,5 | 2,0 | 3,0 |

Table 5. Results of hardness measurements HV0.5 in spot resistance welded joints made of steel X2CrNi12

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thickness of sheets being joined 2.0 + 2.5 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 256 | 165 | 149 | 307 | 318 | 285 | 307 | 285 | 296 | 285 | 318 | 296 | 307 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 330 | 174 | 318 | 318 | 330 | 307 | 307 | 285 | 318 | 318 | 152 | 169 | 161 |
| Thickness of sheets being joined 2.0 + 3.0 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 117 | 165 | 169 | 276 | 258 | 152 | 241 | 296 | 296 | 285 | 241 | 307 | 307 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 276 | 276 | 249 | 189 | 258 | 226 | 201 | 226 | 296 | 249 | 152 | 156 | 141 |
| Thickness of sheets being joined 2.0 + 4.0 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 161 | 161 | 161 | 276 | 226 | 145 | 185 | 285 | 330 | 330 | 318 | 318 | 258 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 234 | 156 | 307 | 296 | 318 | 285 | 307 | 296 | 241 | 226 | 152 | 156 | 169 |
| Thickness of sheets being joined 2.5 + 2.5 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 169 | 165 | 161 | 330 | 307 | 169 | 241 | 307 | 318 | 330 | 266 | 285 | 330 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 330 | 285 | 307 | 213 | 276 | 213 | 296 | 285 | 318 | 330 | 165 | 161 | 165 |
| Thickness of sheets being joined 3.0 + 3.0 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 169 | 165 | 169 | 258 | 276 | 169 | 195 | 226 | 318 | 307 | 296 | 330 | 318 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 318 | 296 | 330 | 285 | 330 | 266 | 318 | 343 | 285 | 296 | 179 | 174 | 174 |
| Thickness of sheets being joined 3.0 + 4.0 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 80 | 165 | 174 | 307 | 307 | 165 | 169 | 307 | 330 | 330 | 234 | 318 | 330 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 285 | 174 | 258 | 318 | 330 | 330 | 307 | 318 | 296 | 296 | 156 | 165 | 174 |
| Thickness of sheets being joined 3.0 + 6.0 (mm) | | | | | | | | | | | | | |
| Measurement no. | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
| HV0,5 | 165 | 149 | 156 | 296 | 296 | 241 | 249 | 276 | 234 | 307 | 318 | 330 | 343 |
| Measurement no. | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** |
| HV0,5 | 285 | 165 | 307 | 330 | 318 | 307 | 296 | 276 | 307 | 318 | 174 | 179 | 179 |

hardness measurements are presented in Table 5. All the results are within allowed limits.

## Summary

The quality of welded joints depends directly on properly selected welding process parameters. Improperly selected parameters may cause imperfections such as an improper weld diameter or the improper depth of weld nugget penetration in the material. The tests confirmed that the adopted welding conditions ensure obtaining joints representing the quality class required by the documentation.

The mechanical properties of the tested joints met the requirements of standard PN-EN 15085-3 [2] with reference to the minimum shear forces and minimum weld diameters.

Table 6. Quality requirements related to tests and documentation according to PN-EN 15085

| Requirement | Weld quality class | | |
|---|---|---|---|
| | CP C1 and CP C2 | CP C3 | CP D |
| Visual inspection[1] | 100% | | |
| Simplified Weld Production Test (SWPT)[2] | - every day prior to commencement of work<br>- upon changing WPS<br>- after changing a tool | | |
| Normal Weld Production Test (NWPT)[3] | - for WPS qualification<br>- for verification of welding quality at regular intervals depending on welding volume, welding equipment and weld quality class | | Not required |
| Documentation | - NWPT 100%<br>Process control: 100% | - NWPT necessary | Not required |

[1] Inspection in relation to welding completeness and external assessment without using optical auxiliary resources;
[2] SWPT (Simplified Weld Production Test): peeling test, weld peel test with a chisel (according to ISO 10447) or simplified torsion test (production test) according to EN ISO 17653;
[3] NWPT (Normal Weld Production Test): for spot welding – tear test according to EN ISO 15614-12 along with macroscopic test

The conducted macroscopic tests revealed that all the welded joints represented the quality class CP C1 and were free from imperfections described in Table F.2 of standard PN-EN 15085-3 [2]. The measured diameters of weld nuggets met the requirements presented in Table F.4 of standard PN-EN 15085-3 [2]. The maximum depth of weld nugget penetration in the material did not exceed the boundary value referred to in this standard. The obtained hardness measurement results confirmed that all the measurement results did not exceed the maximum value of 380 HV, as specified in the requirements of standard PN-EN ISO 15614-1 [10].

Standard PN-EN 15085 obliges the manufacturer to verify, during production, the quality of a welding process, by carrying out simplified and normal production tests (Table 6).

For this reason, SWPT (Simplified Weld Production Test) documentation is used in production conditions and must be available at a welding station. Production-related experience has proved that interlocking and spot resistance welding used in the production of rail cars for joining structure elements with those of the plating significantly reduce component deformation. They also simplify the process of assembly and reduce the cost of fixtures, which can be less complicated (Fig. 6).

Fig. 6. Station for car body component assembly

## Conclusions

The conducted tests justify the formulation of the following conclusions:

1. The welded joints were free from welding imperfections,
2. The results of the visual inspection,

shear and peel tests, metallographic examination, measurements of penetration depth and hardness measurements carried out on spot resistance welded joints for all the tested combinations of joints revealed the compatibility of these results with the requirements of standard PN-EN 15085 for the weld class and dimensions assumed in the documentation.

## References


[1] Szubryt M., Fryc H.: Porównanie własności złączy blach ze stali ferrytycznej X2CrNi12 spawanych plazmowo i zgrzewanych rezystancyjnie punktowo. Biuletyn Instytutu Spawalnictwa, 2008, nr 5.

[2] PN-EN 15085:2007 Kolejnictwo. Spawanie pojazdów szynowych i ich części składowych. Część 1 ÷ 5.

[3] PN-EN ISO 15614-12:2006 Specyfikacja i kwalifikowanie technologii spawania metali. Badanie technologii spawania. Część 12: Zgrzewanie punktowe, liniowe i garbowe

[4] PN-EN 10088-1:2007 Stale odporne na korozję. Część 1: Gatunki stali odpornych na korozję.

[5] PN-EN ISO 17637:2011 Badania nieniszczące złączy spawanych. Badania wizualne złączy spawanych (oryg.)

[6] PN-EN ISO 14273:2005 Wymiary próbki i procedura badania na ścinanie złączy zgrzewanych rezystancyjnie punktowo, liniowo i garbowo.

[7] PN-EN ISO 10447:2007 Zgrzewanie rezystancyjne. Badanie na odrywanie i na odrywanie przecinakiem zgrzein punktowych i garbowych (oryg.).

[8] PN-EN 1321:2000 Spawalnictwo. Badania niszczące metalowych złączy spawanych. Badania makroskopowe i mikroskopowe złączy spawanych.

[9] PN-EN ISO 14271:2011 Zgrzewanie rezystancyjne. Badanie twardości metodą Vickersa (przy małym obciążeniu i mikrotwardości) zgrzein rezystancyjnych punktowych, garbowych i liniowych (oryg.).

[10] PN-EN ISO 5614-1:2008 Specyfikacja i kwalifikowanie technologii spawania metali. Badanie technologii spawania. Część 1: Spawanie łukowe i gazowe stali oraz spawanie łukowe niklu i stopów niklu.