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STUDY OF PROPERTIES OF WELDED JOINT USING DANTEC'S ISTRA 4D SYSTEMS*

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The paper presents displacement and strain fields measured at various stages of tension of flat samples in order to compare the effect of different technological parameters on mechanical properties of welded joints. Results of measurements are also compared with the results of tensile test of the base material to determine the impact of welding process on changes of mechanical properties of tested steel. The measurement of displacements and strains in tensed flat specimens made of S355 steel, hybrid welded using electric arc and laser beam is in the scope of this work. Welding process is performed using Yb:YAG laser and electric arc in GMAW method. D70 Trumpf laser head with maximum power up to 12 kW is used in welding tests with a spot diameter of the laser beam $d = 0.8$ mm. Welded joints are made for different technological parameters of the process with laser beam heat source leading in the tandem. Tension tests of flat samples are performed in accordance with norm PN-EN ISO 6892-1. Dantec Q-400 ISTRA multi-camera 3D correlation system is used for strain and displacement measurements. The method of measurement is based on the correlation of digital images recorded by the three cameras. Surface of tested samples is covered with a layer of white and black paint. The measurement took place by tracking movements of spots covering the surface of the sample, loaded by longitudinal force. 6 Ref., 4 Figures.

Keywords: *hybrid welding, electric arc, laser, welded joints, mechanical properties, tensile tests, deformation fields*

Today's facilities are characterized by high functional diversity, which, while maintaining high quality of workmanship, is very difficult. Products are increasingly demanding, and consequently products have increasingly complex 3D geometry. Measurement tools should combine the speed of collection of measurement points with high accuracy. The use of a non-invasive measurement method makes it possible to detect defects much faster without the need for specialist preparation of test specimens [1–3]. Coupled thermal, structural and mechanical phenomena occurring in welding process have a direct impact on the quality of welded joint. The material in the weld and adjacent region is heated to various temperatures resulting in a variety of structures that occur in the joint and heat affected zone (HAZ), having different mechanical properties in comparison to base material. Theoretical and experimental analysis of mechanical behaviour of welded joint is still one of the fundamental industrial problems. In the welding process using a laser beam a high welding speeds are obtained with a good quality of welds and a narrow thermal influence zone which is helpful in increasing the quality and mechanical properties of the joint as well as the production efficiency. One of the modern welding technologies is laser-arc hybrid welding, which combines laser beam welding with classical electric arc welding cooperating in a single process. This method has many advantages in comparison to welding process with electric arc or laser beam heat sources used separately. Advantages of laser-arc hybrid welding process include higher welding stability, higher melting efficiency, easier input of additional material to the welding pool and a lower input power under the same welding penetration. The investigations about laser-arc hybrid welded steel have been reported widely and applied successfully in a wide range of the industry. These studies include analytical modeling of thermomechanical phenomena occurring in the process and experimental research on plasma formation, liquid material flow through the welding pool, microstructure composition as well as the analysis of welding deformations and mechanical properties of welded joints, performed in both destructive and nondestructive tests. One of usually performed tests on welded joints is the classical tension test. The standard for this type of testing is the norm

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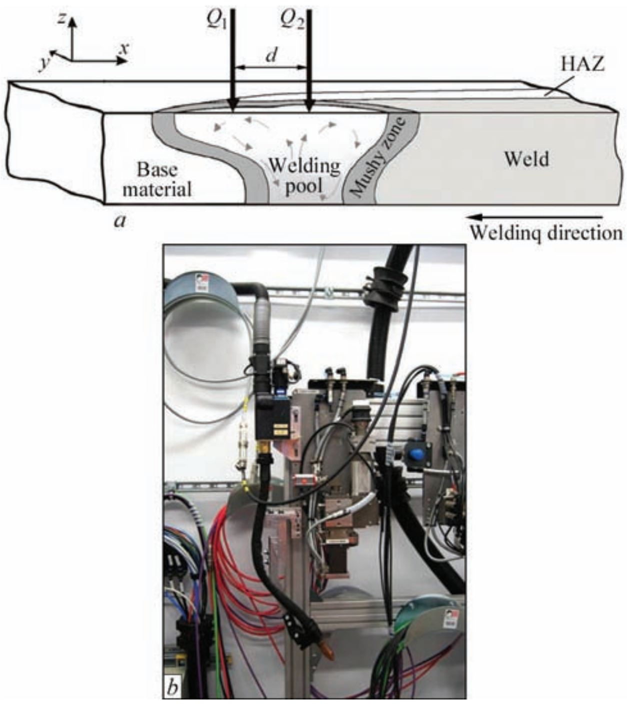

Figure 1. Scheme of hybrid welding process (*a*), hybrid laser head Yb: YAG + MIG (*b*)

PN-EN ISO 6892-1. This test allows the determination of basic mechanical properties of welded joints. However, the development in new measurement systems, such as 3D multicamera correlation system allows the analysis of deformations at the surface area of tensed sample in control area determined for cameras used in the experiment. The knowledge about strain distribution in the joint combined with the analysis of the microstructure of welded joint is essential in determining the material properties in separate joint zones, like the weld, HAZ and transition zone. Moreover, the results of such studies are an excellent base for verification of developed theoretical models.

Considering above facts, the main objective of this study are experimental studies on strain during tension of samples welded by laser-arc hybrid technology using GMAW method and Yb:YAG laser beam. Dantec Q-400 Istra multi-camera 3D correlation system is used to measure the distribution of strains during performed tests made on the base material and welded joint. Presented results include tension diagrams as well as a comparison of strain fields measured for the entire tension cycle.

Experimental set-up, hybrid welding. Laser beam emitted by D70 Trumpf laser head with maximum power up to 12 kW is used with electric arc in GMAW method (Figure 1). Laser head is equipped with collimator lens having a focal length *fc* = = 200 mm, and a focusing lens with a focal length *f* = = 400 mm. The diameter of the beam is set by chang-

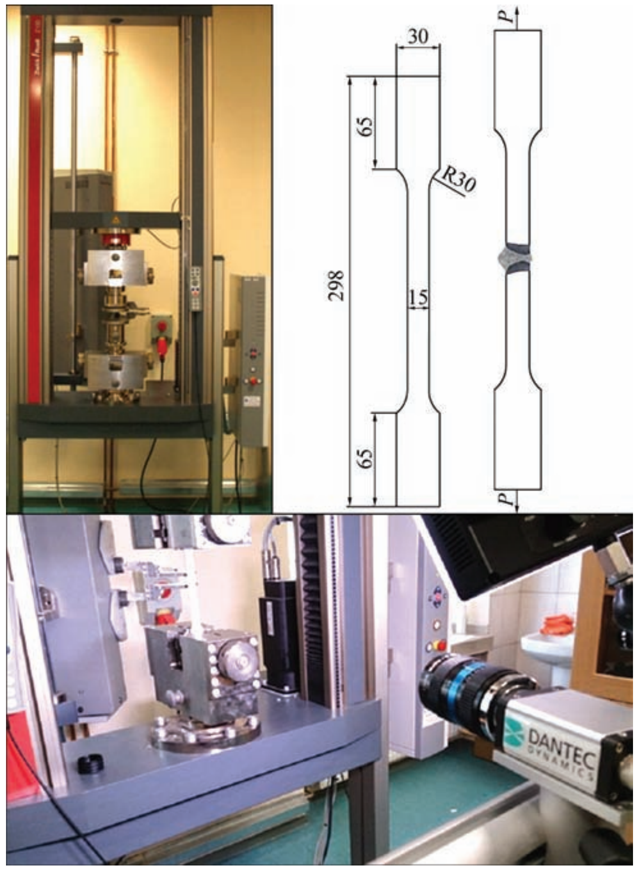

Figure 2. Tension test: universal strength machine Zwick&Roel Z100, dimension of samples used in the test, Q-400 ISTRA multi-camera 3D

ing the optical fiber supplying the laser beam to the head. Optical fiber is used in the research having a diameter 0.4mm. For used optical system double magnification is achieved giving laser focus diameter *d* = = 0.8 mm. Butt welding is performed for sheets made of S355 steel. Welding process proceed without a gap in the shielding gas 82 % Ar + 18 % CO_2, the gas flow is 18 l/min, wire speed 6m/min and welding speed set

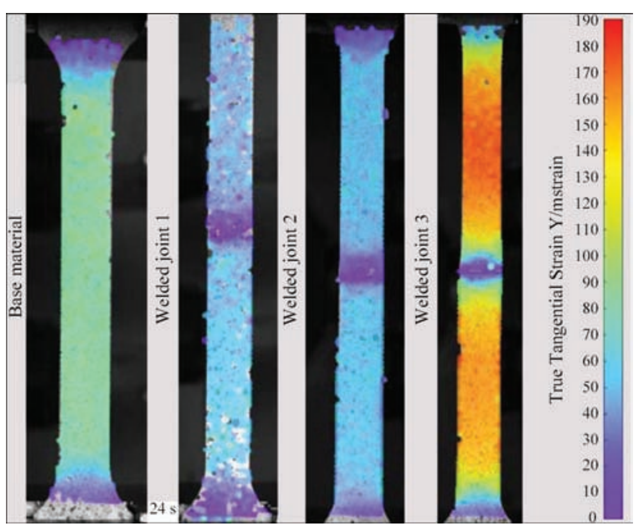

Figure 3. Strain fields in tensed base material and welded joint (*t* = 24 s)

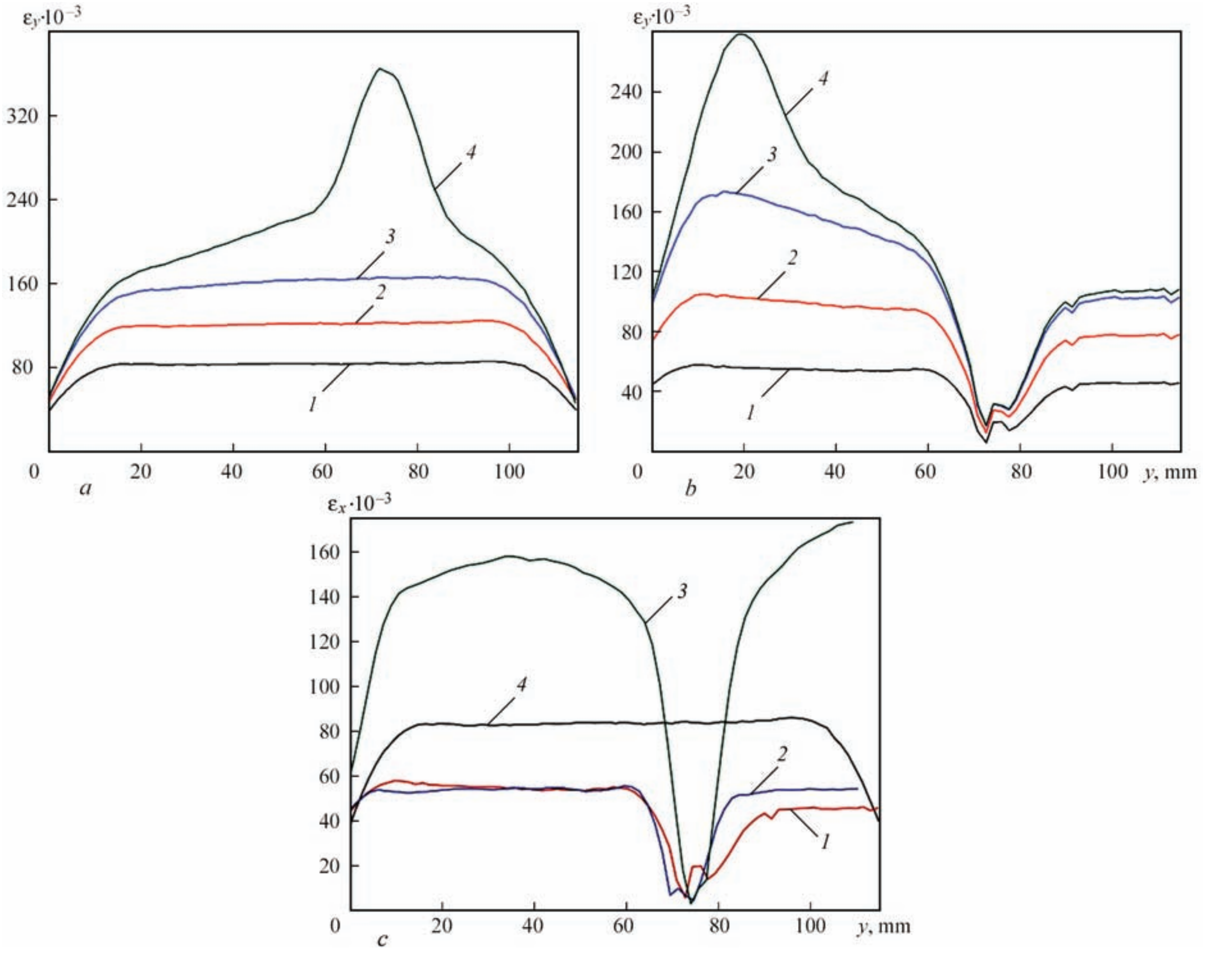

Figure 4. Distribution of strain ε_y in the central axis *y* of sample for different times of tension: *a* — the base material; *b* — welded joint; *c* — comparison for time t = 24 s (for a, b: 1 — 24s, 2 — 28, 3 — 32, 4 — 39; for c: 1–3 — welded joint 1–3; 4 — base material)

to v = 1 m/min. The distance between heat sources d = 2 mm. Laser beam is the leading heat source in the tandem.

Samples are welded in the system with leading laser beam in the tandem as well as in inversed system with leading arc. Laser beam power is set to Q = = 3 kW, arc voltage U = 19 V and current I = 190A in the welding experiment.

Strain measurement system. Samples for the tension test were made from welded joints according to norm PN-EN ISO 6892-1. Universal strength machine Zwick&Roel Z100 is used with extensometer Multisens in all performed tension tests. The accuracy of the strength machine is up to 0,1N in force and 1μm in displacement. Universal strength machine cooperates with Dantec Q-400 Istra multi-camera 3D correlation system [4–6]. Measurement system is composed of optical cameras used to record strains or deformations. The Timing Box is an interface between the control computer and the sensors for synchronization and analog recording of data, and to power-up cameras and PC computer with a number of network cards, allowing for the introduction of signals from cameras and different sources, transmitted via ethernet and installed dedicated Istra4D software.

In the experiment the system of three cameras was used. Cameras are mounted on the beam which is supported by two fully adjustable tripods. Optical cameras used to record strains and derormations are equipped with 50 mm, mod: 670 mm lenses and have maximum resolution 4.19 Megapixels, 29 Hz each. This allowed determining the full size of analyzed sample in the working area of universal testing machine. Strain fields are measured for the entire tension cycle. Trigger mechanism is created in Istra4D software for the measurement. Pictures are made for every time increment Δt = 0.4 s.

Results and discussion, strain distributions. Figure 3 presents comparison of strain fields in tensed base material and welded joint at the various measurement steps in elasto-plastic range as well as before the rupture-during the formation of the neck. It can be observed that the weld and HAZ has a significantly lower strain compared to the base material.

Distribution of strain εy along the length of tensed sample (55 mm in both direction from the center point of the sample) is illustrated in Figure 4. Strain distribution is shown in the central axis y for the base material and welded joint at different times. Visible decrease of strain is present in the joint where HAZ is present. The slight increase of strain in the weld can be because of the inaccurate selection of an additional material in GMAW method.

The comparison of strain ε_y at time $t = 24$ s is presented in Figure 4, *c*. It can be observed that for the base material higher values of strain ε_y are present in comparison to welded joint.

Conclusions

The use of multi-camera 3D correlation system allowed the analysis of strain and deformation for the selected material points, lines or plane throughout the measuring sample. Use of the system allowed the analysis of deformation and strain distributions in the weld and heat affected zone during tension test. It can be observed that lower strains occur in heat affected zone in comparison to the base material which in reference to pictures of microstructure confirm partial hardening of this zone. Visible increase of strain εy in the weld may be due to the inaccurate selection of an additional material in GMAW method. Obtained results allowed for a thorough analysis of mechanical properties separate zones of the joint and do not limit the tensile test to determine the global strength and plastic properties of welded material. Obtained experimental results may be very helpful in verifying mathematical and numerical models of thermomechanical phenomena occurring in welding processes.

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