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Influence of the post-weld surface treatment on the corrosion resistance of the duplex stainless steel 1.4062

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Abstract. The duplex stainless steel 1.4062 (X2CrNiN22-2) is used as alternative material to austenitic stainless steels in the construction industry. The corrosion resistance of welded seams is influenced by the base material, the weld filler material, the welding process and also by the final surface treatment. The scale layer next to the weld seam can be removed by grinding, pickling, electro-polished or blasting depending on the application and the requested corrosion resistance. Blasted surfaces are often used in industrial practice due to the easier and cheaper manufacturing process compared to pickled or electro-polished surfaces. Furthermore blasting with corundum-grain is more effective than blasting with glass-beads which also lower the process costs. In recent years, stainless steel surfaces showed an unusually high susceptibility to pitting corrosion after grinding with corundum. For this reason, it is now also questioned critically whether the corrosion resistance is influenced by the applied blasting agent. This question was specifically investigated by comparing grinded, pickled, corundum-grain- and glass-bead-blasted welding seams. Results of the SEM analyses of the blasting agents and the blasted surfaces will be presented and correlated with the different performed corrosion tests (potential measurement, KorroPad-test and pitting potential) on welding seams with different surface treatments.

1. Introduction

The number of applications of duplex stainless steels (DSS) has increased significantly over the last 10 years in the construction industry. DSS combine the high fracture toughness of austenitic stainless steels (ASS) with the high stress corrosion resistance of ferritic stainless steels (FSS) [1]. The higher mechanical toughness of DSS compared to ASS allows furthermore the reduction of component dimensions. Especially the "lean" DSSs (1.4062, 1.4162, 1.4362 and 1.4662) with lower alloying contents of Ni and Mo reduce the materials costs in many applications [2-3]. Scientific investigations prove the equal or better corrosion resistance of DSSs compared to ASSs of the same corrosion resistance class (CRC) [2, 4]. These positive properties initiate the application of DSS in various applications requesting high corrosion resistance [1-3, 5-12]. There are only a few long-term investigations on the performance of DSSs in the construction industry [4]. Furthermore, production, processing and welding are still challenging and require optimization regarding the corrosion resistance [2, 8, 11].

The corrosion resistance of welding seams is influenced by the used base material, the weld filler material, the welding process and the final surface treatment [13, 14]. The aim of this study is to characterize the influence of different surface treatments of welding seams on the corrosion resistance



of the "lean" DSS 1.4062. Investigations in natural climates would be the best approach to characterize this issue, but the investigations would require several years [2]. For this reason mainly electro-chemical methods were used to characterize the corrosion resistance of industrial welding seams after different surface treatments. The scale layer next to the weld seam is known to reduce the corrosion resistance and has to be removed [2, 4, 14]. Depending on application and requested corrosion resistance, this could be achieved by grinding, pickling, electro-polishing or blasting [4].

It is reported that blasting with corundum is more effective than blasting with glass-beads. In recent years, stainless steel surfaces showed an unusually high susceptibility to pitting corrosion after grinding with corundum [15]. For this reason, it is now questioned whether the corrosion resistance of DSSs is influenced by the used blasting agent. This question was investigated specifically by comparing grinded, pickled, corundum-grain-blasted and glass-bead-blasted surfaces of the DSS 1.4062 and its welding seams. Results of the SEM analyses of the blasting agents and the blasted surfaces will be presented and correlated with the results of various performed corrosion tests.

2. Materials and methods

2.1 Materials, welding process and microstructure characterization

The welding of cold rolled sheets of 1.4062 was performed at Wilhelm Modersohn GmbH & Co KG with gas shielded metal arc welding using a root layer of 1.4062 and higher alloyed top layers of 1.4343. The structure of the welding seams was examined by metallographic investigations. The samples were wet ground with increasing grain size, polished with 3 µm diamond suspension and etched with beraha's reagent (800 ml H₂O, 400 ml HCl, 48 g (NH₄)HF₂ and 0,1 g/l K₂S₂O₅) at room temperature for 20 s. The microstructure was investigated with optical microscopy. The macroscopic appearance of the welding seams after etching is presented in figure 1. The chemical composition of the alloys (1.4062 and 1.4343) used to perform the welding process were analyzed by optical emission spectrometry. Table 1 shows the major alloying elements of the different alloys.

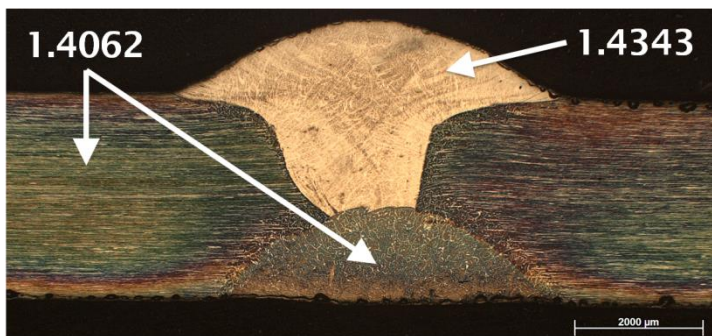


Figure 1. Macrostructure of welding seams used for this study.

Table 1. Alloy composition (mayor elements) of the welding seam in wt.-%.

	alloy	Cr	Ni	Mo	Mn	Si	N	C	P	S
base material	1.4062	24.44	2.54	0.21	1.39	0.42	0.137	0.033	0.015	<0.001
weld filler material (root)	1.4062	24.28	2.64	0.23	1.21	0.30	0.143	0.029	0.017	<0.001
weld filler material (top layer)	1.4343	22.34	8.92	2.89	1.19	0.38	0.128	0.027	0.019	<0.001

2.2 Electrochemical potentiodynamic reactivation

The passivation and reactivation behavior of the welding seams was studied with the double loop electrochemical potentiodynamic reactivation (DL-EPR). These measurements were performed to characterize only the effect of welding on the corrosion resistance on different parts of the welding seam. The weld reinforcement was removed by wet grinding to compare the cold rolled base alloy 1.4062 with the higher alloyed part of the welding seam (1.4343) and the lower alloyed part of the welding seam (1.4062). The surface was initially wet ground with grit 1000, rinsed with deionized water, subsequently cleaned with ethanol and then dried under an air flow before the EPR investigations. An area of 1.54 cm² was exposed to 2.3 ml 0.5 M H₂SO₄ with 0.01 M KSCN as activator using a mini test cell with a classical three electrode setup consisting of a saturated Ag/AgCl reference electrode (+198 mV_{SHE}) and a platinum sheet as counter electrode. A Gamry potentiostat was used to polarize the working electrode from -500 mV_{Ag/AgCl} to +100 mV_{Ag/AgCl} (passivation) followed by a reversal of the polarization direction polarizing back to -500 mV_{Ag/AgCl} (reactivation) under a constant polarization rate of 2 mV/s. The maximum current density measured during the forward scan (*i_p*) characterizes the passivation ability. The maximum current density during the backward scan (*i_R*) is the result of local reactivation and dissolution of sensitized areas. The degree of sensitization (*C*) was calculated as the ratio of *i_R* / *i_p*.

2.3 Surface treatment and SEM-analysis

Different industrial processes (pickling, blasting with glass bead, blasting with corundum, electro-polishing and plasma-polishing) were used to remove the scaling layer from the welding seams. The effect of these post surface treatments on the corrosion resistance of the welding seams was studied with different analytical and electrochemical methods.

The corundum-grains and the glass-beads were studied using scanning electron microscopy (SEM). Unused and used blasting agents were compared to characterize the effect of surface blasting on the blasting agents. All samples were sputtered with gold to decrease the electric charge of the blasting agents. Furthermore, the corundum-grain and the glass-bead blasted steel surfaces were characterized with SEM using topographic (SE) and elemental contrast (BSE) at the same surface area. An EDX-analysis was performed to identify the elements of detectable surface irregularities.

2.4 Potential measurements and the KorroPad-test

The corrosion behavior of the pickled, corundum-grain and the glass-bead blasted steel surfaces (without welding seam) were characterized by potential measurements. A test solution with 3 g/l Cl⁻ and pH 4.5 was applied on the surface using a mini test cell (1.54 cm², 4 ml). The electrochemical potential was measured against saturated Ag/AgCl reference electrode (+198 mV_{SHE}) with a Gamry potentiostat.

The KorroPad indicator test [16] was used to investigate the pitting corrosion resistance of pickled and blasted (glass and corundum) surfaces (without welding seam). This test detects the susceptibility of stainless steel surfaces to pitting corrosion by means of blue indications [17, 18]. The KorroPad consists of an indicator solution mixed with an activator embedded in a gel pad. The KorroPad has a test area of approximately 300 mm² and a nearly constant redox potential of 240 mV_{Ag/AgCl}. The KorroPad was originally designed for lower alloyed austenitic stainless steels (1.4301, 1.4404).

At the initiation state of pitting corrosion small dots are generated depending on the stability of the passive film. The steel surfaces were exposed to air with 95 % relative humidity for 24 h before the KorroPad-test to give each state the same opportunity to build up a passive film. The KorroPads were placed on the prepared surface and the electrochemical potential was measured during the reaction time of 15 min against a saturated Ag/AgCl reference electrode (+198 mV_{SHE}) with a Gamry potentiostat. The blue coloration of the KP was evaluated after the test using a high resolution scanner.

2.5 Potentiodynamic polarization test

The pitting corrosion behavior was investigated by electrochemical dynamic polarization in all generated surface states on the higher alloyed welding seam (1.4343). The samples were exposed to air with 95 % relative humidity for 24 h before the experiment to give each state the same opportunity to build up a passive film. The crevice between the sealing ring of the mini test cell and the sample surface was covered with an inert lacquer to prevent crevice corrosion. A sample area of 1.54 cm² was exposed to the test solution (3 g/l Cl⁻, pH 4.5) and the polarization was performed with a classical three electrode setup consisting of a saturated Ag/AgCl reference electrode (+198 mV_{SHE}) and a platinum sheet as counter electrode. A Gamry potentiostat was used to polarize the working electrode from the open circuit potential to the critical pitting potential at a constant polarization rate of 2 mV/s. The critical pitting potential was determined at a current density of 100 μA/cm².

3. Results and discussion

The surface treatment has a strong influence on the corrosion behavior of the welding seam. Initial metallographic investigations (2.1.) and the EPR-test (2.2.) were performed to describe the quality of the welding seam prior to the effect of surface treatment.

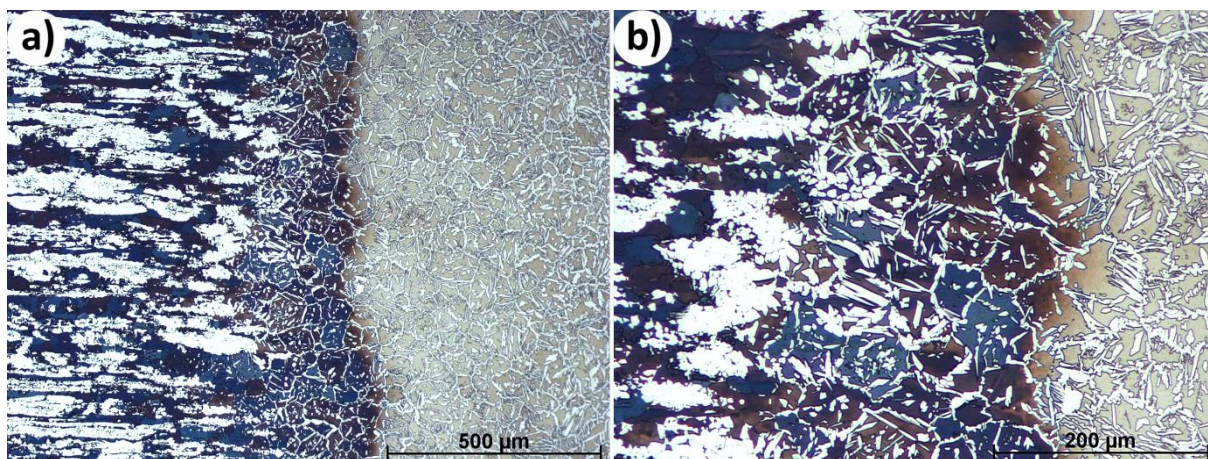


Figure 2. Microstructure of the welding seam: a) metallurgical bonding and b) heat affected zone.

Figure 2 shows the typical duplex microstructure with austenitic (white) and ferritic (dark) phases in all parts of the welding seam. The effect of the tint etching with beraha's reagent is more effective on the cold rolled 1.4062 (left) and its heat affected zone (middle), which is approximately 200 μm thick. The higher alloyed 1.4343 (right) shows a less etched ferritic matrix, which can be attributed to the higher alloying content of Mo and Ni.

The results of the EPR-test performed on the different parts of the welding seam are presented in figure 3. The cold rolled base alloy (1.4062) and the welding seam of the same alloy showed higher passivation current densities which are the result of the lower Mo and Ni-content compared to the dissimilar welding seam with alloy 1.4343. The reactivation at all three parts of the welding seam is low, but the base alloy is less sensitized compared to both parts of the welding seam. The degree of sensitization is below 0.05 for all three parts and the slightly increased reactivation of the welding seams should have no dominant effect on the pitting corrosion resistance. This was confirmed with the KorroPad-test showing no indication of pitting corrosion for ground surfaces. Furthermore, the critical pitting potential of the ground welding seam was as high as for the ground cold rolled base alloy (1.4062). It can be concluded that the welding seam itself has no dominant negative effect on the pitting corrosion resistance.

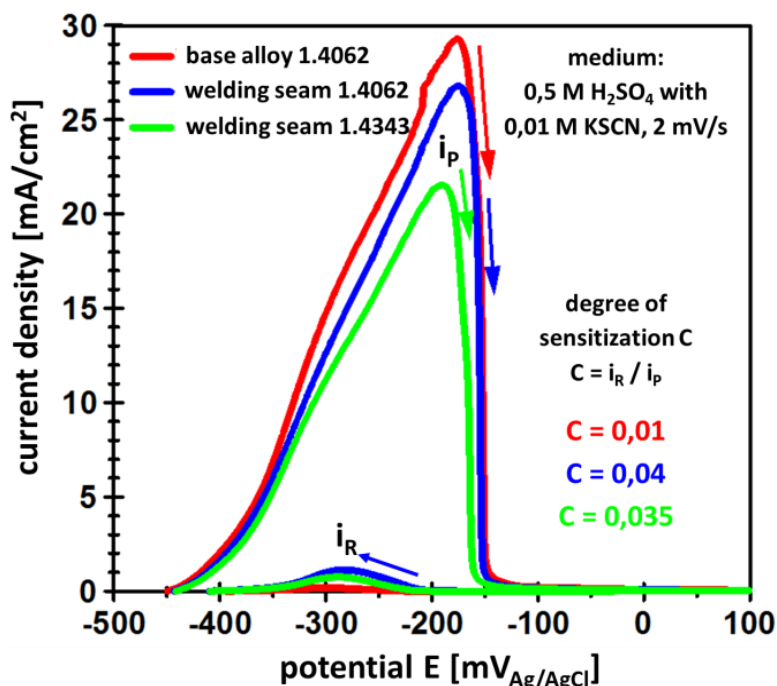


Figure 3. Results of the electrochemical potentiodynamic reactivation (EPR) performed on different locations of the welding seam.

The further investigations focus on the effect of the surface treatment of the welding seam which is necessary to remove the corrosion-prone scale layer. The typical appearance of four different surface states investigated is shown in figure 4. The corundum-blasted and glass-bead-blasted surfaces as well as the electro-polished and plasma-polished surfaces have a similar appearance.

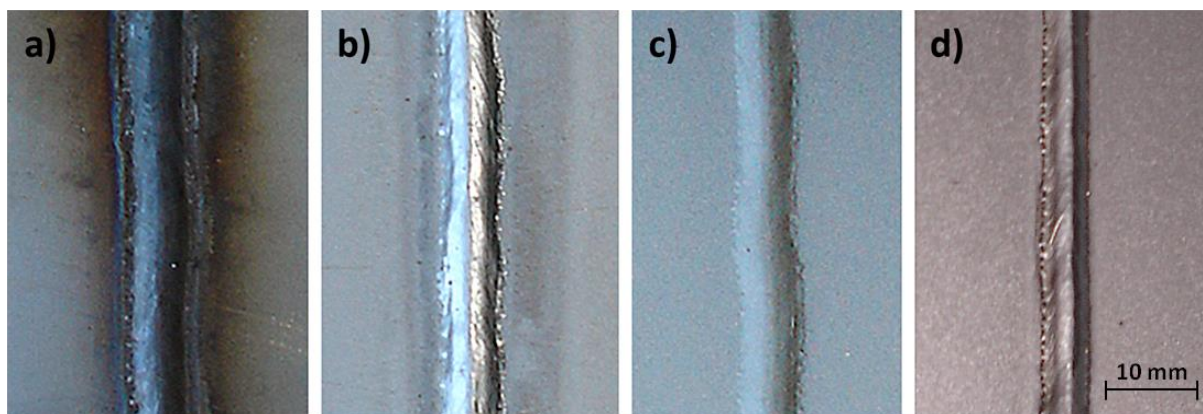


Figure 4. Typical surfaces of welding seams: a) scale layer, b) pickled, c) blasted and d) polished.

The blasting agents and blasted surfaces were studied in order to evaluate the effect of the blasting agents (glass vs. corundum) on the pitting corrosion resistance. Figure 5 shows SEM images of unused and used blasting agents which were as well used for blasting of the welding seam. The grain size of the blasting agents decreases due to the blasting process. The investigation of the blasted surfaces in the SEM with SE- and BSE-contrast is presented in figure 6 for the same surface area. The blasted surfaces are heavily rugged and the roughness is comparable (corundum: $R_z 26 \pm 2$, $R_a 3,8 \pm 0,2$ and glass: $R_z 29 \pm 8$, $R_a 4,1 \pm 0,5$) for both blasting agents. The dark particles were analyzed by EDX-spot-analysis and it was confirmed that the small grained blasting agents were incorporated in the blasted surface.

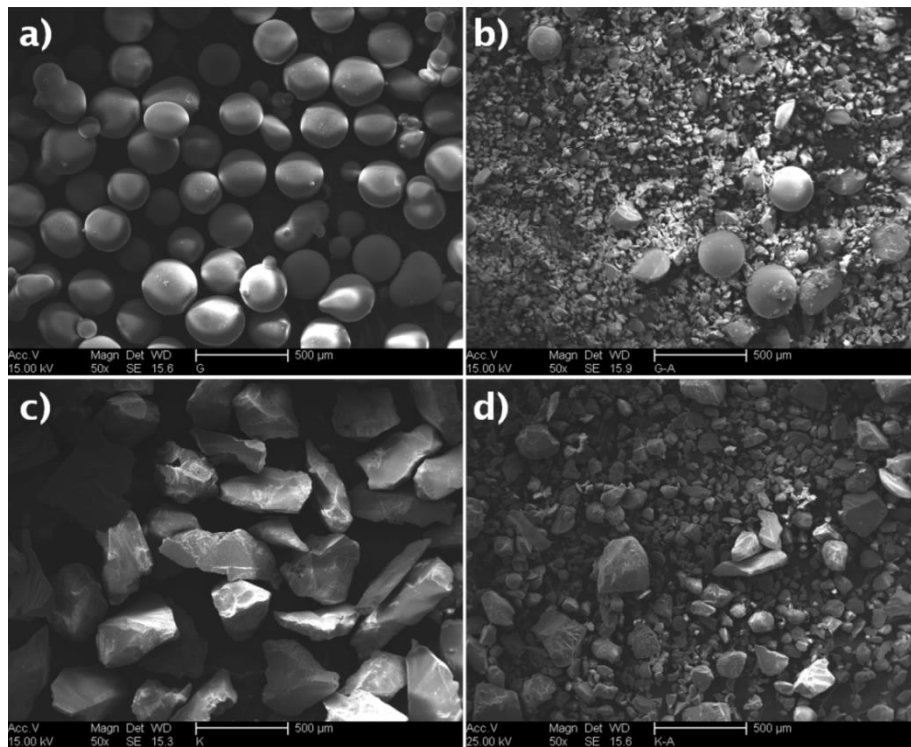


Figure 5. SEM images of blasting agents: a) unused glass bead, b) used glass bead, c) unused corundum-grains and d) used corundum-grains.

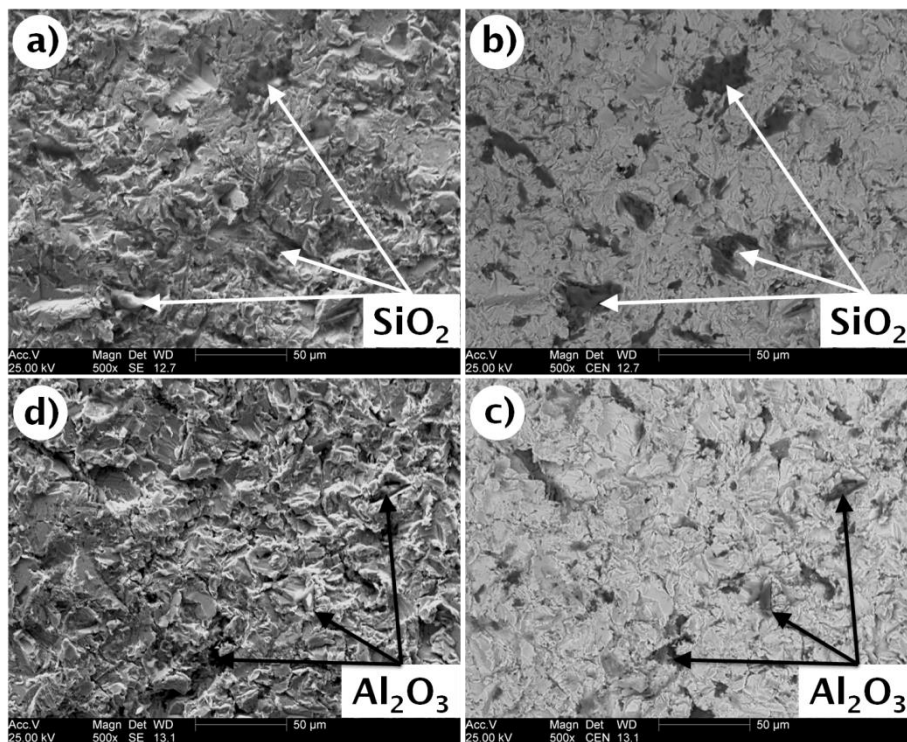


Figure 6. SEM images of blasted surfaces: a) glass bead with SE-contrast, b) glass bead with BSE-contrast, c) corundum-grain with SE-contrast, d) corundum-grain with BSE-contrast.

The effect of these microscopic defects in the surface of the DSS 1.4062 on the corrosion resistance was studied with the KorroPad-test, which was instrumented with an additional potential measurement. Furthermore, a conventional potential measurement in a electrochemical test solution with 3 g/l Cl⁻, pH 4.5 (2.4.) was performed for comparison. These investigations were performed in some distance to the welding seam to detect only the effect of the surface treatment. The blasted surfaces showed lower initial potentials during the KorroPad-test compared to the pickled surfaces, see figure 7 a).

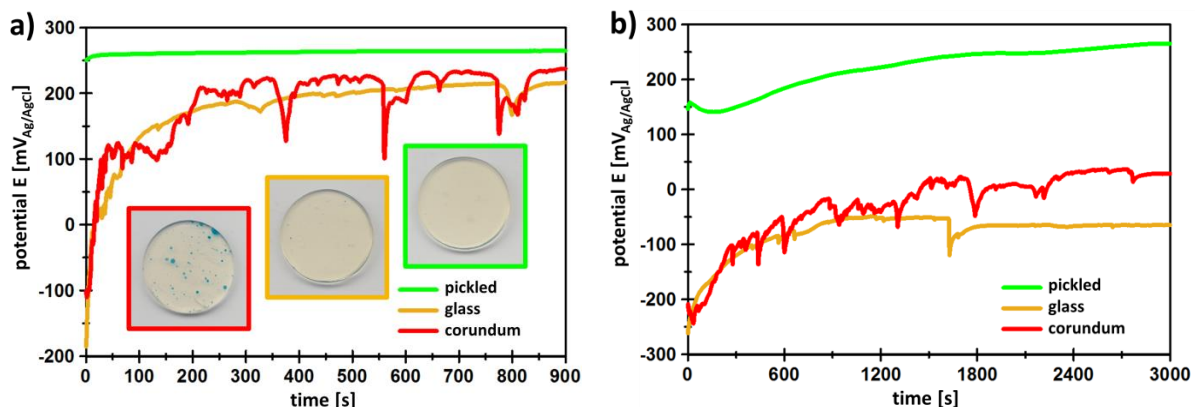


Figure 7. Corrosion potential a) during the KorroPad-test as well as the appearance of the KorroPads b) in 3 g/l Cl⁻, pH 4.5 for different surface states (without welding seam).

Especially the corundum-blasted surface shows a high number of potential drops. These are the result of metastable pitting corrosion, which leads to many blue indications in the KorroPad. The potential development of the glass-bead-blasted surface shows only a few potential drops, which initiate only isolated indication in the KorroPad. The potential measurement in the test solution with 3 g/l Cl⁻ and a pH 4.5 shows a similar tendency, (figure 7 b). These results confirm the weaker passive layer stability of corundum-blasted compared to glass-bead-blasted surfaces by means of more potential drops. The pickled surface shows a constant noble potential and therefore a high passive layer stability.

Finally, the critical pitting potentials were evaluated on the welding seams with the higher alloyed weld filler material (1.4343) in all different surfaces states, see figure 8.

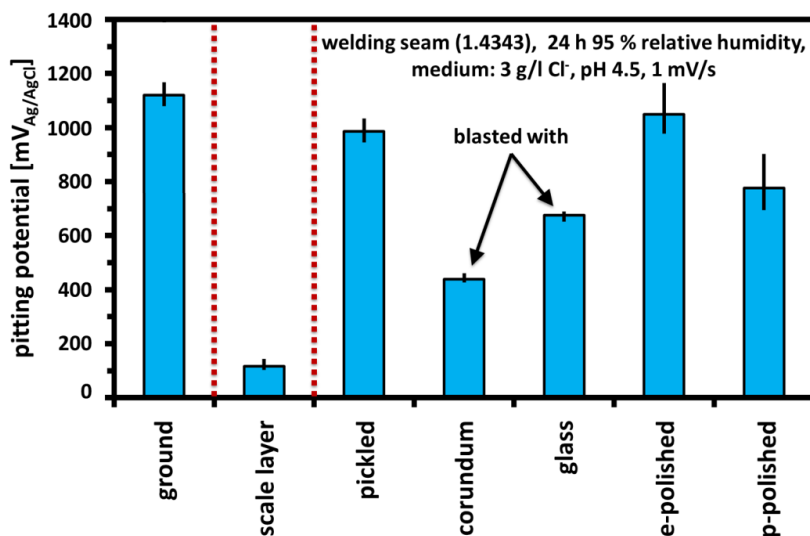


Figure 8. Critical pitting potentials of different surface modifications of the higher alloyed part of the welding seam (1.4343).

The surface treatment determines the critical pitting potential significantly. The welding seam with scale layer shows the weakest pitting corrosion resistance, which is the reason for the typically performed surface treatments. The pitting corrosion resistance of blasted surfaces is higher compared to the scale layer, but it is much lower compared to ground, pickled or polished welding seams. Moreover, blasting with corundum result in a lower critical pitting potential compared to blasting with glass-bead.

4. Conclusions

The corrosion resistance of the "lean" duplex stainless steel 1.4062 (X2CrNiN22-2) was studied on welding seams with different surface treatments. The corrosion resistance of the welding seam itself was comparable to the cold rolled base alloy. The scale layer shows the weakest pitting corrosion resistance, which was estimated. The surface treatments, which were used to remove the scale layer, result in major differences in the pitting corrosion resistance. Blasting leads to highly unstable passive layers, as could be detected by the KorroPad-test and the potential measurements. The blasting process reduces the grain size of the blasting agents and EDX-spot-analysis of the blasted surfaces confirmed the incorporation of the small grained blasting agents in the steels surface. These surface defects hinder the formation of a stable passive layer and reduce the pitting corrosion resistance. In case of blasting with corundum this effect is more pronounced compared to blasting with glass-bead and the susceptibility to pitting corrosion is significantly higher. This was proven by KorroPad-test, the potential measurement and the higher critical pitting potentials of glass bead blasted surfaces compared to corundum grain blasted surfaces. The pitting potential measurements showed a pronounced differentiation of the pitting corrosion resistance in the following order: scale layer < blasting with corundum < blasting with glass-bead < plasma-polished < ground, pickled and electro-polished. Future work will focus on the optimization of the blasting process and the post-treatment of corundum blasted surfaces to increase the passive layer stability.

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