846. Static and vibrational analysis of the GMAW and SMAW joints quality

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Abstract. Structural steel S235JR is one of the main high-strength steels, while the most common welding methods are gas metal arc welding and shielded metal arc welding. Any of weld-strength-related defects can lead to weaker, less ductile welds, cracking and rupture in various steel constructions. Therefore quality of GMAW and SMAW joints were analyzed by using both the destructive tensile strength test and the non-destructive holographic interferometry method. Tensile test results of 10 arc welded specimens and holograms of harmonically excited specimens are presented in this paper. Specifications of specimens and welding parameters are also reviewed along with methodology of the experimental investigation and criteria of the analysis.

Keywords: SMAW, GMAW, welding, yield strength, ultimate strength, holography, vibrational analysis.

Introduction

Welding is an economical and fast process of joining two materials. Actually, many products could not even be made without the use of welding [1-3], for example, building constructions, pipelines, automobiles, etc. Welding processes play an important role in metal fabrication industry. There are various welding techniques: submerged arc welding [4], tungsten inert gas welding [1, 5], metal inert gas welding [2], plasma arc welding [6], etc.

The two most commonly used types are gas metal arc welding (GMAW) [7, 8] and shielded metal arc welding (SMAW) [5, 9]. All commercially important metals such as carbon steels, high-strength low-alloy steels, stainless steels, aluminum, copper, titanium and nickel alloys can be welded in all positions with GMAW process by choosing appropriate shielding gas, electrode, and welding variables [10, 11]. SMAW is not so universal. It is designed to weld iron and steels but aluminum, nickel and copper alloys can also be welded with this method. But it is dominant in the maintenance and repair industry, in the construction of steel structures and in industrial fabrication because of its versatility and simplicity [12].

The most common quality problems in SMAW are weld spatter, porosity, poor fusion, shallow penetration and cracking [5, 9]. Two of the most prevalent quality problems in GMAW are dross and porosity [10, 11]. Any of these weld-strength-related defects can lead to weaker, less ductile welds and cracking. According to nature of weld joint making and properties of welded structure, the mentioned defects are not visible without the use of advanced nondestructive or destructive testing methods [1, 13-15].

Therefore the aim of this paper is to examine quality of 10 arc welded specimens and to determine causes of defects using tensile strength testing machine and non-destructive holographic method. For better interpretation of GMAW and SMAW weld seam quality, results of tensile strength test for specimens manufactured from structural steel S235JR according to LST EN 895:1998 standard, are analyzed. S235JR steel plate is one of the main carbon and low alloy steels, which is used to build ships, bridges and belongs to group of high strength steels.

Specimen dimensions and welding parameters are also reviewed along with methodology of the experiment and criteria of the analysis.

Experimental setup

Specifications of specimens

Quality control tests of the welding seam were performed on the specimens manufactured according to Lithuanian standard LST EN 895:1998. This is the standard for tensile strength test. Dimensions of the specimens to be welded are shown in Fig. 1, while the welding scheme is depicted in Fig. 2.

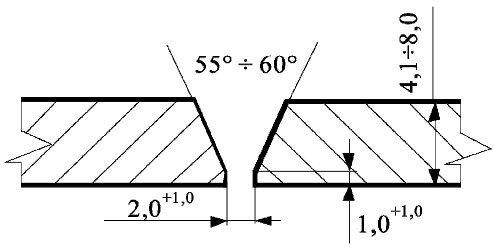

Fig. 1. Allowable deviations for the dimensions of the specimens

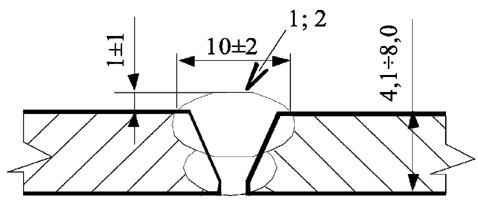

Fig. 2. Welding scheme. Welding was conducted in two passes

Table 1. Chemical composition of steel S235JR

C %	Mn %	Si %	P %	S %	N %	CEV %
≤ 0.17	≤ 1.40	–	≤ 0.035	≤ 0.035	≤ 0.012	0.35 – 0.40

Fig. 3. GMAW (a) and SMAW (b) welded specimens

The welding was done in two passes (Fig. 2). Five specimens were welded in SMAW method and five - in GMAW. The steel used is structural steel S235JR (Table 1) (thickness - 5 mm, width - 28 mm, characteristic yield strength - 235 MPa, characteristic ultimate strength - 360 MPa, countable yield strength - 215 MPa, countable ultimate strength - 325 MPa) [16]. The composition of shielding gas used: 82 % argon, 18 % CO_2 and < 0.03 % NO. Filler metal used is OK Autrod 12.50 coated non-copper filler metal. Characteristic GMAW and SMAW welded specimens are presented in Fig. 3. Average cross-section area of the GMAW seam is 198 mm^2, and 195.8 mm^2 of the SMAW seam, while average cross-section area of the base metal near weld seam is 140 mm^2.

Tensile strength test

Static tests of weld seam-like specimens were performed on the basis of test machine of 10 metric tons (Type RM 104), providing controlled uniformly increasing tension force applied to the specimen. The specimen ends are gripped and fixed in the machine and its gauge length L_0 (a calibrated distance between two marks on the specimen surface) is continuously measured until the rupture. During the tensile strength test such data was acquired: the values of yield and ultimate forces, elongation of specimen at the point of failure and contraction of the specimen cross-sectional area, visual analysis of specimens and diagrams of the experiment. The expected results for this test is that the material will not fail until the characteristic yield and ultimate strength for the base material is reached (for failure in base metal) and/or that the welding seam would hold at least 90 % of the base metal strength (if failure appears at welding seam).

Holographic method

Quality of welding seams was also analyzed by means of non-destructive holographic method. It is particularly powerful tool for studying fractures of small seams. The testing was performed with HYTEC PRISM holographic interferometry system that is presented in Fig. 4, while specimens were subjected to harmonic excitation by means of a electrodynamic shaker with the frequency of 2.4 kHz. HYTEC PRISM system is a two beam speckle pattern interferometer. The laser beam (λ = 532 μm) directed at the object is the object beam, the other beam, which goes directly to the camera, is the reference beam. Laser light is scattered from the object and collected by the camera lens, which also images the object onto the CCD camera sensors. The reference beam goes directly to the camera, usually in an optical fiber, where it overlaps the image of the object. Shape changes that occur between a reference and a stressed state of the object produce fringes on top of the image of the object, which is displayed on the monitor.

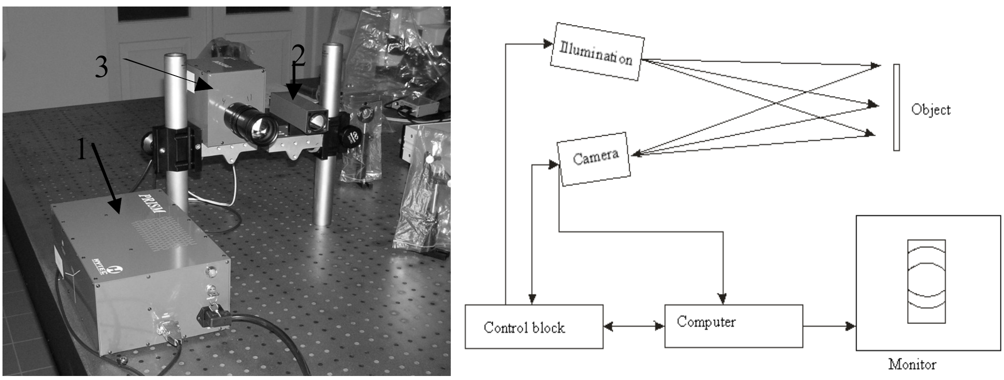

Fig. 4. Holographic HYTEC PRISM system (1 – control block; 2 – illumination head; 3 – CCD camera) and its optical setup

Results and discussions

The diagrams obtained from the tensile strength tests of the GMAW specimens are provided in Fig. 5 and results of the SMAW specimens tests - in Fig. 6. The black, bold lines mark the minimum values of yield and ultimate strength of the base metal and black, dashed, bold lines mark the minimum values of yield and ultimate strength of the welding seam.

GMAW stress-strain diagrams given in Fig. 5 indicate that only one specimen (No. 2) has failed. The specimen is presented in Fig. 7. Though the specimen has only failed to reach the required yield strength σ_y = 324 MPa according to STR 2.05.08:2005 standard, yet it is considered to be a fault since yield strength failure may lead to faster fatigue of the construction resulting in failure of the complete construction. In the case of irregularities visual inspection of location of failure was applied to find out the possible causes of failure.

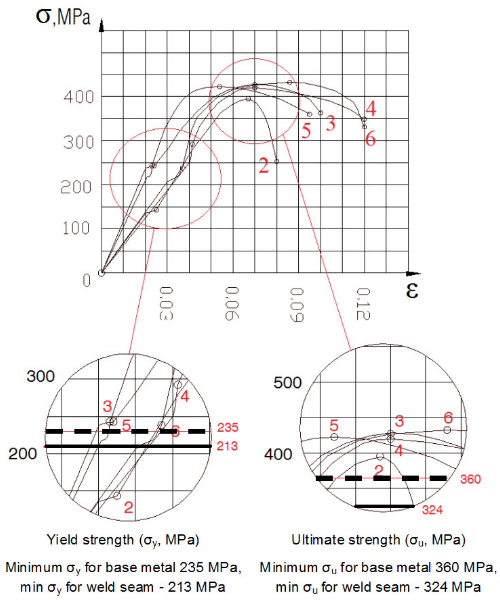

Fig. 5. Stress-strain diagrams of GMAW welded specimens

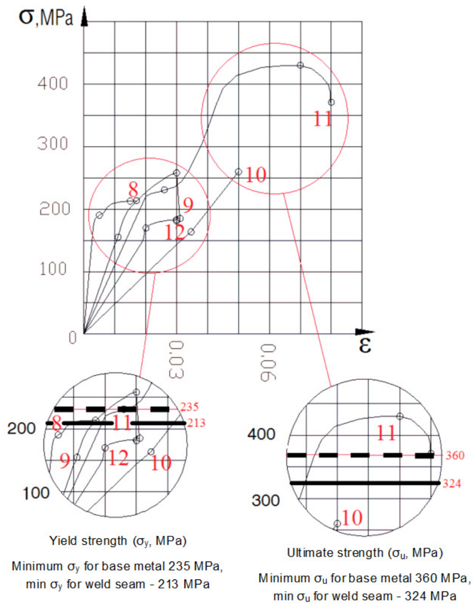

Fig. 6. Stress-strain diagrams of SMAW welded specimens

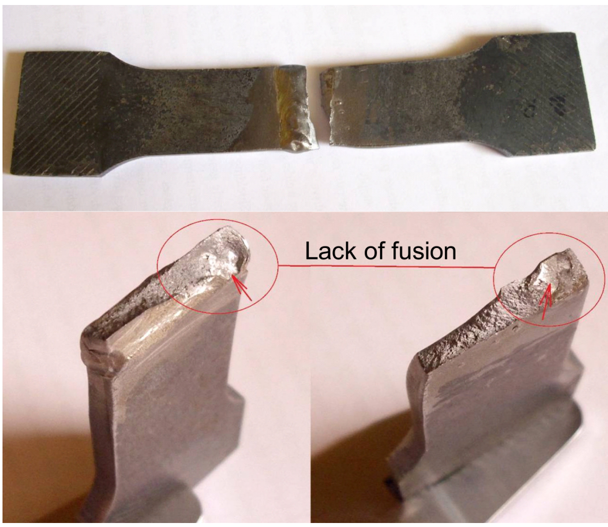

Fig. 7. Location of rupture in GMAW specimen No. 2

The visual evidence suggests that the cause of failure can be lack of fusion in the marked area. This type of failure is dangerous because it reduces the factual contact surface of the weld reducing specimens ability to sustain stress and resulting in failure to reach materials yield strength (minimum required yield strength for the specimens base metal is 235 MPa and the welding seam should hold at least 90 % of the given value, that is 213 MPa.).

The failure to reach minimum required yield strength is dangerous because exceeding this point results in permanent material deformations and this is undesired in constructions or mechanical use. Possible causes of lack of fusion may be attributed to poor welding technique or because the weld metal was permitted to roll in front of the arc. The arc should be directed so that it covers all areas of the joint, the arc, not the puddle, should do the fusing and electrode should be kept at the leading edge of the puddle. Then welding seam is prevented from lack of fusion.

All other GMAW specimens (Nos. 3-6) have satisfied the requirements. No visual evidence of possible weld faults or failures has been detected. All the specimens have fractured in the area of base metal (Fig. 8), indicating high seam quality.

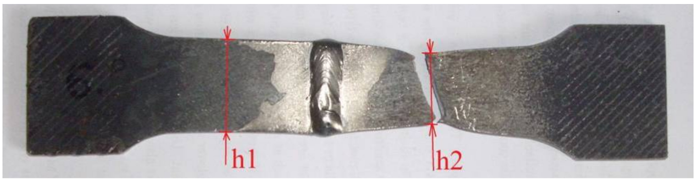

Fig. 8. Specimen No. 3 with clear evidence of necking

Fig. 6 clearly indicates that only a single specimen (No. 11) of SMAW welding has succeeded to achieve the minimal requirements for both yield and ultimate strength. All other specimens have failed to reach both yield and ultimate strength.

Images of the SMAW specimen No. 8 are provided in Fig. 9. It demonstrates clear signs of undercutting, incomplete penetration, burn through, and lack of fusion, which caused the failure of the specimen during the tensile strength test. All these faults are dangerous because they reduce the effective weld cross-section area significantly resulting in specimens inability to resist tension or to demonstrate its volatile properties as the fracture appears at the welding seam at fairly low stresses. True fraction strength of SMAW welded specimens is 1.8 times smaller than GMAW welded specimens (Table 2).

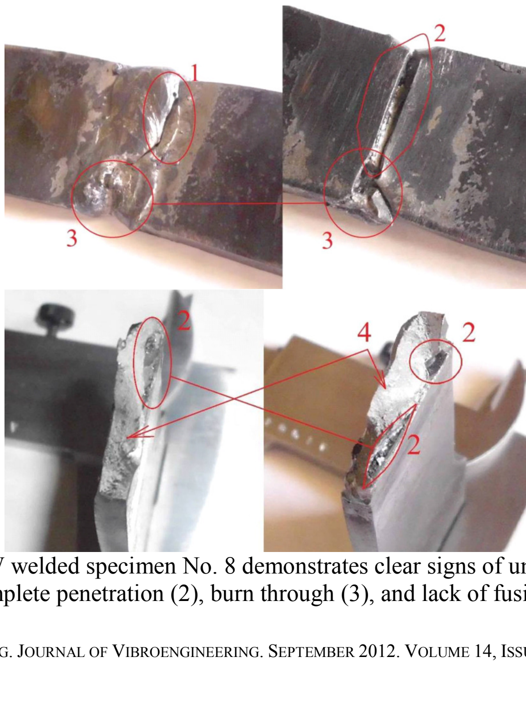

Fig. 9. SMAW welded specimen No. 8 demonstrates clear signs of undercutting (1), incomplete penetration (2), burn through (3), and lack of fusion (4)

Table 2. True fraction strength of GMAW and SMAW specimens

GMAW welded specimens		SMAW welded specimens	
No.	σ_{tf}, MPa	No.	σ_{tf}, MPa
2	294.7	8	275.4
3	642	9	294.1
4	679.9	10	478.5
5	647.8	11	768.3
6	838	12	247.2
Average	620.5	Average	343.9

Comparative extent δ of the specimen No. 8 has reached only 1 % and that satisfies material property of brittle fraction. The same faults were also observed for other SMAW specimens (No. 9, 10, and 12). The comparative elongation δ of these specimens has reached only 2 %. It means that specimens have failed to demonstrate their volatile properties. Failure of SMAW specimens may be caused by overly high or low travel speed, overly high or low voltage/current, incorrect torch angle, wire size or poor welding technique.

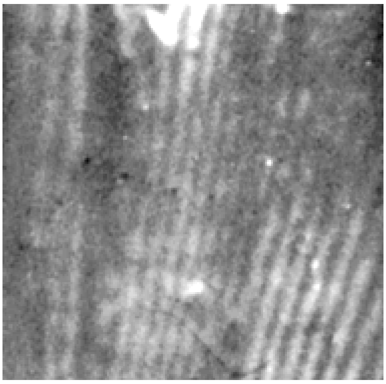

Fig. 10. Hologram of the harmonically excited GMAW joint at 2.4 kHz

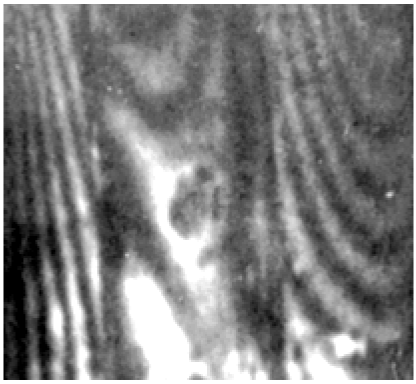

Fig. 11. Hologram of the harmonically excited SMAW joint at 2.4 kHz

Results of tensile strength test were confirmed using holographic method. In hologram of harmonically excited GMAW joint (Fig. 10) interference lines are parallel and evenly distributed implying that GMAW joints quality is good. While hologram of harmonically excited SMAW joint (Fig. 11) reveals presence of fractures because interference lines on base metal and weld seam are not connected and they represents different response to excitation.

Conclusions

Gas metal arc welding and shielded metal arc welding play an important role in metal working industry as well as in the field of maintenance and repair. Therefore 5 GMAW and 5 SMAW welded specimens were tested for the tensile strength. 4 of 5 GMAW welded specimens have passed the test exceeding required yield strength of 235 MPa, and ultimate strength of 360 MPa. While 4 of 5 SMAW specimens failed to satisfy the requirements. Visual inspection of tested specimens was performed for clarification of the obtained results. The inspection confirmed the primary results and numerous defects were detected in SMAW specimens. The main conclusion is that GMAW specimens were appropriately welded revealing no, or very few notable defects and demonstrating sufficient mechanical properties. The SMAW specimens, on the contrary, failed to demonstrate required mechanical properties, exhibiting numerous macrostructural defects. In addition, results of tensile strength tests were confirmed by vibrational analysis using holographic interferometry method.

Many of the problems that are specific to the welding can be avoided by proper joint design and understanding the possible options and variables that must be specified for each operation.

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