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Influence of argon pollution on the weld Surface Morphology

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Summary

In this paper the surfaces of butt welded joints in steel tubes were analyzed using an optical 3D measurement system to determine the morphology and topographic parameters. It was established that pollution of the argon shield gas with oxygen did not influence the width of the heat-affected zone. However, the composition of the shield gas significantly influenced the surface asymmetry, *Ssk*, and its inclination *Sku*. The measurement of these parameters enabled the selection of a higher quality surface, which was visually proven by the reduction in discoloration of the surface of the weld joint. High quality surfaces eliminate a potential habitat for bacteria and a future source of corrosion as well as providing less resistance to fluid flow.

Key words

surface metrology; surface morphology; topography inspection; waviness; weld quality;

Nomenclature

GPS – Geometric Product Specifications

HAZ – heat affected zone

IFM – Infinite Focus Measurement

Sa – Average Roughness

Sdr – Developed Interfacial Area Ratio

Sdq – Root Mean Square (RMS) Surface Slope

Sku – Kurtosis

Sp – Maximum Peak Height

Sq – Root Mean Square Roughness

Ssk – Skewness

Sv – Maximum Valley Depth

Sz – Maximum Height of Surface

TIG – Tungsten Inert Gas

1. Introduction

Precise characterization of surface morphology is of prime importance in many engineering industries because certain functional properties of the materials are often determined by the surface characteristics. Achieving the desired surface quality is of great importance for the functional behavior of a part. Welding is the principal joining method used by engineering industry. Examples of experimental investigations about weld joint quality can be found in the open literature. Tseng and Hsu [1] investigate five kinds of oxide fluxes. They showed the effect of activated TIG process on weld morphology, angular distortion, delta-ferrite content, and hardness of 316L stainless steels. Dewan et al., [2] presents residual stresses, microhardness, microstructures, and uniaxial tensile properties in TIG welded of AISI-4140 alloys steel with SAE-4130 chromium–molybdenum alloy. Wen et al., [3] presents microstructural change and fatigue properties of linear friction welding of Ti6Al4V joints with special attention to the relationship between the microstructure and cyclic deformation behavior. These publications do not mention the problems related to the argon pollution. The purity of argon as a shielding gas is very important for weld joint quality. Low argon quality causes discoloration of the weld area and changes to the surface morphology of welded tubes. The surface morphology of the pipe installation influences the interaction of liquids and gases with the surface and through surface wear may cause impurities or has an influence on electrisation. It is a very important issue in branches such as the pharmaceutical and food industries. A material often used in the food and pharmaceutical industries is stainless steel where the working surfaces of devices are in direct contact with food and drugs ingredients. This type of material has been used for many years due to its good mechanical properties [4] and good corrosion resistance [5]. According to Tsisar et al. [6] martensitic steels have a tendency toward weld cracking during cooling when hard brittle martensite is formed. Kim et al. [7] investigated the effects of shielding gas on the pitting corrosion of hyper duplex stainless steel welds. They reported that the pitting resistance of a solution heat-treated weld with a combination of Ar and N_2 as the shielding gas is greatly increased due to an increase of austenite in the weld material and heat affected zone (HAZ). Further research on the process of welding stainless steels has been dealt with by many researchers. Chern et al. [8] investigated the effects of the specific fluxes used in the tungsten inert gas process on surface appearance, weld morphology, angular distortion, mechanical properties, and microstructures when welding duplex stainless steel. Yajiang et al. [9] studied Fe_3Al and Cr18–Ni8 steel in the tungsten inert gas arc welding process. Micro-cracks, fracture and dislocation morphology in the weld zone were analyzed by scanning electron microscope, electron probe micro-analyzer and transmission electron microscopy. Zhang et al. [10] investigated the effect of tungsten inert gas welding and subsequent post-weld heat treatment on the microstructure evolution and pitting corrosion behavior of duplex stainless steel. However, these publications don't mention the geometrical parameters of the weld surface morphology.

Surface profilometry has been known for many years as a method of topography inspection. Gharbi et al. [11] investigated the influence of the main process parameters on the surface finish quality during the direct metal deposition process. Their work was carried out using an Yb-YAG disk laser and a widely used titanium alloy (Ti–6Al–4V) . Koszela et al. [12] presented textured cylinder liner surface topographies and computer software for visualization of oil pockets array on machined surface. Mathia et al. [13] described problems of surface topography characterization and future trends in surface metrology. Parthasarathi et al. [14] studied characterization of worn surface topography in a prototype fast breeder reactor. Safara Nosar and Olsson [15] investigated 3D surface topography images and surface profiles behind the initial stages of material transfer between stainless steel and tool steel in metal forming operations. Wieczorowski [16] presented a novel spiral method of surface profilometry. Representing surface properties using topographic parameters is accepted as being superior to using 2D parameters. The surface parameters can be used within functions describing surface behavior. In order to establish effective quality control of the weld zone, it has been recommended that an extensive investigation is needed. This should include the clarification of the deterioration problems of surface weld joints which are important in practical use [17].

This paper focuses on research problems related to the morphology of the surface after orbital welding. The main purpose of this study was to determine the influence of argon pollution as a key process factor in controlling surface integrity parameters. A secondary aim of this study also was to present the quality of the welds.

2. Material and methods

2.1. Welded material and welding method

The welded material was pipes Ø50x1.5 of an austenitic stainless steel 1.4301 (DIN EN 10088-1). The elemental composition of the welded material is given in Table 1.

Table 1 Chemical composition of 1.4301 austenitic stainless steel

Element	%C	%Si	%Mn	%P	%S	%Cr	%Ni	%N	Others
wt. [%]	0.07	1.00	2.00	0.045	0.015	17.50 to 19.50	8.00 to 10.50	0.11	-

The welding method used was orbital welding which is a mechanized version of the tungsten inert gas arc welding (TIG) process. This method is used to weld pipes or stationary tubes. The tungsten electrode contained in the weld head rotor rotates (orbits) around the weld joint circumference. The welding speeds were 125 mm/min. The TIG process can be an autogenous process in which the edges of the weld joint are heated by the arc and fused together, without the addition of filler material. Alternatively, filler material may be added to the weld pool. The device for checking the weld quality by the measurement of argon contaminants was an Orbitec Oxy-2 residual oxygen analyzer. Residual oxygen measuring devices can control and document the amount of oxygen in the area of the weld when they are linked to the weld controller. In the controller it is possible to set a limit on the amount of residual oxygen present. A schematic diagram of the experimental arrangement is shown in Fig. 1.

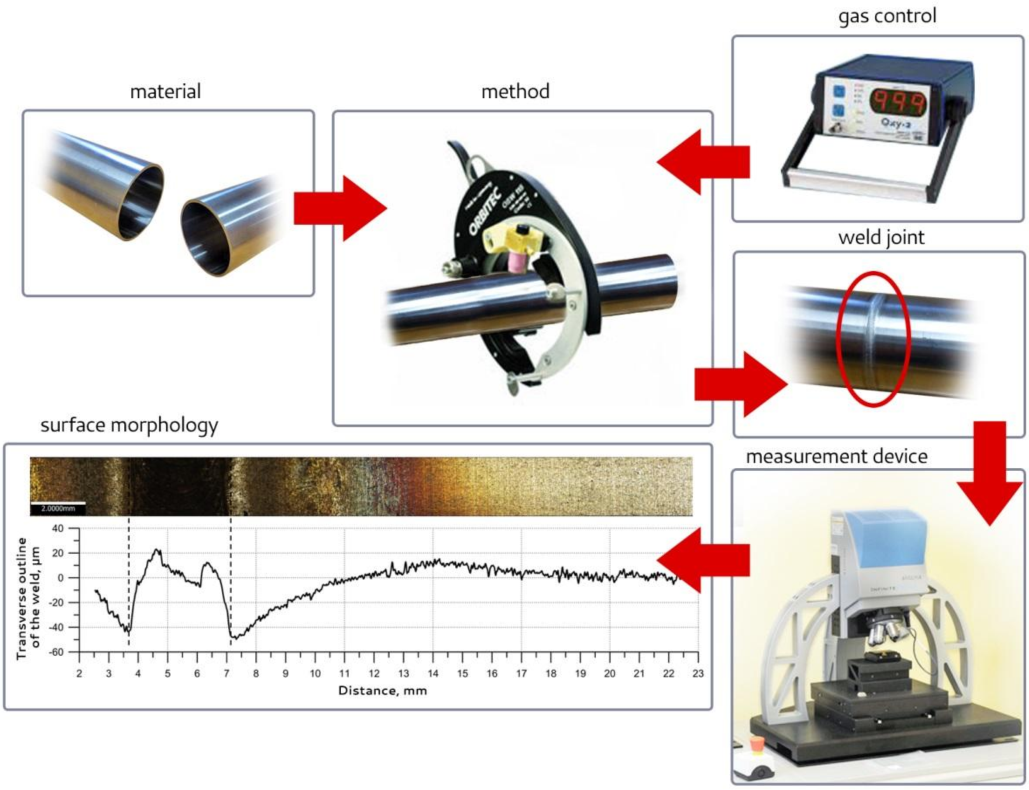

Figure 1. Schematic diagram of experimental arrangement

2.2 Surface Morphology analysis

Surface Morphology analysis was performed using an Infinite Focus Measurement Machine (IFM). The IFM is an optical 3D measurement device which allows the acquisition of datasets at a high depth of focus. The IFM method allows for the capture of images with a lateral resolution down to 400 nm and a vertical resolution down to 20 nm. The IFM 4.2 software version was used to collect and present the measurement data. The surface morphology was measured from the functional side – from the inside of pipe. The surface morphology analysis was carried out in the OUTech Surface Integrity Lab.

Before performing the Surface Morphology analysis, the quality of welds was checked by means of the X-ray examination (Fig. 2). It was found that all the welds presented in Fig. 2 were performed correctly, and there is no incompatibility which might occur during welding.

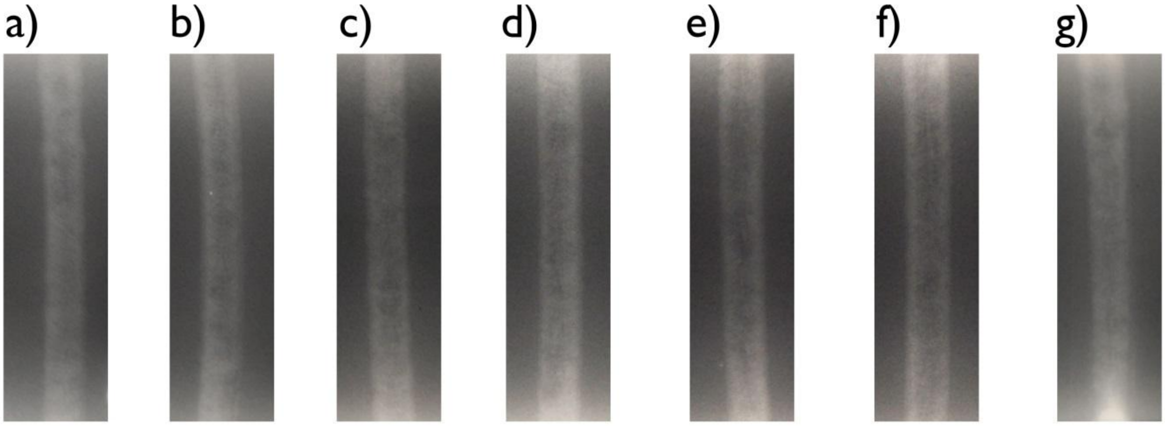

Figure 2. X-ray image of a weld joint: 800 ppm a); 600 ppm b); 400 ppm c); 200 ppm d); 60 ppm e); 20 ppm f); 8 ppm g)

3. Results and discussions

3.1. Variation in Surface Morphology

Correct shield gas formation gives a guarantee of the highest quality of welds during TIG welding of highly alloyed and stainless steels. From the point of view of the efficiency of the welding process and the properties of the executed joints, an appropriate choice of shield gas is extremely important. The most common choice is argon which is heavier than air and non-reactive. Its principal task is to protect the weld area against the ingress and unfavorable influences of impurities coming from the surrounding atmosphere. In addition, argon influences physicochemical phenomena forming in the weld arc during the welding process. Thus, it directly influences a number of factors determining the proper progression of the welding process. The quality of shield gas argon is determined by measuring the level of pollution (typically expressed as parts per million (ppm)), mainly oxygen, in the gas fed to the welding zone. The examination results presented in Fig. 3, concerning the impact of argon pollution on the quality of welds were carried out under laboratory conditions. The measurements were performed for seven different levels of pollution giving visible discoloration of the weld area. Experimental studies were carried out from the inside of pipe. The research consisted of measuring the surface of the steel including the weld. Waviness measurement was performed using IFM.

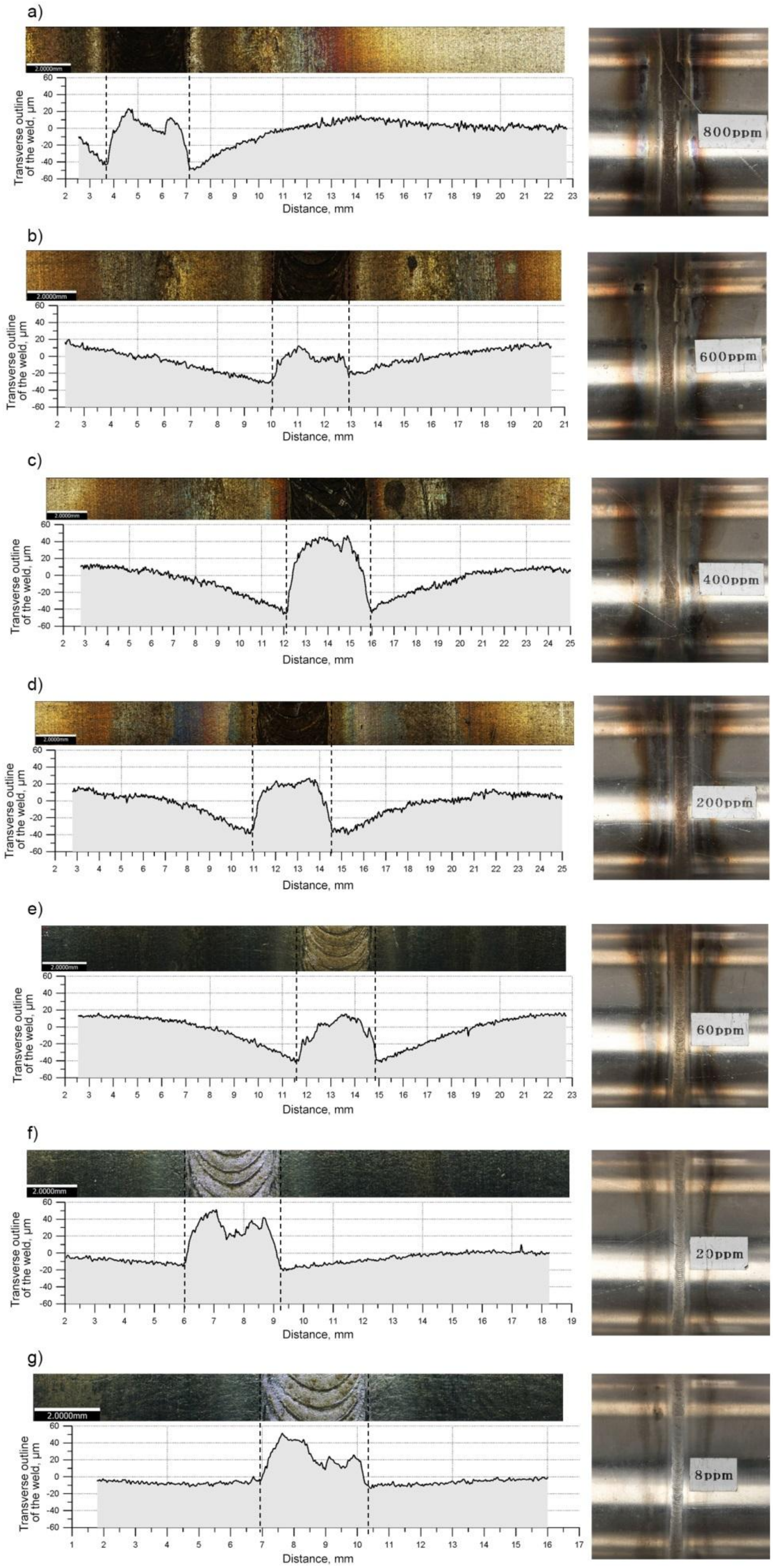

Figure 3. Surface morphology of weld area depending on the argon pollution: 800 ppm a); 600 ppm b); 400 ppm c); 200 ppm d); 60 ppm e); 20 ppm f); 8 ppm g)

The brown area visible in Fig. 3 is a result of metal oxidizing at high temperature but it is much bigger than the HAZ where the microstructure will be altered. This discoloured region can harbour bacterial contamination and be an initiation point for corrosion. Argon is an inert gas, which means that it does not react with the weld puddle and does not cause oxidation of the tungsten electrode. Its low ionization potential (15.8 eV) facilitates ionization of the gas space between the tungsten electrode and the welded material. Low thermal conductivity in comparison with other gases reduces the cross-section of the arc column. This brings about an increased concentration of heat in the arc core, which increases the depth of fusion in a narrow area. The concentration of energy in the arc core and resultant high surface tension of the weld pool under a shield of pure argon causes high levels of sprue on the face of the weld. The welding arc under a shield of pure argon lacks stability, thus argon with the addition of active gases, particularly oxygen, is used for welding. However, an excess of oxygen in the mixture results in the introduction of the excessive amounts of heat into the welded material. This then intensifies the physicochemical phenomena in the welding zone. Hence, the degree of argon purity influences the quality of the weld. In addition to the obvious impact on the quality and durability of the weld, the excessive amount of heat introduced into the welded material brings about the changes in the surface morphology. The surface morphology, alongside the 3D functional roughness parameters, influences the performance of the engineered surface. In industrial practice, the geometric product specification (GPS) of the surface can be an important issue. In particular waviness and surface texture parameters can greatly influence the interaction between machine elements and the interaction of fluids with the surface.

3.2. Variation in Surface Texture

The study of the dependence of the waviness of the weld joint surface on the degree of pollution of the argon shield was performed using the IFM by means of the Focus-Variation method. Figures 4 and 5 show the measured surface waviness for different levels of pollution of argon. It is possible to isolate two zones: Zone A and Zone B. Zone A is a zone of 3.5 mm in width, which corresponds to the width of the face of the weld. Because all the analyzed weld joints were formed with the same technological parameters, Zone A does not change its width. The width of Zone B being the heat-affected zone in the welding process, was defined as the width where the waviness deviated from the base level. The maximum width of Zone B for the analyzed welding parameters was set to 7 mm and divided into 7 subzones of 1 mm wide.

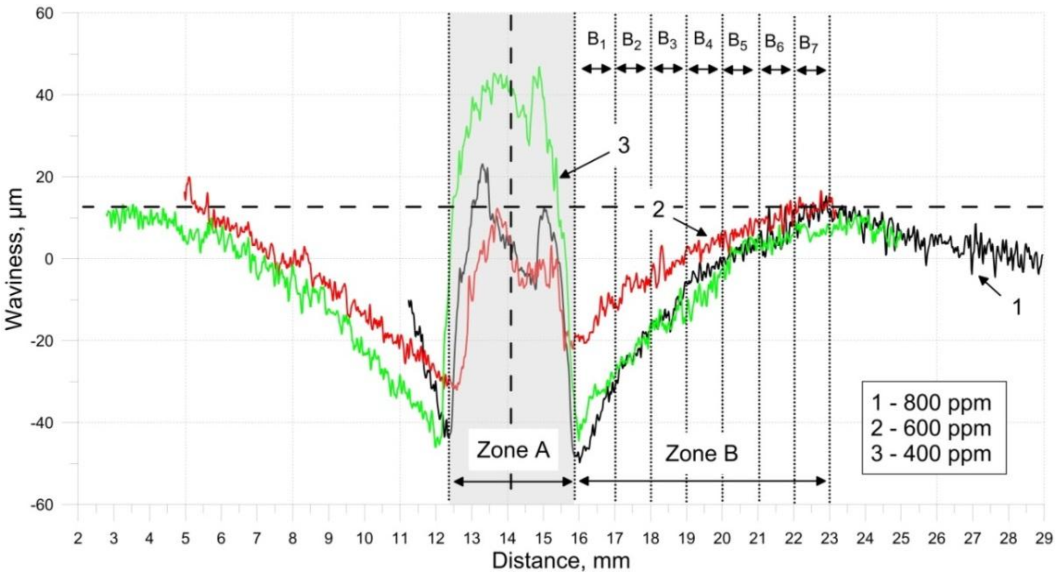

Figure 4. Influence of argon pollution on the weld joint area (400–800 ppm)

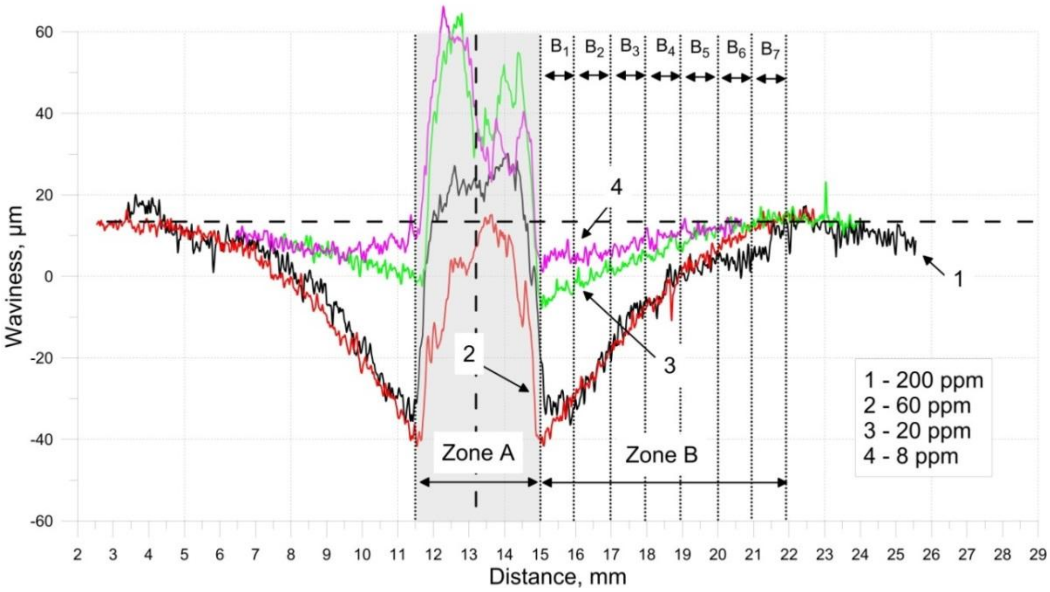

Figure 5. Influence of argon pollution on the weld joint area (80–200 ppm)

The results of the measurements of the surface waviness, in spite of the fact that they are characterized by considerable fluctuations in Zone A, display stability in Zone B. The surface waviness in Zone B is a measure of more widely spaced components of surface texture and was up to 40 μm from the base surface. The magnitude of waviness depended on the subzones – for all the samples, the largest values were observed for subzone B_1, analogously, the smallest ones for subzone B_7, most distant from the source of heat. Moreover, in Figures 4 and 5 it is possible to observe a decrease in the waviness values as the argon shielding gas becomes purer. For 8 ppm, the maximum deviation of surface waviness from the base level in zone B was about 10 μm. For polution levels of 600 and 800 ppm, it was 30 and 60 μm, respectively.

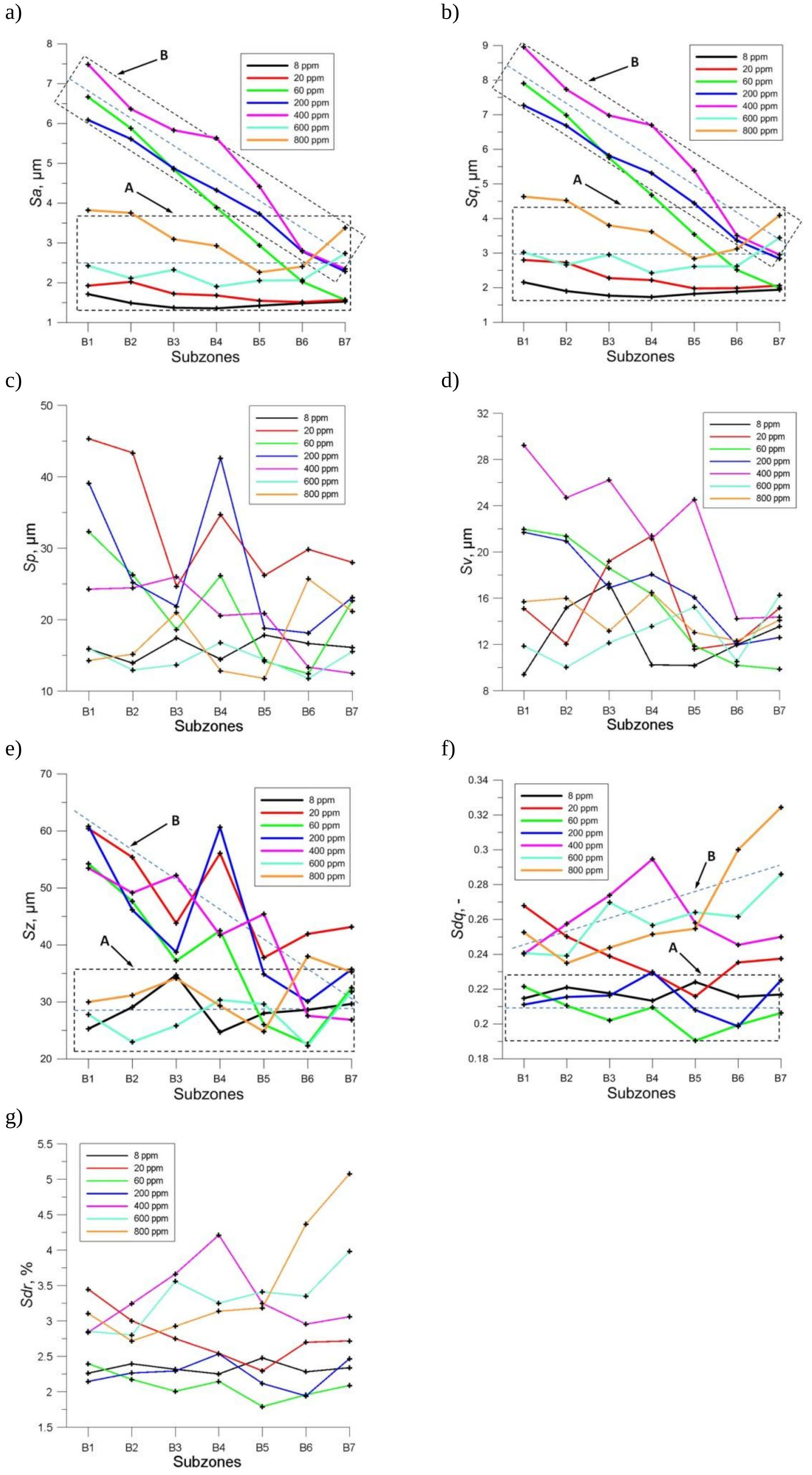

Figure 6. Selected amplitude (a–e) and hybrid (f, g) surface roughness parameters of weld joint area $B_{1\text{-}7}$ subzone.

The selected amplitude and hybrid surface roughness parameters of the weld joint area from subzones B_1 to B_7 are presented on Figure 6. On these graphs two characteristic areas can be distinguished. The first area includes samples for which significant changes in roughness parameters, as a function of distance from the heat sources (subzones), were not obtained (Fig. 6a, b – region A). This area includes welds executed with essentially pure argon shields (8 and 20 ppm pollution), and, what is interesting, joints executed with very high pollution levels in the shield gas (600 and 800 ppm). The other area includes samples for which the roughness values distinctly decrease with distance from the joint penetration area (Fig. 6a, b – region B). In these cases, the difference in values for *Sa* and *Sq* between subzones B_1 and B_7 is 5-6 μm. A similar characteristic was observed for parameter *Sz* (Fig. 6e). Welds executed with shield gas pollution levels of 8, 600 and 800 ppm were characterized by the an almost constant value of parameter *Sz*=26 μm with fluctuations limited to ±5 μm (Fig. 6e – region A) in zone B. For the remaining gases, *Sz* ranged from 58 to 35 μm with fluctuations of ±5-15 μm (Fig. 6e – region B). On this basis we can conclude that the quality of surface in the heat-affected zone depends on the purity of argon, and primarily on the value of doping with oxygen. It was observed that for a very pure gas, and for the gas with the highest levels of O_2 a surface in Zone B was obtained with constant and rather small values of roughness. For gases belonging to the 60-400 ppm group roughness values decreased with distance from the source of heat. The phenomenon of constant values of *Sa*, *Sq* and *Sz* for argon highly contaminated with oxygen is related to the change in the ionization conditions and formation of the electric arc. The effect is interesting for technological reasons and it should be subject to further research. The largest heights of elevations and depths of depressions were assessed based on parameters *Sp* and *Sv* (Fig. 6 c and d respectively). For both analyzed parameters it was observed that the lowest values of *Sp* and *Sv* were obtained for very pure argon (8 ppm), as well as for the gas with a large dope of oxygen (600 ppm). The position of the subzone for which the measurement was performed did not have significant influence in this case. For this group of shielding gases, for parameter *Sp*, average values of about 15-18 ±6 μm were obtained. For the remaining group of gases, i.e. 20, 60, 200 and 400 ppm, the values of *Sp* were much higher, within the range 25-45 μm with maximum values in the B_1-B_4 zones. A similar characteristic can be observed for parameter *Sv*: In the heat-affected zone the maximum values of depressions of *Sv* are lower than *Sp* by about 40%. Doping argon with oxygen within the range 60-400 ppm still leads to an intensification of surface disturbances, with measured maximum depressions in the range 22-29 μm.

The Root Mean Square Surface Slope parameter *Sdq* is presented in Fig. 6f. This parameter is a general measurement of the slopes which comprise the surface. It is often used to differentiate surfaces with similar average roughness, *Sa*. It was found that in spite of the considerable variation in parameter Sa (ranging from 1.4 to 7.7 μm) shown in Fig. 6a, the structure of the examined surfaces is similar. The degree of change of parameter *Sdq* is small and it peaks at 0.19 to 0.32. Therefore, it is the same order of magnitude. The degree of purity of the applied shielding gas did not influence the change in the surface structure. A confirmation of this conclusion can be seen in the images of surface morphology characterization presented in Fig. 8.

To differentiate surfaces of similar amplitudes and average roughness we could use an *Sdr* parameter. It is known that *Sdr* increases with the spatial intricacy of the texture. In Fig. 6g, two groups of surfaces can be distinguished. The first group includes surfaces formed with shield gas pollution levels of 8, 60 and 200 ppm. In this area *Sdr* is relatively stable at approximately 2.3%. The other area includes surfaces for which changes of amplitude and average roughness values are higher. For this case we obtain *Sdr* = 3-3.5%. These latter surfaces were formed during welding with gases with high proportions of oxygen, namely 400, 600 and 800 ppm. The surface protected with gas of 20 ppm is of a different character. With distance from the weld area, i.e. from subzone B_1, parameter *Sdr* decreases from 3.5% to 2.3 for B_5. For the more distant subzones (B_6 and B_7), parameter *Sdr* takes intermediate values, namely 2.7%. When comparing the selected areas with the areas related to parameters *Sa*, *Sq* or *Sz* (Fig. 6a, 6b and 6e, respectively), certain relations were observed. For the group of parameters *Sa*, *Sq* and *Sz*, whose values basically do not change as a function of subzone, the spatial intricacy of the texture is stable and low. For the group of parameters which do appear to be functions of the distance from the welds, parameter *Sdr* takes higher values and is not as stable.

The distribution of values of the coefficient of surface asymmetry *Ssk* and the coefficient of its inclination *Sku* is presented in Fig. 7. The values of these parameters are strongly influenced by single elevations and depressions on the surface. The majority of surfaces, regardless of the analyzed subzone and the purity of the shielding gas, are characterized by small values of parameters *Sku* and *Ssk*. For *Ssk*, the range from -0.5 to 0.5 was obtained, and for *Sku* it is an area from 2 to 4. As can be seen in Fig. 7, surfaces with negative values of skew and low values of *Sku* are produced for subzones near the weld area with high values of shield gas pollution (Fig.7 a and b). Basically, a different configuration of parameters *Sku* and *Ssk* was observed for 8ppm, and particularly for 20 ppm (Fig.7 – region A). For subzone B_1

Sku takes the value 47.5, and *Ssk* = 3.25. It is much greater than for the remaining cases. This suggests that the structure of this surface significantly differs from the others. The known problem of ionizing the arc and stabilizing its location with little O_2 in the shield gas was probably responsible for this effect. Also higher values of *Ssk* and *Sku* were obtained for 8 ppm, which to some extent proves the role of O_2 in the process of shaping this structure. Practically, surfaces with zero or positive skeweness were generated for last subzone B_7, where the heat influence is slight.

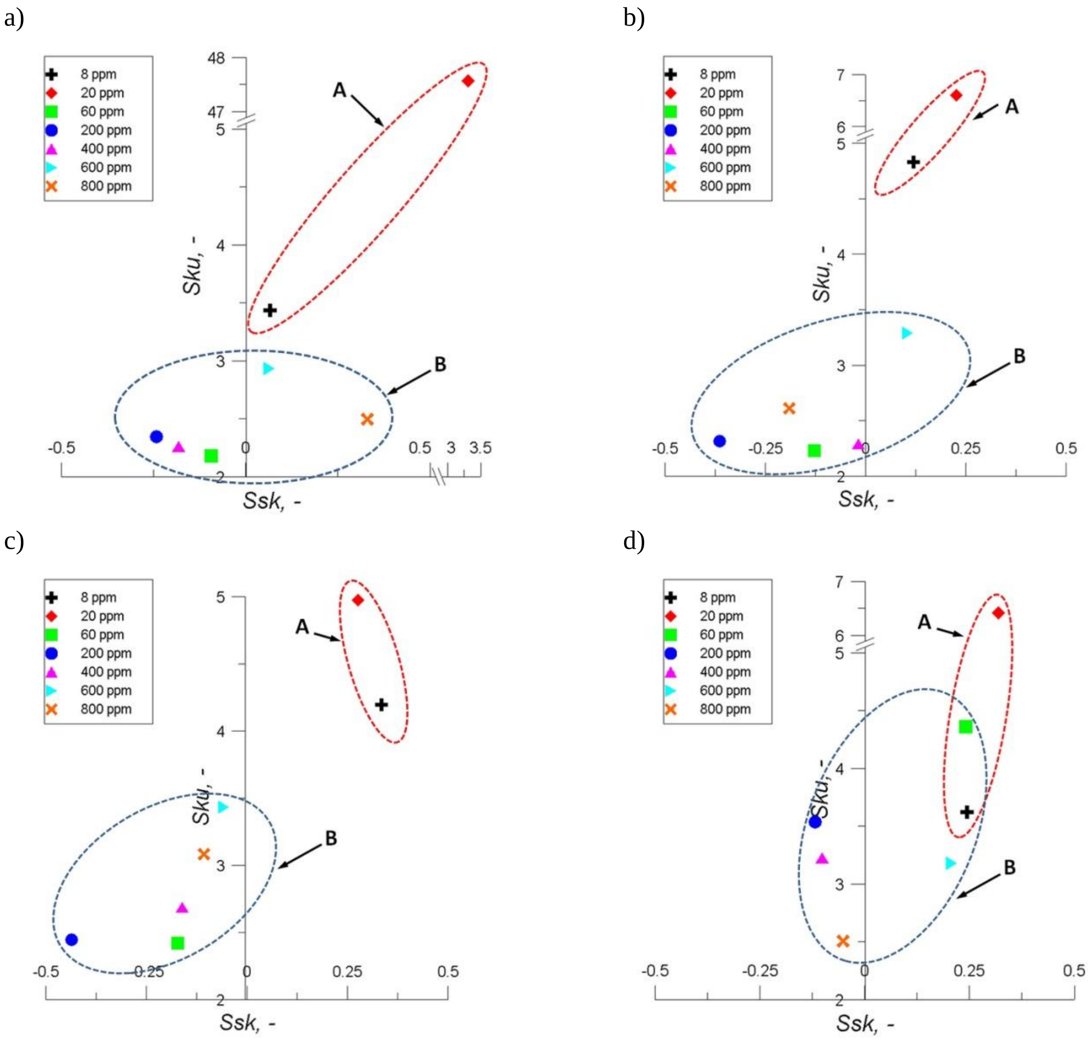

Figure 7. The maps of kurtosis (*Sku*) versus skewness (*Ssk*) for selected subzones B_1 (a), B_3 (b), B_5 (c) and B_7 (d) of weld joint area.

The values of the characteristic surface parameters (*Sa, Sq, Sp, Sv, Sz*) changed significantly moving away from the weld. Additionally, the values of skewness *Ssk* are negative for higher values of argon pollution. This indicates that the majority of the material is localized near the peaks of the surface.

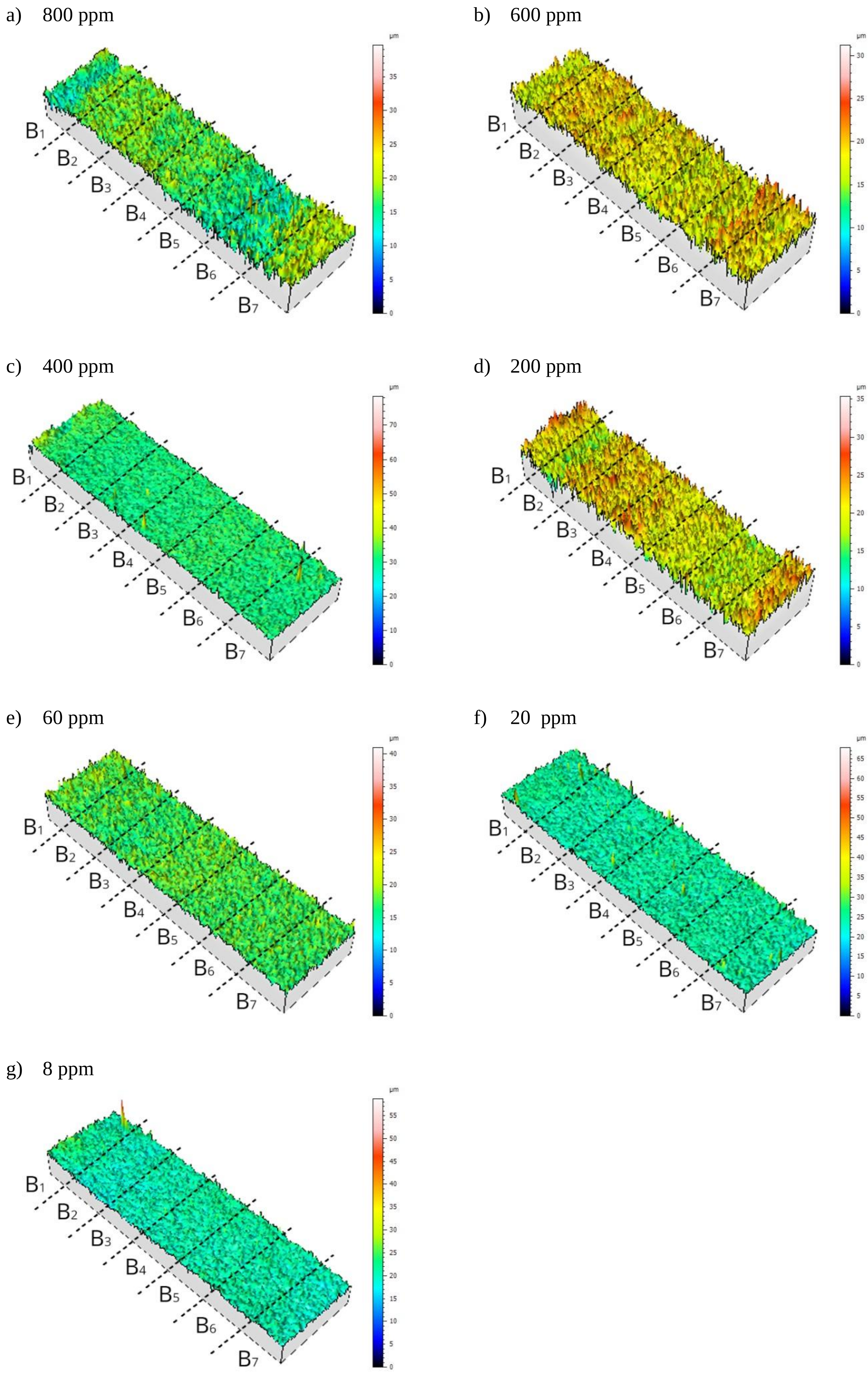

Figure 8. Surface morphology characterization depending on argon pollution

The physical appearance of the surface morphology was visually examined as part of the characterization process. Seven images obtained by using a Focus-Variation are shown in Figure 8. The samples had a smooth surface, but some particular features were revealed on the surface. For example, several areas of the surfaces were characterized by isolated peaks around the weld (Fig. 8f and Fig. 8g), and in the zone most distant from the face of weld (Fig. 8c). These single peaks changed the statistical result of the measurement of 3D parameters in subzone B_1 and B_2, which are characterized by the greatest fluctuations of changes in subzone B_7 for the 400 ppm sample.

4. Conclusions

The results obtained show that the method used to measure the surface topography of a welded joint has allowed the functional characteristics of that surface to be extracted. This has been possible largely thanks to the proper design of the experiment and experimental methods. The quality of the argon shielding gas influences the form of the product surface. The use of surface parameters enabled the impact of the proportion of oxygen, on the quality of the surface in the zone affected by heat from the welding process, to be shown. Based on the experimental observations, the authors formulated the following conclusions:

I. The application of argon with pollution levels below 20 ppm eliminates discolorations on the surface of welded stainless steel pipe joints, and thus eliminates of a potential habitat for bacteria and a future source of corrosion.

II. From the metrological point of view, pollution of the argon shield gas with oxygen does not influence the width of the heat affected zone.

III. It was found that, on the basis of the analysis of selected amplitude parameters (*Sa*, *Sq*, *Sz*), that for shield gases with medium levels of pollution with oxygen (60, 200 and 400 ppm), the surface texture parameters decrease their values with distance from the face of the weld. For pure gases (8 and 20 ppm) and also highly contaminated gases (oxygen levels 600 and 800 ppm), roughness parameters stayed at a constant level equal to the values obtained for the zone most distant from the face of the weld.

IV. It was observed that in spite of considerable differences in the obtained values of *Sa* or *Sz* parameters, the surface texture assessed based on parameter *Sdq* is similar, and the level of purity of the applied shielding gas did not influence the surface morphology.

V. The composition of the shielding gas significantly influences the values of the coefficients of surface asymmetry *Ssk* and its inclination *Sku*. Purer gases (8 and 20 ppm pollution) contribute to the formation of surfaces with high values of *Ssk* and *Sku* close to the weld face. For the areas which are most distant from the weld face, a distinct shift of the values of the surface asymmetry coefficients towards zero was obtained for all the examined compositions of the shielding gas.

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References

[1] K.H. Tseng, C.Y. Hsu, Performance of activated TIG process in austenitic stainless steel welds, Journal of Materials Processing Technology. 211 (2011) 503 – 512.

[2] M.W. Dewan, J. Liang, M.A. Wahab, A.M. Okeil, Effect of post-weld heat treatment and electrolytic plasma processing on tungsten inert gas welded AISI 4140 alloy steel, Materials and Design. 54 (2014) 6 – 13.

[3] G.D. Wen, T.J. Ma, W.Y. Li, J.L. Li, H.Z. Guo, D.L. Chen, Cyclic deformation behavior of linear friction welded Ti6Al4V joints, Materials Science and Engineering A. 597 (2014) 408 – 414.

[4] G.M. Krolczyk, P. Nieslony, S. Legutko, Determination of tool life and research wear during duplex stainless steel turning, Archives of Civil and Mechanical Engineering. 15 (2015) 347 – 354.

[5] G. Krolczyk, P. Nieslony, S. Legutko, Microhardness and Surface Integrity in Turning Process of Duplex Stainless Steel (DSS) for Different Cutting Conditions, Journal of Materials Engineering and Performance. 23 (2014) 859 – 866.

[6] V. Tsisar, M. Kondo, T. Muroga, T. Nagasaka, I. Matushita, Morphological and compositional features of corrosion behavior of SUS410–SUS410, SUS316–SUS316 and SUS410–SUS316 TIG welded joints in Li, Fusion Engineering and Design. 87 (2012) 363 – 368.

[7] S.-T. Kim, S.-H. Jang, I.-S. Lee, Y.-S. Park, Effects of solution heat-treatment and nitrogen in shielding gas on the resistance to pitting corrosion of hyper duplex stainless steel welds, Corrosion Science. 53 (2011) 1939 – 1947.

[8] T.-S. Chern, K.-H. Tseng, H.-L. Tsai, Study of the characteristics of duplex stainless steel activated tungsten inert gas welds, Materials & Design. 32 (2011) 255 – 263.

[9] L. Yajiang, M. Haijun, W. Juan, A study of crack and fracture on the welding joint of Fe3Al and Cr18–Ni8 stainless steel, Materials Science and Engineering: A. 528 (2011) 4343 – 4347.

[10] Z. Zhang, Z. Wang, Y. Jiang, H. Tan, D. Han, Y. Guo, et al., Effect of post-weld heat treatment on microstructure evolution and pitting corrosion behavior of UNS S31803 duplex stainless steel welds, Corrosion Science. 62 (2012) 42 – 50.

[11] M. Gharbi, P. Peyre, C. Gorny, M. Carin, S. Morville, P. Le Masson, et al., Influence of various process conditions on surface finishes induced by the direct metal deposition laser technique on a Ti–6Al–4V alloy, Journal of Materials Processing Technology. 213 (2013) 791 – 800.

[12] W. Koszela, P. Pawlus, E. Rejwer, S. Ochwat, Possibilities of oil pockets creation by the burnishing technique, Archives of Civil and Mechanical Engineering. 13 (2013) 465 – 471.

[13] T.G. Mathia, P. Pawlus, M. Wieczorowski, Recent trends in surface metrology, Wear. 271 (2011) 494 – 508.

[14] N.L. Parthasarathi, U. Borah, S.K. Albert, Effect of temperature on sliding wear of AISI 316 L(N) stainless steel – Analysis of measured wear and surface roughness of wear tracks, Materials & Design. 51 (2013) 676 – 682.

[15] N. Safara Nosar, M. Olsson, Influence of tool steel surface topography on adhesion and material transfer in stainless steel/tool steel sliding contact, Wear. 303 (2013) 30 – 39.

[16] M. Wieczorowski, Spiral sampling as a fast way of data acquisition in surface topography, International Journal of Machine Tools and Manufacture. 41 (2001) 2017 – 2022.

[17] D. Özyürek, An effect of weld current and weld atmosphere on the resistance spot weldability of 304L austenitic stainless steel, Materials & Design. 29 (2008) 597 – 603.