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Effect of Shielding-Gas Nitrogen Content on the Properties of TIG and A-TIG Orbital-Welded Tubular Joints Made of Duplex Steel

Abstract: The article discusses tests results concerning the joining of duplex steel pipes performed using the TIG and A-TIG (with the addition of activating flux) orbital welding technology. The shielding gas used in related tests contained pure argon as well as argon with an addition of nitrogen. Technological welding tests were performed using a closed head without the feeding of a filler metal. The research work included visual and penetrant tests as well as macro and microscopic observations and ferrite meter-aided measurements of the ferrite content in welds.

Keywords: TIG welding, orbital welding, duplex steel, shielding gases

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Introduction

Nitrogen is considered to be a contaminant and an element responsible for the formation of welding imperfections in welded joints. However, when joining duplex steels, an addition of nitrogen to a shielding gas entails numerous advantages resulting from high dissociation energy. In addition, nitrogen is an austenite-forming agent [4,6]. The tests presented in the article aimed to identify the effect of a nitrogen content in a shielding gas on the content of ferrite in joints of TIG and A-TIG orbitally welded austenitic-ferritic duplex steels.

TIG Orbital Welding

Orbital welding is a process involving the use of two joining methods, i.e. TIG (Fig. 1) and MIG/MAG. The MIG/MAG method is used in an orbital welding variant where the tip of an electrode moves in a pendulous manner. The TIG method is usually applied to join elements having small cross-sections and when making a root run in a joint. TIG orbital welding involves the orbital motion of a non-consumable tungsten electrode around the circumference of an element fixed in the clamps of a welding head (Fig. 1) [3, 5, 13, 14]. As a result, in each second of its duration, the welding process is performed in a different position. In addition, a certain area of a joint constitutes a "problematic zone", usually containing welding imperfections (Fig. 2).

Restricted welding positions in which the welding process is performed pose difficulties related to weld geometry, the proper filling of a root run and to the process stability. The primary issue accompanying the performance of

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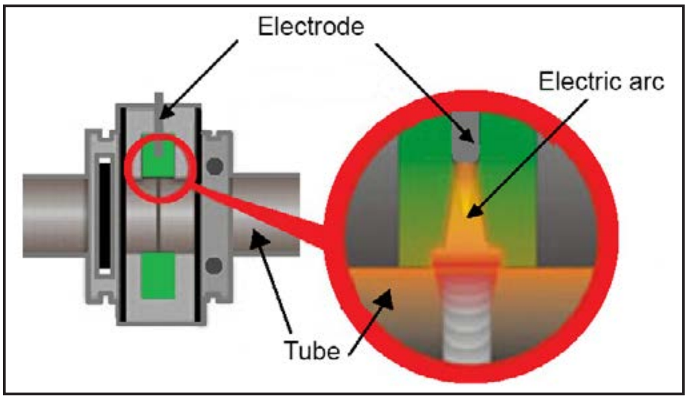

Fig. 1. Schematic TIG orbital welding [14]

the welding process is the proper formation of the weld face and weld root without compromising satisfactory mechanical and functional properties. The making of the first filling layers is confronted with the existence of a zone making it difficult to “maintain” the liquid metal pool (Fig. 2). In the above-named position, gravity force “moves” the weld pool in the direction opposite to the direction of welding. As a result, the zone of contact between the electrode and the liquid metal pool becomes elongated. A very important aspect in the orbital welding of tubes is the precise matching of elements to be welded. Many a time the making of the above-named joints is made more complicated by the dimensional variability of elements (diameter, tube external circumference) responsible for fluctuations of welding conditions around the joint circumference and, consequently, leading to the formation of welding imperfections. In view of the above-presented difficulties, orbital welding requires the very precise preparation and matching of elements to be welded.

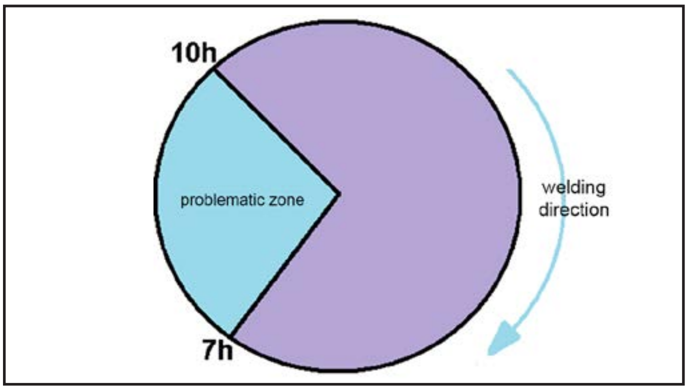

Fig. 2. Schematic orbital welding and the problematic zone responsible for difficulty maintaining the liquid metal pool [14]

Effect of Nitrogen in a Shielding Gas on the Properties of Tubular Joints in Duplex Steel

Shielding gas mixtures of argon and nitrogen are used to increase the content of austenite in the weld structure in joints made of duplex steels. A nitrogen addition improves the plastic properties of the joint, provides higher resistance to intercrystalline and stress corrosion as well as to hot cracking. A 5% addition of nitrogen in a shielding gas mixture is sufficient for the weld to obtain a δ/γ phase ratio of 1, thus improving welding process efficiency by increasing arc temperature and improving the “spreadability” of the liquid metal pool [3,4,6,7,12]. The maximum efficiency can be obtained where the content of nitrogen in a shielding gas mixture is restricted within the range of 4-6%. The foregoing is accompanied by a significant increase in penetration depth (50%) [6].

Test Rig

The orbital welding station consisted of a welding power source (Fig. 3), a controller and an Osk 115 gw Orbitec closed welding head enabling the welding of tubes having diameters restricted within the range of 9.53 to 114.3 mm (Fig. 4).

Fig. 3. TETRIX 351 welding power source in the orbital welding station [14]

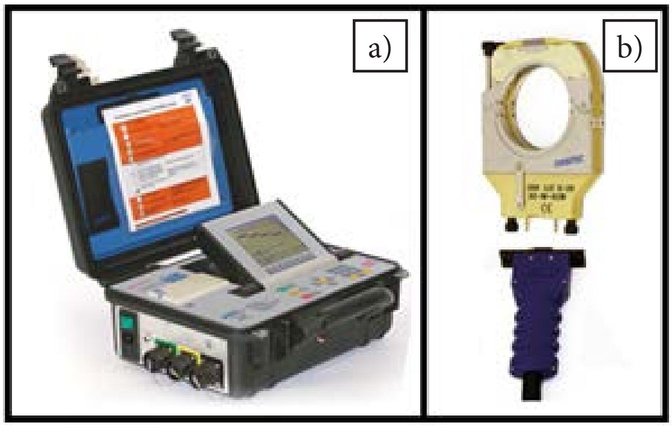

Fig. 4. Components of the orbital welding station: A- controller, B- closed welding head [14]

Tests and Results

The research work included the making of butt joints of tubes (φ 42 × 2.77 mm) made in duplex steel X2CrNiMoN22-5-3 (1.4462). The joints were made using the TIG and A-TIG orbital welding technologies. The tubes were subjected to square butt weld preparation and were matched without gaps. The TIG method-based technological welding tests were performed without a filler metal, whereas the A-TIG welding tests involved the use of activating flux BC-31.

The first stage involved the identification of a window of parameters enabling the obtainment of proper joints. Initially, the welding tests were shielded by argon (PN-EN ISO 14175-I1-Ar), whereas afterwards the tests were performed using three mixtures of argon and nitrogen, i.e. PN-EN ISO 14175-N2-ArN-5 2009 (argon and a nitrogen addition of 5%) and PN-EN ISO 14175-N3-ArN-10 2009 (argon and 10% of nitrogen). The subsequent stage involved the A-TIG orbital welding of tubes. The process of welding was performed using a closed welding head and the above-presented mixtures.

The joints were subjected to visual tests (VT), penetrant tests (PT) as well as to macro and microscopic metallographic tests. The tests were performed to determine the effect of a welding technology on the quality of the joints. The content of ferrite in the welds was measured using a ferrite meter.

The visual tests revealed that the obtainment of joints representing quality level B in accordance with PN EN ISO 5817:2014-05 required the correction of technological parameters suggested by the controller software programme. It was necessary to separately adjust current values and welding rates in relation to each shielding gas mixture and each quarter of the tubular joint. The initial tests revealed the presence of welding imperfections including incomplete penetration or burn-throughs. It was also found that the quality of the joint was significantly affected by a parameter referred to as "the time of liquid metal pool formation", i.e. the time during which arc was burning between the electrode and the welded element but the welding rate amounted to zero (electrode "stood still"). It was possible to obtain full penetration at the welding initiation area after increasing the time of the liquid metal pool formation from 5 to 15 seconds. The obtainment of a joint characterised by proper geometry and appropriate quality around the entire circumference proved difficult. In the first half of the joint the shape of the weld (face) was significantly dependent on parameters adjusted at the beginning of the welding process. The setting of excessively high current in relation to the first quarter of the joint resulted in the formation of welding imperfections including the lack of penetration and excess weld metal. The application of the same welding parameters in relation to all areas of the joint was accompanied by the formation of welding imperfections including root concavity or the lack of penetration. The elimination of the above-named imperfections required the modification of current values without changing the welding rate. The welding current correction affected the width of the weld and the height of excess weld metal.

The tests also revealed that the addition of nitrogen in the shielding gas increased the "spreadability" of the liquid metal pool, which, in turn, decreased the value of current previously used to weld tubes using the shielding gas containing 100% Ar. The use of the activating flux (A-TIG) significantly reduced the weld face width in comparison with that obtained using the TIG process as well as increased penetration depth and process efficiency. The welding performed using gas shielding mixtures N2 and N3 and the A-TIG method resulted in the formation of welding imperfections such as burn-throughs, undercuts and excessive penetration around the entire circumference of the tube. A decrease in values of welding technological parameters did not result in the obtainment of satisfactory results. The shielding gas reacted with the flux making the A-TIG welding process shielded by the N2 and N3 gas mixtures impossible.

The macroscopic metallographic tests did not reveal the presence of welding imperfections such as the lack of penetration, porosity, inclusions, concavities or undercuts. The joints were characterised by a narrow HAZ, characteristic of duplex steels (Fig. 5). The addition of nitrogen in the shielding gas mixtures did not significantly affect the face width in the TIG welded joints (Fig. 6÷8). The penetrant tests confirmed the lack of welding imperfections.

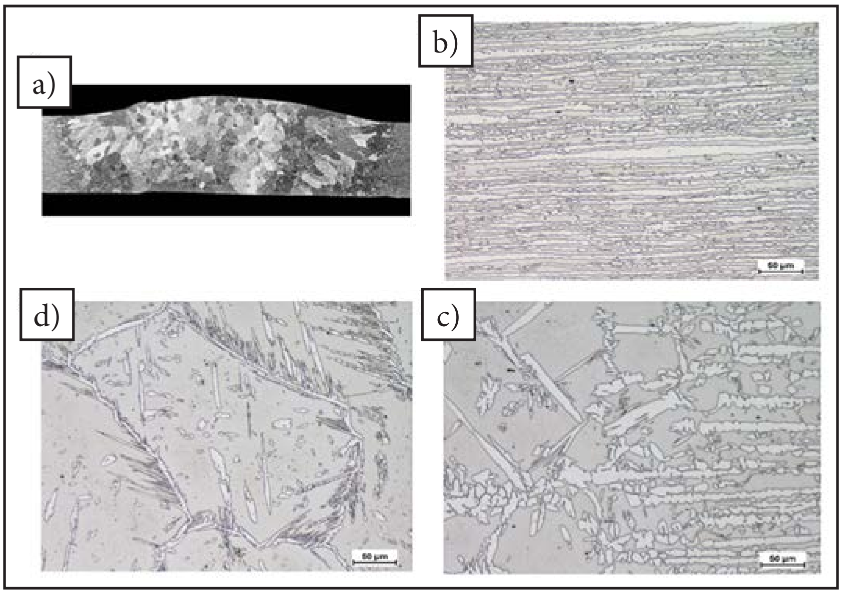

Fig. 5. Macro and microstructure of the TIG orbitally welded joint; shielding gas: 100% Ar (I1 according to PN-EN ISO 14175:2007), a) joint macrostructure, b) base material microstructure, c) HAZ microstructure, d) weld microstructure

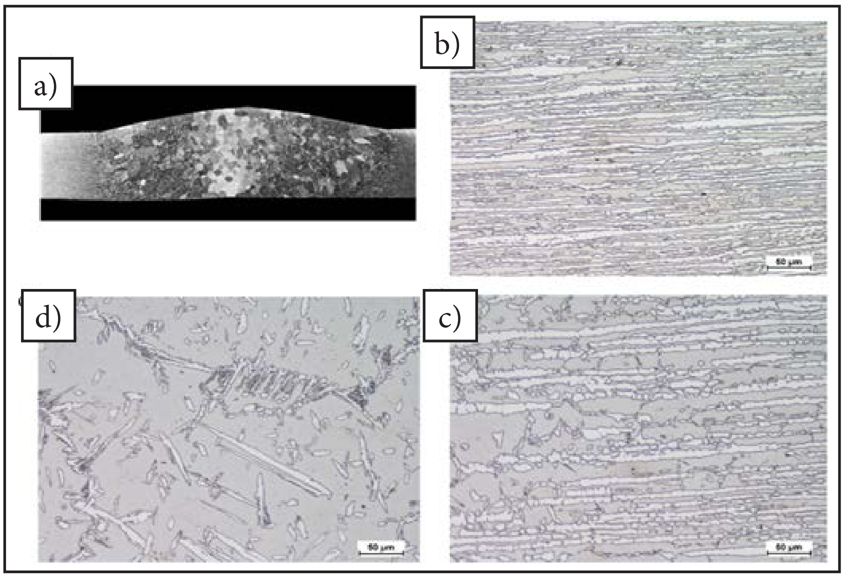

Fig. 6. Macro and microstructure of TIG orbitally welded joint no. 2; shielding gas 95% Ar + 5% N2 (N2 according to PN-EN ISO 14175:2007); a) joint macrostructure, b) base material microstructure, c) HAZ microstructure, d) weld microstructure

Summary and Concluding Remarks

The computer-aided structural analysis and ferrite measurements performed in accordance with PN-EN ISO 8249:2005 made it possible to identify the content of ferrite in the welds of the joints of the TIG and A-TIG orbitally welded tubes. The test results confirmed information contained in related reference publications concerning the effect of a nitrogen addition in the shielding gas mixture on the stabilisation of austenite in the weld. Each time, a 5 % addition of nitrogen to argon in the shielding gas mixture triggered a 10% decrease in the ferrite content in the weld. The obtained joint structure (proportion of austenite and ferrite phases) depends on numerous technological factors including a welding method, a welding position, a heat input and the properties of the base material (thickness and chemical composition). Orbital welding requires that the welding process be performed in restricted positions, additionally impeding the obtainment of a desirable ferrite content in the joint (50÷60%) of tubes

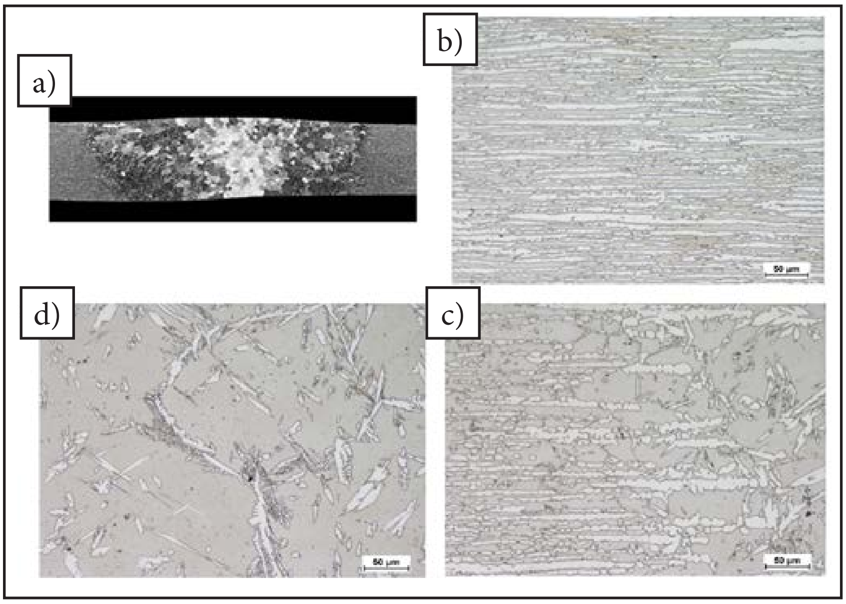

Fig. 7. Macro and microstructure of TIG orbitally welded joint no. 3; shielding gas 90 %Ar + 10% N2 (N3 according to PN-EN ISO 14175:2007); a) joint macrostructure, b) base material microstructure, c) HAZ microstructure, d) weld microstructure

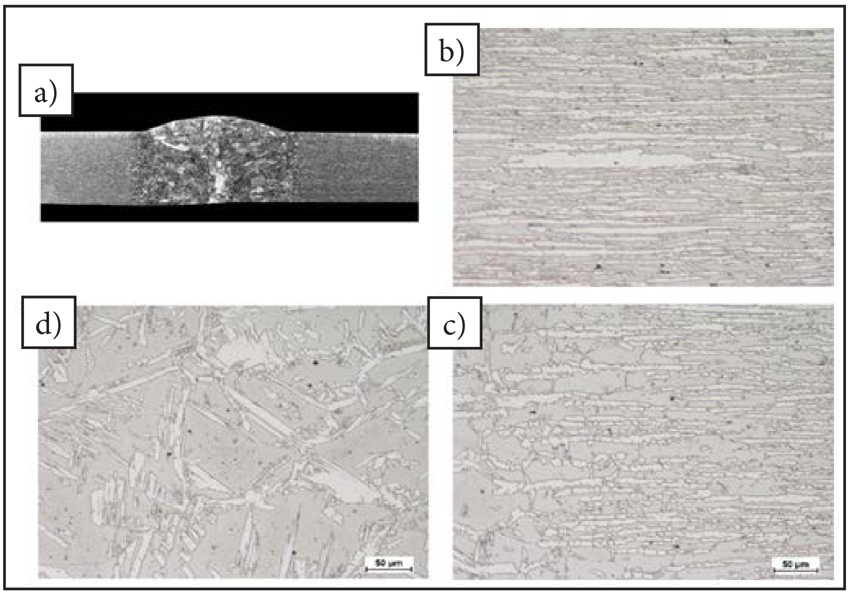

Fig. 8. Macro and microstructure of A-TIG orbitally welded joint no. 4; shielding gas 100% Ar (I1 according to PN-EN ISO 14175:2007); a) joint macrostructure, b) base material microstructure, c) HAZ microstructure, d) weld microstructure

(φ 42 x 2.77 mm) welded using the N2 and N3 shielding gas mixture.

The average ferrite measurement values obtained using a ferrite meter were slightly different from the results obtained using the computer-aided analysis of structures in the weld. The computer-aided analysis involved selected microscopic photographs of areas provided with the highest heat input during the welding process, possibly leading to different results.

The obtained results concerning the joints of A-TIG orbitally welded tubes revealed a strong correlation between the volumetric distribution of structures in the weld and a heat input during welding. Because of the use of the activating flux, the process performed using a lower heat input to the joint resulted in the obtainment of a significant decrease (approximately 30%) in the ferrite content in comparison with that obtained in the argon-shielded TIG welding process.

An addition of nitrogen to argon (shielding gases N2 and N3) did not enable a decrease in a heat input (during welding) to values comparable with those obtained using the A-TIG process. Because of the foregoing, the butt welded joints of N2 or N3 gas-shielded TIG orbitally welded tubes (φ 42 x 2.77 mm) made of duplex steel were characterised by a higher ferritic phase content than desired.

The performed tests justified the formulation of the following conclusions:

1. The making of proper butt joints of orbitally welded tubes (φ 42 x 2.77 mm) made of duplex steel required the modification of welding process parameters suggested by the device controller.
2. The process of orbital welding entailed the continuous change in welding positions. The adjustment of parameters should allow for changes in existing conditions.
3. The increase in the weld pool formation time from 5 s to 15 s enabled proper penetration at the beginning of the welding process.
4. Process parameter settings in the first quarter of the joint significantly affected the quality of the weld.

5. A nitrogen addition in the shielding gas mixture favourably affected austenite stabilisation. However, nitrogen is not the only factor strongly influencing the structural ratio in the weld. The ferrite content was related both to the welding method and process performance conditions.
6. The use of the mixture containing argon and a 10% nitrogen content (N2) in orbital welding proved impossible as it led to the formation of welding imperfections including burn-through, undercut and excessive penetration.

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