TRANSPORT
2008
23(3): 240–244

THE IMPACT OF THE INTERNAL WELDING DEFECTS ON THE JOINT STRENGTH

Rimantas Didžiokas[1], Jolanta Janutėnienė[2], Jurgita Jonaitytė[3]

[1, 2] Klaipėda University, Bijūnų g. 17, 91225 Klaipėda, Lithuania
[3] "Baltija" Shipbuilding Yard, Pilies g. 8, 91503 Klaipėda, Lithuania
E-mails: [1, 2] mik.jtf@ku.lt; [3] jurgita.jonaityte@gmail.com

Received 14 January 2008; accepted 12 June 2008

Abstract. The paper looks at the impact of the internal welding defects on the strength of joints. The tension tests provided the values of the welded joint strength limits depending on the area of sporadic voids, slag intrusions and the field of discontinuities. Considering the results of the conducted experiments, the mathematical relationships between the strength of the welded joint and defected area were concluded. In presence of all three defects, the distance of the defects from the weld surface was measured. It is deduced that the defects nearer to the surface reduce the strength of the welded joint more than those noticed in deeper layers.

Keywords: welding, materials, tensile test, strength.

1. Introduction

Welding is one of the main technological fabrication processes of ship's hull. The quality of welded joints has a direct impact on the reliability of a ship. The structural mechanical features of welded materials as well as the quality of the weld depending on its internal defects are very important to the strength of welded joints. The destructive and non-destructive control is established on purpose to increase the reliability of welded joints in ship structures. The methods of destructive and nondestructive testing of welded joints are reviewed by Barkhatov (2003) and Meola *et al.* (2004). The ways of testing the reliability of the examined results are investigated.

The internal weld defects such as gas voids (porosity), slags and weld discontinuities are the constant problems of welded joints. The poor welded joints decrease production and labor productivity as well as raise production costs. The results of research confirm that the defects of internal welding have impact on the weld strength. Such impact on the abutting joints is analyzed by Serrano *et al.* (1998). Experimental research has proved that the quality and size of defects make impact on the strength of the studied joints. The relationship between the mechanical characteristics of welded joints and the amount of the fayalite slags in the weld was investigated by Navasaitis *et al.* (2003). Research of the impact ductility of the poor weld has proved that slag intrusions in the weld have impact on the ductility of its material.

The failure caused by the defects related to the welding procedures is investigated by Nguyen *et al.* (2004). These defects included cracks in the weld joint, unfused welds, slags and porosity. Weldmetal tearing resistance often overrides weld discontinuity's impact on weldment failure. The latter process is investigated by Matthews *et al.* (2001). The impact of porosity on thermite welds was analyzed by Chen *et al.* (2006). The relationship between the fatigue strength and the amount of the gas voids in the weld area was found by applying X-ray methods. The impact of porosity variation on multipass V-groove weld metal properties is investigated by Pereira Pessoa *et al.* (2006).

Although research on the internal defects of the welded joints of metal connections having impact on the mechanical characteristics of the weld has been carried out, such investigation is neither sufficient nor their results are elaborate enough to be applicable in the concrete cases. The impact of the internal defects on the strength welded joints of steel AH36 is analyzed in this work. Rutile powder welding wire NST FC-1 was used for welding and the shielded metal arc welding was done by semiautomatic machines using FRONIUS welding equipment.

The main purpose of this article is to determine how different types of the internal welding defects make impact on the strength limit of the weld depending on the defect parameters and their positioning in the weld. The research object is the internal defects of welded joints including slag intrusions, weld discontinuities and gas voids (porosity).

ISSN 1648-4142 print / ISSN 1648-3480 online
www.transport.vgtu.lt
DOI: 10.3846/1648-4142.2008.23.240-244

2. Methods and equipment

Experimental research was carried out. To define defect type, width and the distance from the weld middle line, the X-ray method was chosen. The depth of the defect was found using the ultrasonic method. The seam strength was defined by the transverse tension test. The regression correlation analysis was applied to the results of research.

2.1. Selection of the structural elements from the welds for the test

The research objects were chosen from all structural steelwork that had been welded by shielded metal arc welding using the semiautomatic machines. Welding was done applying FRONIUS welding equipment containing TransPlusSynergic 4000/5000 power source, VR 4000 wire feeder and JobMaster welding burner.

The type of the welded seams is V shaped butt joint with the oblique edges. The weld cross-section scheme is shown in Fig. 1.

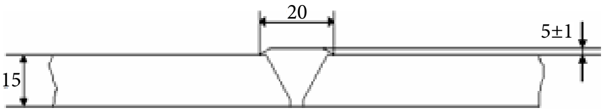

Fig. 1. The weld cross-section scheme

The parameters of the welding process and the structural elements of the joint are chosen according to standard (LST EN 440:1997).

The samples for a tension test are cut from the sheet across the welded joint. After the mechanical treatment of samples the welding seam must stay in the middle of the sample.

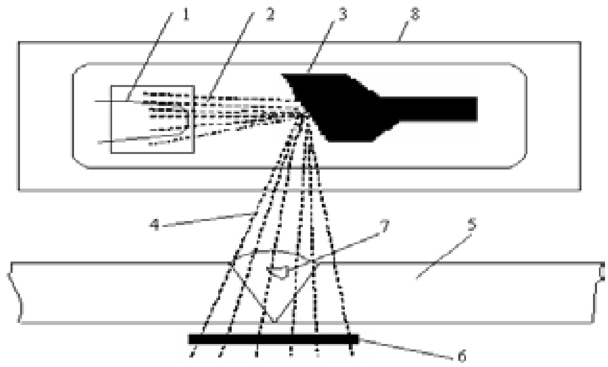

Fig. 2. The scheme of detecting the internal weld defects: 1 – cathode, 2 – electron flux, 3 – anode, 4 – X-ray, 5 – the X-rayed metal, 6 – cartridge, 7 – defect, 8 – leaden case

2.2. X-ray testing of the welds

The x-ray method was chosen to find the internal defects of the welds. The application procedure of this method is defined in standard (LST EN 1435:1998). The test was done using the X-ray scanner DOP 200.

The X-rays passing through the metal weaken because they are absorbed by the metal atomic grating. The weakening process of the X-rays depends on the thickness of the metal and its physical and chemical qualities. After passing the metal, the X-rays of different intensity are recorded on the cartridge situated on the opposite side (Fig. 2). Darker spots appear on the cartridge in the defected areas. The defects recorded on the X-ray cartridge are identified according to their type and geometrical parameters (length, width and the distance from the weld middle line).

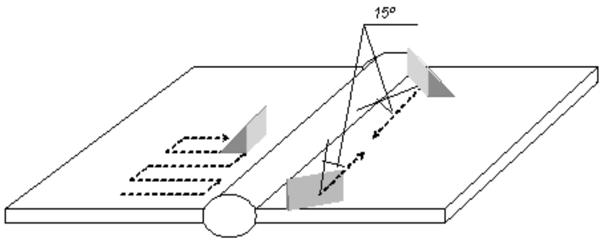

Fig. 3. Ultrasonic testing of the butt joint

2.3. Ultrasonic testing of welds

The location of the defects in the weld was detected using the method of ultrasonic testing by standard (LST EN 1714:2000). The test was done using the ultrasonic scanner USM 52. The scheme of appliance is shown in Fig. 3.

High frequency sound oscillation directed to the weld reflects from non metallic inclusions, voids and cracks. The reflected ultrasonic signal is amplified, transformed into the alternating current and directed to the electron ray tube (oscillograph) where the defect is drawn by the impulse of a specific shape which after being decoded shows the location of the defect.

2.4. Methods for estimating the strength characteristics of the welds

The transverse tensile test (according to the standard LST EN 1714:2000) is done to determinate the main mechanical qualities of the material. The test is performed in the room temperature (23±5) °C. The samples are tensioned by the hydraulic machine ГРМ-1. The maximum power developed is 500kN.

The tension load is mountainously increased until the sample is destroyed. The strength limit and the breakage place of every sample are recorded.

2.5. Methods for analyzing the collected data

The regression correlation analysis was applied to the research results. The analysis allows determining relationship intensity, shape and mathematical expression between the variables and depended variable. The above mentioned dependences between various parameters were calculated using MS Excel spreadsheet software. The relationship between two random values is estimated by the correlation coefficient.

3. Results of the experiments

The X-ray photos of the welded joints given in Figs 4–6 show the characteristic defects occurring in the welds. Slag intrusions occurring in the welded connections can be sporadic or located in a chain (Fig. 4). The welding discontinuities (Fig. 5) can be located between the layers and along the toe or root (the X-ray photo). Gas voids (Fig. 6) can be sporadic, linear or scattered.

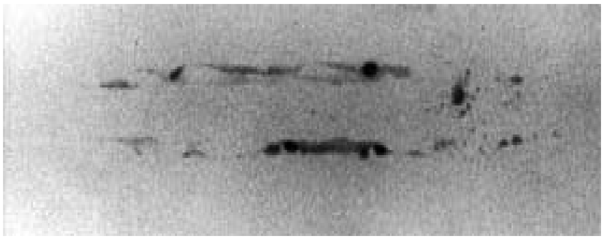

Fig. 4. Slag intrusion lines (X- ray photo)

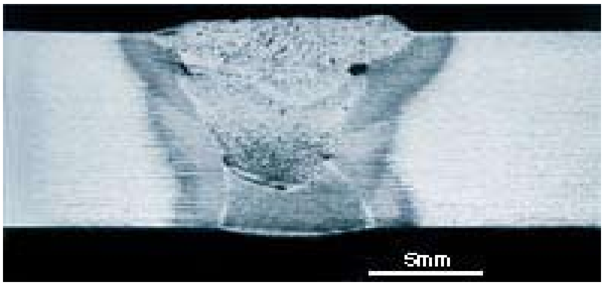

Fig. 5. Discontinuities between the layers (the X-ray photo)

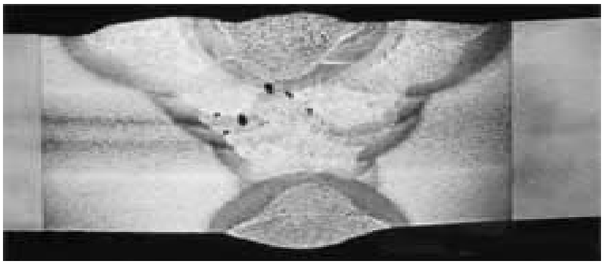

Fig. 6. Gas voids

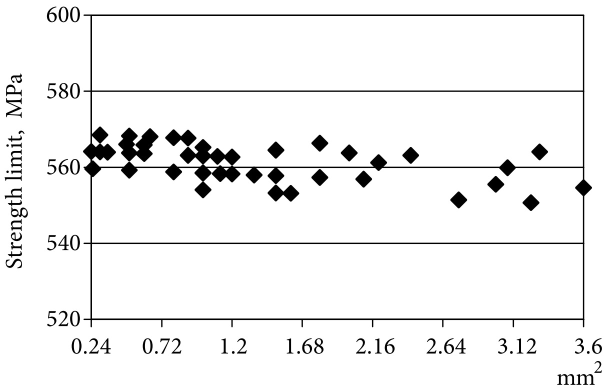

Fig. 7. Values of the welded joints strength limit depending on the area of sporadic gas voids

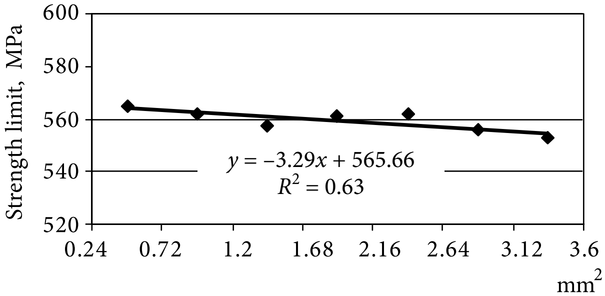

Fig. 8. Welded connection strength dependence on the area of gas voids

3.1. Dependence of the weld's strength limit on the geometric characteristics of gas voids

The samples welded using the rutile-powder welding wire NST FC-1 with rapidly cooling slag broke right in the metal of the welded joint. From all X-ray photos the images with at least one visible defect of varying coverage were selected.

During the tension experiment, the values of the welded joints limit were estimated in relation to the area of sporadic gas voids (see Fig. 7).

The values provided by the experiments were divided into intervals and the average value of the interval was calculated.

After the regression analysis of the experiment results had been completed, the dependence of welded connection strength on the area of gas voids was achieved (see Fig. 8). The equation of linear regression is

$$y = -3.29x + 565.7, \tag{1}$$

where: y – strength limit, x – the area of gas voids.

The results of experimental research were analyzed from different perspectives - the distance of sporadic gas voids from the middle of the welding line and the strength limit value of welded joints (Fig. 9).

It can be noticed that the defects located nearer the weld edge decrease the strength of the welded joint. Similarly, the relationship between gas voids location in relation to the middle of the welding line and the strength of the welded joint was observed.

After the regression analysis is deduced, the equation of parabola

$$y = -0.19x^2 - 0.13x + 564.83, \tag{2}$$

where: y – strength limit, x – the distance of gas voids from the middle of the welding line (Fig. 10).

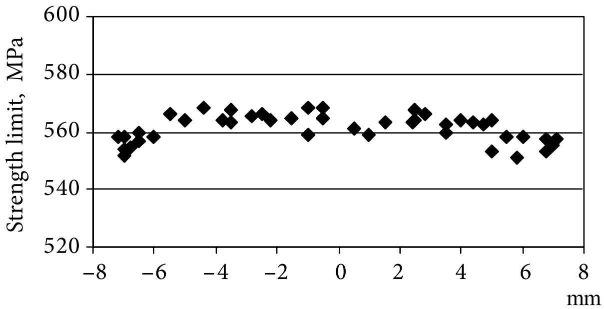

Fig. 9. The strength limit values of welded joints

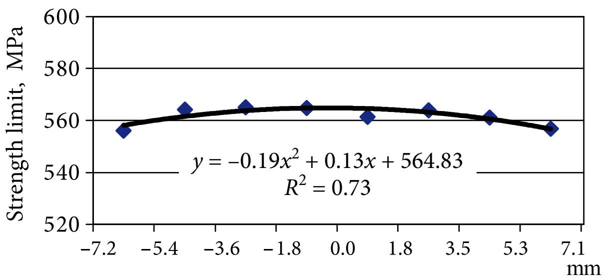

Fig. 10. Relationship between welded joint strength and the distance of gas voids from the middle of the welding line

3.2. Relationship between welded joint strength and the geometric parameters of slags

The results of the tension test of the sporadic slag intrusions area and welded joints with the before introduced results are given in Fig. 11.

After the regression analysis of the results had been performed, a relationship between the strength of the welded connection and the area of slag intrusions was proved (Fig. 12).

The equation of linear regression is

$$y = -1.59x + 564.32, \tag{3}$$

where: y – strength limit, x – the slag area.

Similarly, the impact of the localization of slag defects in relation to the middle of the welding line on welded joint strength was estimated.

Regression analysis shows dependence between welded joint strength and the localization of slag defects relatively to the middle of the welding line (Fig. 13).

This dependence shows that welded joint strength decreases when the defect is located nearer the weld edge.

3.3. The relationship between welded joint strength limit and sporadic discontinuities

The results of the tension tests on the joints with sporadic welding discontinuities are shown in Fig. 14.

Regression analysis shows dependence between welded joint strength and sporadic discontinuities (Fig. 15).

The equation of linear regression is

$$y = -1.52x + 566, \tag{4}$$

where: y – strength limit, x – sporadic discontinuities.

Similarly, a relationship between welded joint strength and the distance of discontinuities from the middle of the welding line was achieved (Fig. 16).

In presence of all three defects, their distance to the surface of the joint was measured. In all cases the results

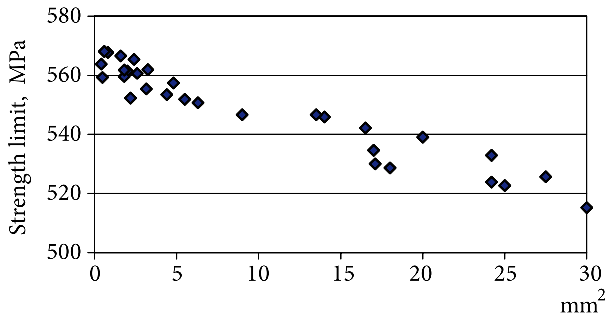

Fig. 11. Values of the strength limit of the welded joint and the geometric slag parameters

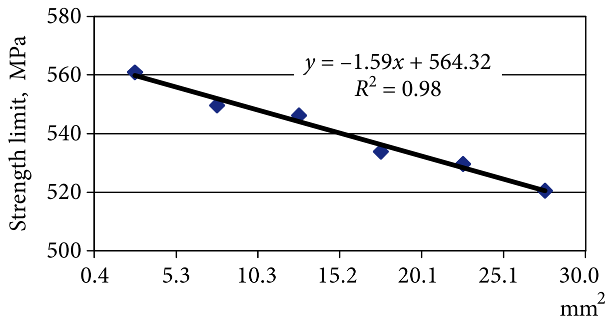

Fig. 12. Relationship between the strength of the welded connection and the slag area

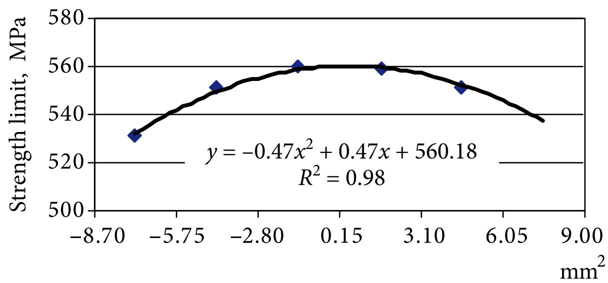

Fig. 13. Dependence between welded joint strength and sporadic slag distance from the middle of the welding line

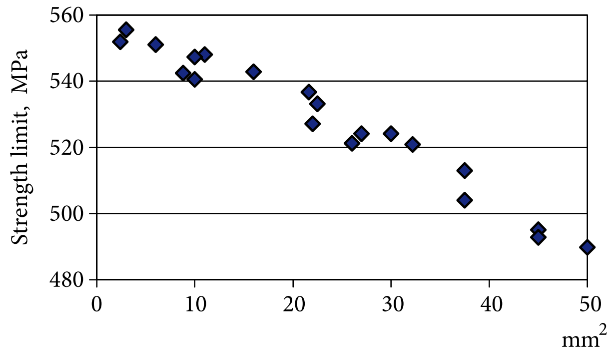

Fig. 14. Welded joint strength limit values with sporadic welding discontinuities

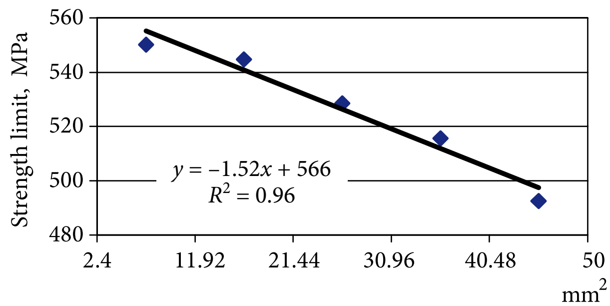

Fig. 15. Dependence between welded joint strength and sporadic discontinuities

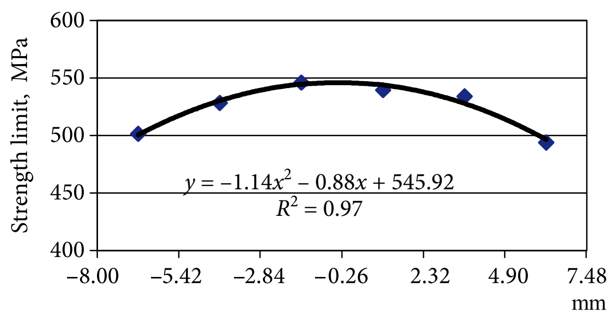

Fig. 16. Relation between joint strength and the distance of discontinuities from the middle of the welding line

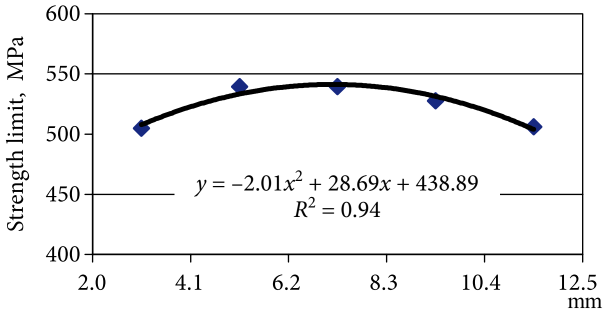

Fig. 17. Relationship of the strength of the welded joint and sporadic discontinuities distance from the surface of the weld

were very similar – the defects nearer to the surface degrade the welded joint more than those in deeper layers.

The relation of the strength of the welded line and defect distance from the surface is displayed in Fig. 17.

4. Conclusions

1. The experimental investigations of the welded joints have proved that the defects (voids, slag intrusions, discontinuities) reduce the strength of welded joints when joint material is a weakly alloyed NST FC-1 rutile-powder wire.
2. The experiments prove the relation between welded connections strength and a defected area, their distance from the middle of the welding line and the depth from the weld surface. The linear regression equations relation of the strength limit and the area of defects (voids, slag intrusions, discontinuities) are deduced.
3. The resultant mathematical relationships allow estimating compliance with the strength requirements of metal constructions manufactured from AH36 steal by carrying on standard routines to evaluate the quality of the welding joint measuring the internal defects of the joints.
4. The results of this study provide material for improving and refining the existing requirements for the quality of welding joints by performing a classification in relation to the requirements to the strength of welded joints. In turn, this would increase the efficiency of manufacturing steal constructions.

References

Barkhatov, V. A. 2003. Development of methods of ultrasonic nondestructive testing of welded joints, *Russian Journal of Nondestructive Testing* 39(1): 23–47.

Chen, Y.; Lawrence, F. V.; Barkan, C. P. L.; Dantzig, J. A. 2006. Weld defect formation in rail thermite welds, in *Proceedings of the I MECH E. Part F. Journal of Rail and Rapid Transit* 220: 373–384.

Matthews, J. R.; Hyatt, C. V.; Porter, J. F. 2001. Future treatment of weld acceptance: The significance of incomplete fusion discontinuities in low structural transition temperature gas metal arc weldments, *Materials Evaluation* 59(4): 523–530.

Meola, C.; Squillace, A.; Minutolo, F. M. C.; Morace, R. E. 2004. Analysis of stainless steel welded joints: a comparison between destructive and non-destructive techniques, *Journal of Materials Processing Technology* 155–156: 1893–1899.

Navasaitis, J.; Jutas, A.; Žiliukas, A.; Leišis, V.; Mockaitis, J.; Žaldarys, G.; Meslinas, N. 2003. Analysis of microstructure and mechanical properties of wrought iron, *Material Science* (Medžiagotyra) 9(1): 9–12.

Nguyen, T.; Romios, M.; Es-Said O. S. 2004. Failure of a conveyor trunnion shaft on a centrifuge, *Engineering Failure Analysis* 11(3): 401–412.

Pereira Pessoa, E. C.; Bracarense, A. Q.; Zica, E. M.; Liu, S.; Perez-Guerrero, F. 2006. Porosity variation along multi-pass underwater wet welds and its influence on mechanical properties, *Journal of Materials Processing Technology* 179(1–3): 239–243.

Serrano, E.; Larsen, H. J.; Gustafsson, P. J. 1998. Influence of defects on the strength of finger-joints, in *Proceedings of the 5th World Conference on Timber Engineering*, 854–855.

LST EN 440:1997. Suvirinimo medžiagos. Elektrodinė viela ir siūlės metalas. Nelegiruotųjų ir smulkiagrūdžių plienų lankinis suvirinimas lydžiuoju elektrodu apsauginėse dujose. Klasifikavimas [Welding consumables. Wire electrodes and deposits for gas shielded metal arc welding of non alloy and fine grain steels. Classification]. Lithuanian standards board, Vilnius.

LST EN 1435:1998. Virintinių siūlių neardomoji kontrolė. Suvirintųjų sujungimų radiografinė kontrolė [Non-destructive examination of welds. Radiographic examination of welded joints]. Lithuanian standards board, Vilnius.

LST EN 1714:2000. virintinių siūlių neardomoji kontrolė. Suvirintųjų sujungimų ultragarsinė kontrolė [Non-destructive examination of welds. Ultrasonic examination of welded joints]. Lithuanian standards board, Vilnius.