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Comparative corrosion studies of 2205 duplex steel after electropolishing and passivation in Ringer's solution

Krzysztof Rokosz[1,a], Tadeusz Hryniewicz[1,b], Grzegorz Solecki[1,2,c]

[1]Division of Bioengineering and Surface Electrochemistry, Department of Engineering and Informatics Systems, Faculty of Mechanical Engineering, Koszalin University of Technology, Racławicka 15-17, PL 75-620 Koszalin, Poland

[2]BerlinerLuft Sp. z o.o., Chocimska 7, PL 78-200 Białogard, Poland

[a-c]E-mail address: rokosz@tu.koszalin.pl , Tadeusz.Hryniewicz@tu.koszalin.pl , grzegorz.solecki.sg@gmail.com

ABSTRACT

In present work, the results of corrosion analysis of pitting and general corrosion of austenitic duplex 2205 (EN 1.4462) stainless steel in Ringer's solution, are presented. The corrosion rate was studied using potentiodynamic polarisation method by means of the ATLAS 98 potentiostat with POL 98 software. For these measurements the platinum EPT-101 and calomel reference EK-101P electrodes were used. For each run, the electrolytic cell made of glass was used, containing up to 500 ml of the electrolyte. The specimens used for the studies were obtained from a cold-rolled sheet of steel in three forms: as received (without any pretreatment), after abrasive polishing, and after electrochemical polishing. Some of them were passivated for 15 and 30 minutes, respectively, in 20% HNO_3 by volume. The study results show clearly that the samples of duplex 2205 stainless steels after electropolishing and passivation for 15 minutes in 20% HNO_3 by volume revealed the highest corrosion resistance.

***Keywords*:** stainless steel duplex 2205, electropolishing, passivation, pitting corrosion, potentiodynamic corrosion measurements

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1. INTRODUCTION

Nowadays, the steels [**1-3**] parallel with titanium and its alloy [**4-9**] are used in many sorts of industries (chemical, mechanical, food, transport, off-shore, in the paper, petrochemical mining industries, etc.). The duplex steels are now very often used besides the austenitic and superaustenitic ones because of their noble corrosion resistance as well mechanical properties. It has to be pointed out that with the use of electrochemical polishing [**9-12**], magnetoelectropolishing [**13-25**], high-current-density electropolishing [**26**, **27**], high-voltage electropolishing [**28**] as well as performing passivation in nitric acid, it is possible to obtain the passive layer enriched with chromium compounds, such as $Cr_2O_3 \cdot nH_2O$, $CrOOH \cdot nH_2O$, $Cr(OH)_3 \cdot nH_2O$, which are much more than iron compounds ($Fe_2O_3 \cdot nH_2O$, $FeO \cdot nH_2O$, $Fe_3O_4 \cdot nH_2O$, $FeOOH \cdot nH_2O$). All these compounds provide a very good pitting corrosion protection.

2. METHOD

The 2205 (EN 1.4462) duplex stainless steel samples (cuboid with dimensions of 50 × 30 × 1.5 mm) were used for the study. The main elements forming the steel are: chromium (21-23%), molybdenum (2.5-3.5%), nickel (4.5-6.5%), manganese (max 2%), silicon (max 1%), including carbon (max: 0.03%), phosphorus (max 0.03%), sulfur (max 0.02%), nitrogen (0.08-0.20%) and iron as the rest of the steel composition.

The electrolytic polishing operations were performed at the current density of 50 A/dm^2. The main elements of the Electropolishing (EP) setup were a processing cell, a DC power supply RNG-3010, the electrodes and connecting wiring. The studies were carried out in the electrolyte of initial temperature of 40 °C, with the temperature control of ±5 °C. Generally, the final electrolyte temperature was increased up to 55 °C. For the studies, as the electrolyte a mixture of two acids, i.e H_2SO_4:H_3PO_4 equal to 2:3, was used. The passivation was performed in the solution of 20% by volume nitric acid (HNO_3) for 15 or 30 minutes in temperature of 25 °C.

The corrosion potentiodynamic polarization tests were carried out on the ATLAS 98 testing device using the POL 98 software. The tests were carried out with a potential of –400 mV relative to the saturated calomel electrode (SCE) in the anodic side with a potential step of 5 mV (potential change rate of 0.5 mV/s) up to current density of 1000 $\mu A/cm^2$. The scan in cathodic side was performed with the potential change rate of 1 mV/s. As counter, reference and working electrodes a platinum plate with a surface area of 25 mm^2 (EPT-101), calomel reference (EK-101P), and 2205 duplex steel (examined sample), were used, respectively. For each run, the electrolytic cell made of glass was used, containing up to 500 ml of the electrolyte.

3. RESULTS AND DISCUSSION

In **Figure 1**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel as received. The corrosion potential of general corrosion was changing in the range from –212 mV_{SCE} up to 35 mV_{SCE} (range: 247 mV_{SCE}), while pitting corrosion potential

was in the range of from 1200 mV_{SCE} up to 1235 mV_{SCE} (range: 35 mV_{SCE}). In **Figure 2**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel only after passivation for 15 minutes in 20% (vol.) HNO_3.The corrosion potential of general corrosion was changing in the range from –210 mV_{SCE} up to –98 mV_{SCE} (range: 112 mV_{SCE}), while pitting corrosion potential was in the range of from 1180 mV_{SCE} up to 1239 mV_{SCE} (range: 59 mV_{SCE}).

In **Figure 3**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel only after passivation for 30 minutes in 20% (vol.) HNO_3. The corrosion potential of general corrosion was changing in the range from –210 mV_{SCE} up to –99 mV_{SCE} (range: 111 mV_{SCE}), while pitting corrosion potential was in the range of from 1185 mV_{SCE} up to 1259 mV_{SCE} (range: 74 mV_{SCE}).

In **Table 1**, there are corrosion results related to duplex 2205 stainless steel without any treatment (as received) after passivation for 15 and 30 minutes in 20% (vol.) HNO_3. Corrosion potential for non-passivated sample was equal to −85.5 ±123.5 mV_{SCE} (median: −83 mV_{SCE}), while the pitting corrosion potential 216.2 ±17.5 mV_{SCE} (median: 1216 mV_{SCE}). In case of passivated sample in 20% (vol.) HNO_3 for 15 minutes the corrosion potential was equal to −156 ±56 mV_{SCE} (median: −170 mV_{SCE}), while pitting corrosion potential was 1209.3 ±29.5 mV_{SCE} (median: 1206 mV_{SCE}). The corrosion potential of sample passivated in 20% (vol.) HNO_3 for 30 minutes was equal to −159.5 ±55.5 mV_{SCE} (median: −160 mV) $_{SCE}$, while pitting corrosion potential was 1229.3 ±37 mV_{SCE} (median: 1231,5 mV_{SCE}).

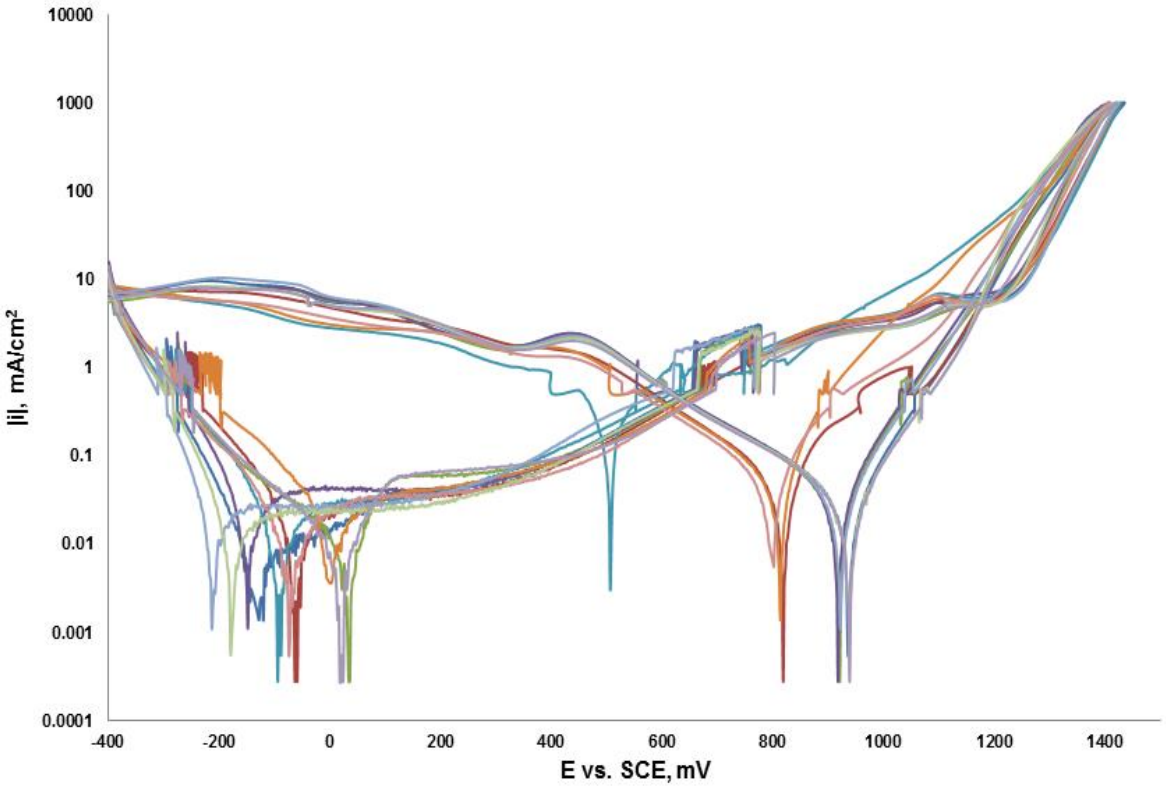

Fig. 1. Potentiodynamic curves of duplex 2205 stainless steel (AR – as received)

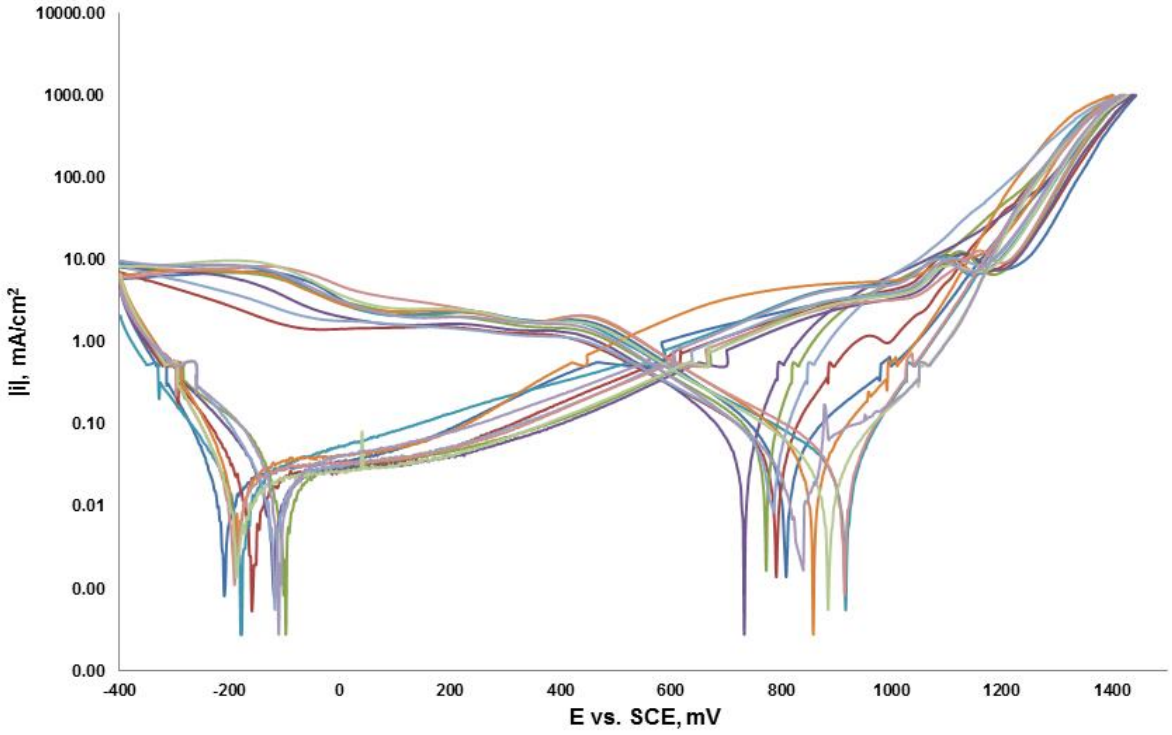

Fig. 2. Potentiodynamic curves of duplex 2205 stainless steel (as receved) after passivation for 15 min. in 20% (vol.) HNO_3

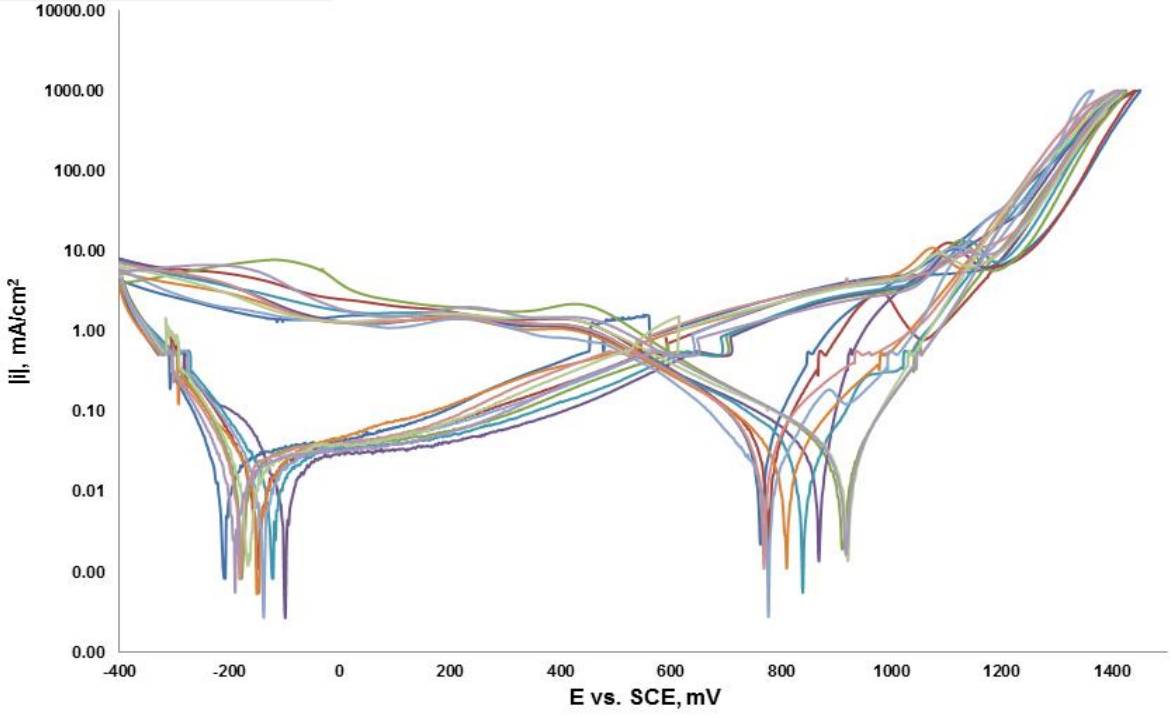

Fig. 3. Potentiodynamic curves of duplex 2205 stainless steel (as receved) after passivation for 30 min. in 20% (vol.) HNO_3

Table 1. Results of potentiodynamic measurements of duplex 2205 stainless steel (AR – as received) and after passivation in 20% (vol.) HNO_3 for 15 and 30 minutes,

Sample	2205-AR		2205-AR - 20% HNO_3 – 15 min		2205-AR - 20% HNO_3 – 30 min	
	E_{pit}	E_{cor}	E_{pit}	E_{cor}	E_{pit}	E_{cor}
1	1226	–139	1239	–210	1244	–210
2	1215	–62	1204	–160	1259	–149
3	1230	35	1215	–98	1240	–178
4	1217	–147	1205	–119	1224	–99
5	1220	–93	1194	–180	1237	–123
6	1205	–5	1180	–189	1213	–151
7	1235	–212	1202	–114	1185	–138
8	1200	–73	1230	–191	1229	–182
9	1210	–178	1217	–188	1234	–169
10	1204	19	1207	–111	1228	–196
Average	**1216.2**	**–85.5**	**1209.3**	**–156**	**1229.3**	**–159.5**
Stand. dev.	**11.7**	**84.3**	**17**	**41.3**	**19.9**	**34.1**
Median	**1216**	**–83**	**1206**	**–170**	**1231.5**	**–160**
Max	**1235**	**35**	**1239**	**–98**	**1259**	**–99**
Min	**1200**	**–212**	**1180**	**–210**	**1185**	**–210**
Range	**35**	**247**	**59**	**112**	**74**	**111**

In **Figure 4**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after abrasive polishing (MP) using abrasive paper No. 500. The corrosion potential of general corrosion was changing in the range from –213 mV_{SCE} up to –160 mV_{SCE} (range: 53 mV_{SCE}), while pitting corrosion potential was in the range from 1040 mV_{SCE} up to 1168 mV_{SCE} (range: 128 mV_{SCE}). In **Figure 5**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after abrasive polishing and passivation for 15 minutes in 20% (vol.) HNO_3. The corrosion potential of general corrosion was changing in the range from –228 mV_{SCE} up to 14 mV_{SCE} (range: 242 mV_{SCE}), while pitting corrosion potential was in range of from 1107 mV_{SCE} up to 1436 mV_{SCE} (range: 329 mV_{SCE}).

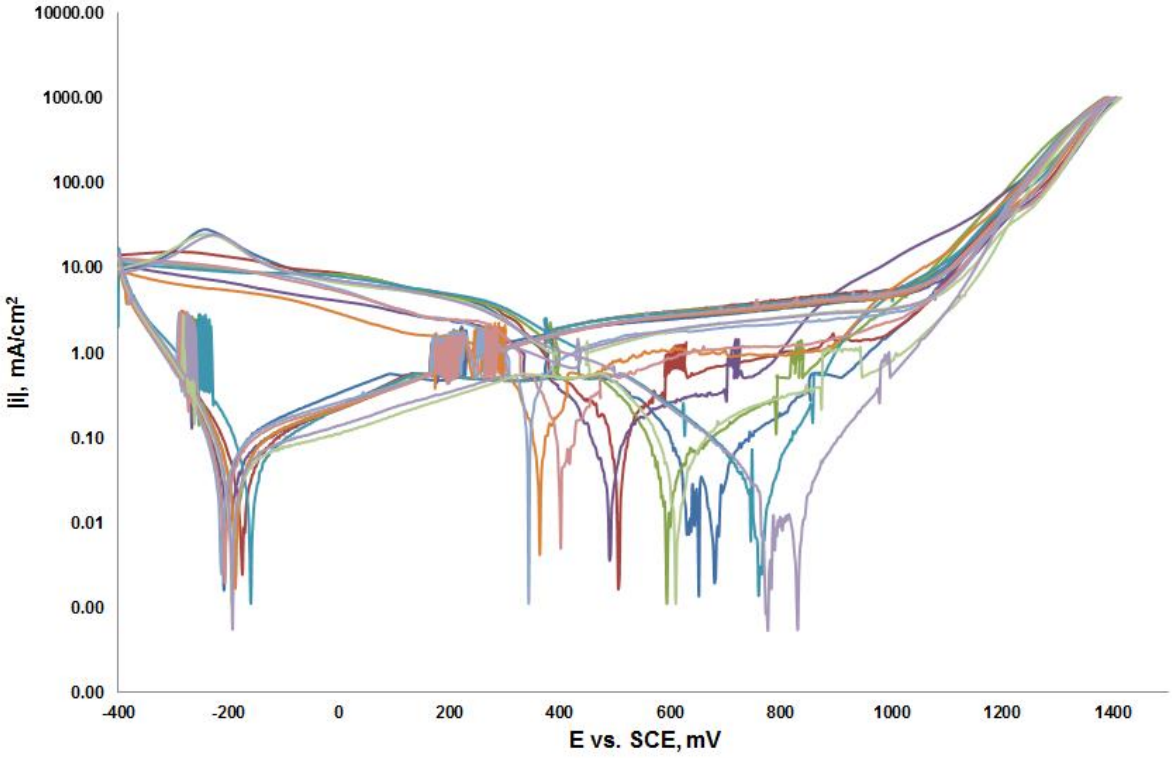

Fig. 4. Potentiodynamic curves of duplex 2205 stainless steel after abrasive polishing (MP)

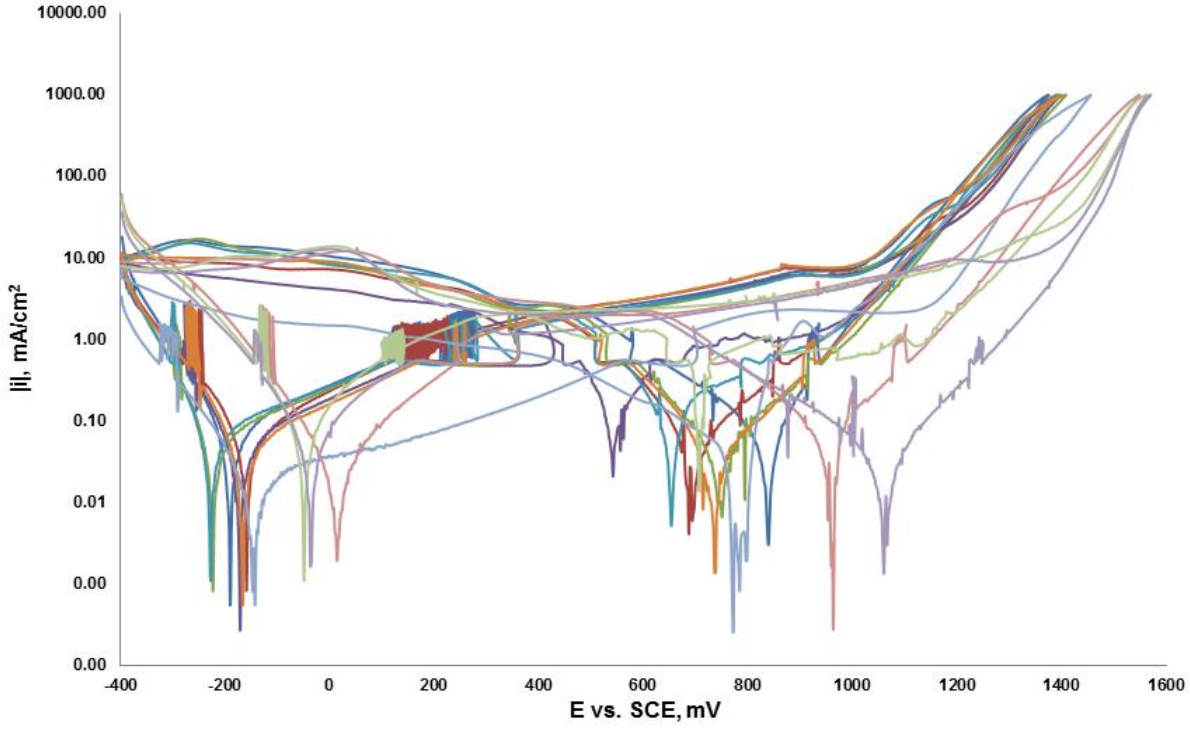

Fig. 5. Potentiodynamic curves of duplex 2205 stainless steel after abrasive polishing and passivation for 15 min. in 20% (vol.) HNO_3

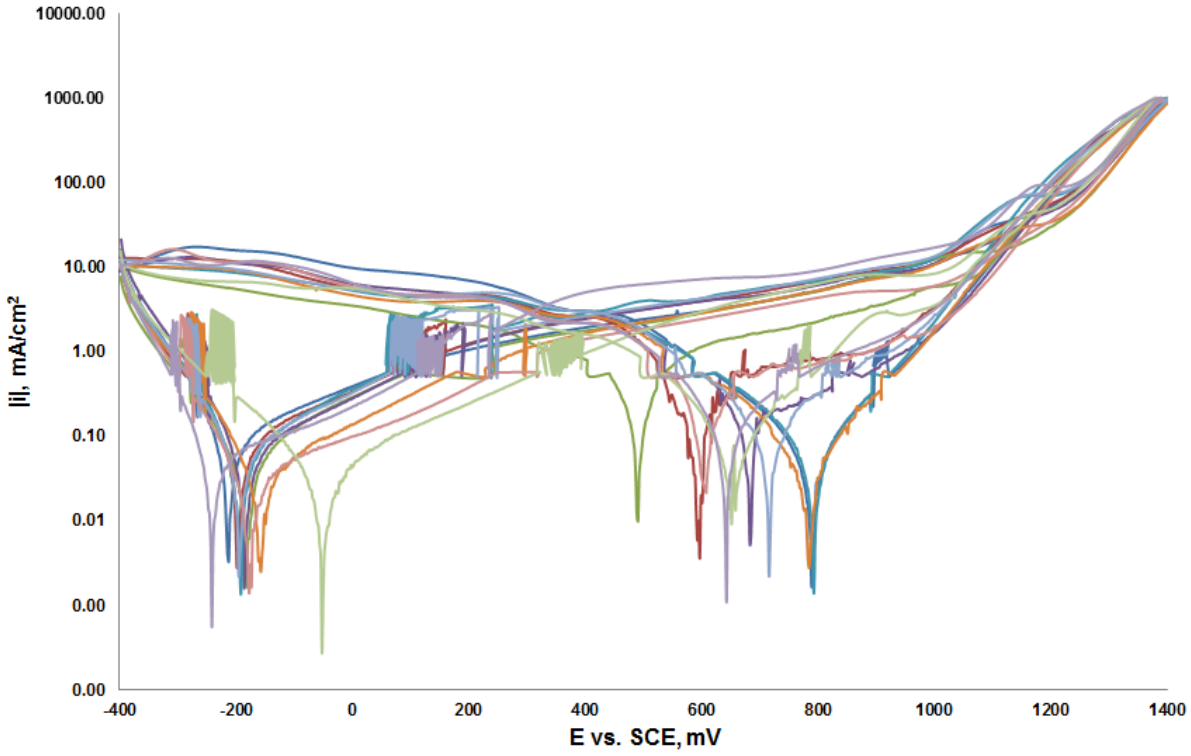

Fig. 6. Potentiodynamic curves of duplex 2205 stainless steel after abrasive polishing and passivation for 30 min. in 20% (vol.) HNO_3

In **Figure 6**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after abrasive polishing and passivation for 30 minutes in 20% (vol.) HNO_3. The corrosion potential of general corrosion was changing in the range from –241 mV_{SCE} up to 52 mV_{SCE} (range: 189 mV_{SCE}), while pitting corrosion potential was in the range of from 1063 mV_{SCE} up to 1201 mV_{SCE} (range: 138 mV_{SCE}). In **Table 2**, there are corrosion results related to duplex 2205 stainless steel after abrasive polishing and after passivation for 15 and 30 minutes in 20% (vol.) HNO_3. Corrosion potential for non-passivated sample was equal to −193 ±26.5 mV_{SCE} (median: −193.5 mV_{SCE}), while the pitting corrosion potential was 1105.2±64 mV_{SCE} (median: 1097 mV_{SCE}). In case of passivated sample in 20% (vol.) HNO_3 for 15 minutes, the corrosion potential was equal to −135.2±121 mV_{SCE} (median: −162.5 mV_{SCE}), while pitting corrosion potential was 1228.7 ±164.5 mV_{SCE} (median: 1177.5 mV_{SCE}). The corrosion potential of sample passivated in 20% (vol.) HNO_3 for 30 minutes was equal to −179.6±94.5 mV_{SCE} (median: −188.5 mV_{SCE}), while pitting corrosion potential was 1150.7±69 mV_{SCE} (median: 1156.5 mV_{SCE}).

In **Figure 7**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after electrochemical polishing. The corrosion potential of general corrosion was in the range from –351 mV_{SCE} up to 28 mV_{SCE} (range: 379 mV_{SCE}), while pitting corrosion potential was changing from 832 mV_{SCE} up to 1301 mV_{SCE} (range: 469 mV_{SCE}). In **Figure 8**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after abrasive polishing and passivation for 15 minutes in 20% (vol.) HNO_3.

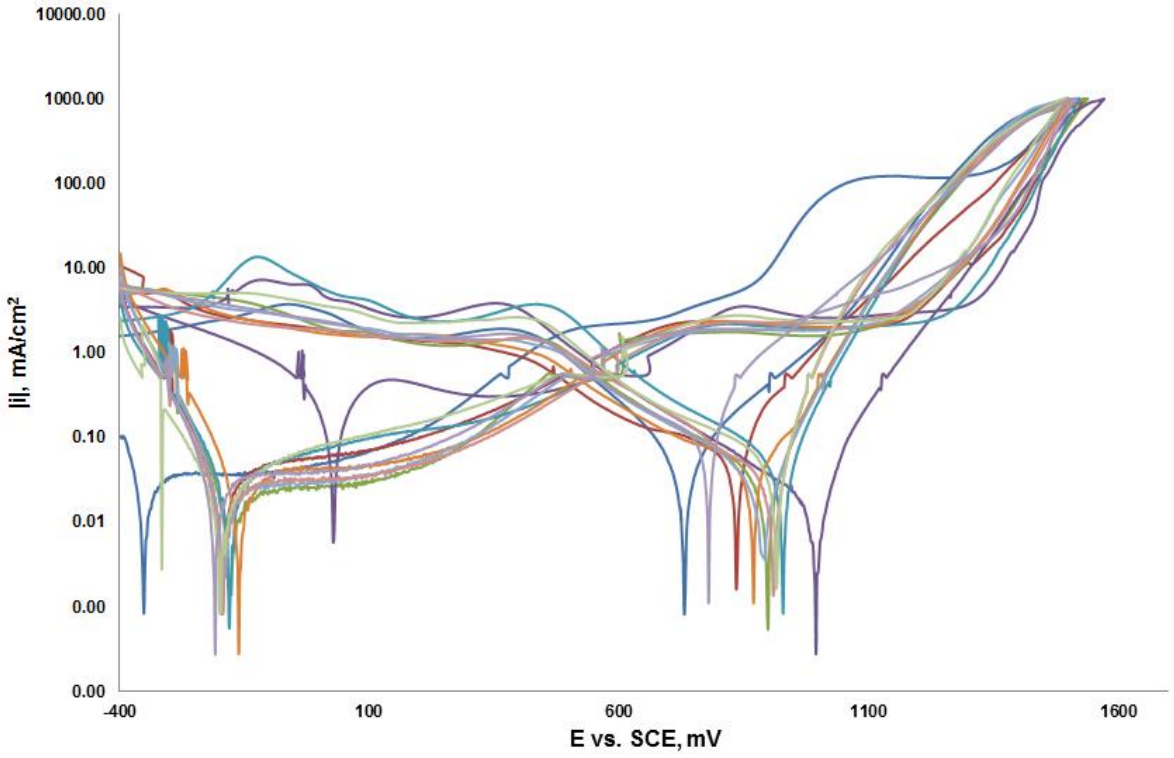

Fig. 7. Potentiodynamic curves of duplex 2205 stainless steel after electrochemical polishing (EP)

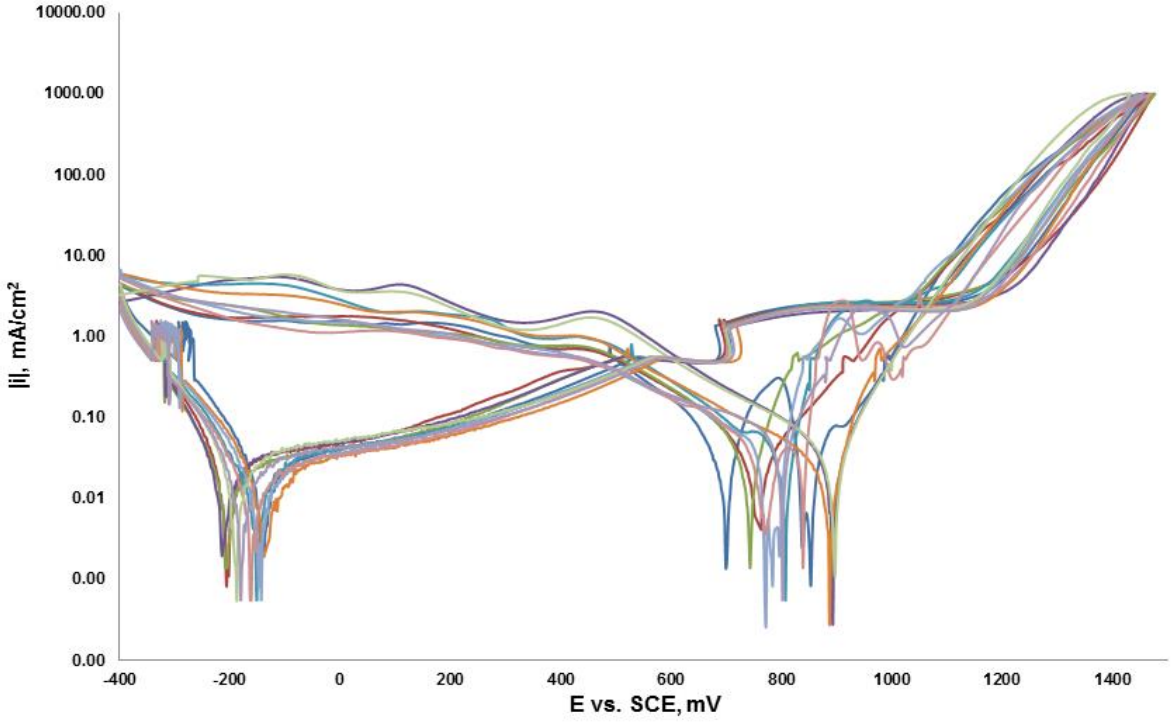

Fig. 8. Potentiodynamic curves of duplex 2205 stainless steel after electrochemical polishing and passivation for 15 min. in 20% (vol.) HNO_3

The corrosion potential of general corrosion was equal in range from –214 mV_{SCE} up to 144 mV_{SCE} (range: 358 mV_{SCE}), while pitting corrosion potential was in the range from 1181 mV_{SCE} up to 1235 mV_{SCE} (range: 54 mV_{SCE}).

Table 2. Results of potentiodynamic measurements of duplex 2205 stainless steel after abrasive polishing (MP) and passivation in 20% (vol.) HNO_3 for 15 and 30 minutes.

Sample	**2205-MP**		**2205-MP - 20% HNO_3 – 15 min**		**2205-MP - 20% HNO_3 – 30 min**	
	E_{pit}	E_{cor}	E_{pit}	E_{cor}	E_{pit}	E_{cor}
1	1101	–209	1107	–190	1152	–214
2	1091	–175	1176	–159	1121	–198
3	1040	–188	1179	–223	1179	–181
4	1093	–203	1157	–171	1161	–186
5	1079	–160	1173	–228	1063	–191
6	1089	–188	1153	–166	1201	–161
7	1118	–213	1231	–143	1192	–195
8	1126	–207	1297	14	1172	–177
9	1168	–194	1378	–49	1148	–52
10	1147	–193	1436	–37	1118	–241
Average	**1105.2**	**–193**	**1228.7**	**–135.2**	**1150.7**	**–179.6**
Stand. dev.	**36.3**	**16.4**	**107.5**	**82.7**	**41.2**	**49.8**
Median	**1097**	**–193.5**	**1177.5**	**–162.5**	**1156.5**	**–188.5**
Max	**1168**	**–160**	**1436**	**14**	**1201**	**–52**
Min	**1040**	**–213**	**1107**	**–228**	**1063**	**–241**
Range	**128**	**53**	**329**	**242**	**138**	**189**

The corrosion potential of general corrosion was equal in range from –214 mV_{SCE} up to 144 mV_{SCE} (range: 358 mV_{SCE}), while pitting corrosion potential was in the range from 1181 mV_{SCE} up to 1235 mV_{SCE} (range: 54 mV_{SCE}).

In **Figure 9**, there are presented potentiodynamic corrosion results of duplex 2205 stainless steel after abrasive polishing and passivation for 30 minutes in 20% (vol.) HNO_3.

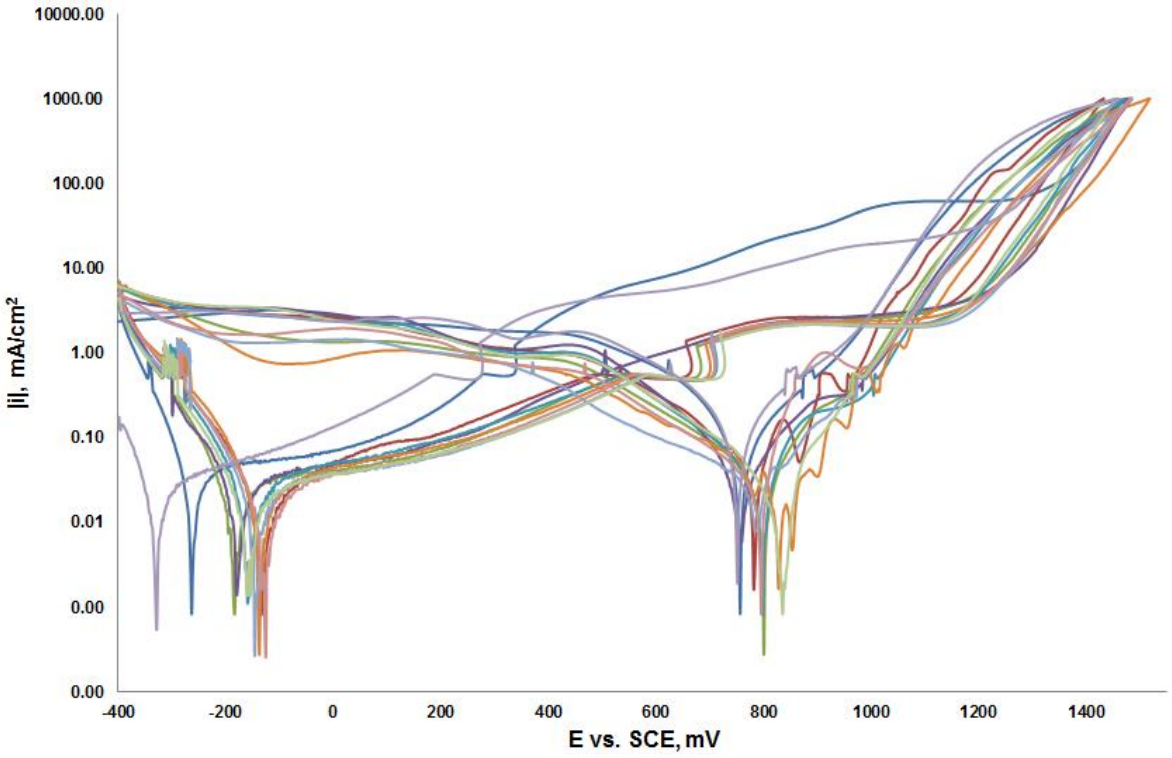

Fig. 9. Potentiodynamic curves of duplex 2205 stainless steel after electrochemical polishing and passivation for 30 min. in 20% (vol.) HNO_3

The corrosion potential of general corrosion was changing in range from −263 mV_{SCE} up to −125 mV_{SCE} (range: 138 mV_{SCE}), while pitting corrosion potential was in the range of from 1188 mV_{SCE} up to 1272 mV_{SCE} (range: 84 mV_{SCE}). In **Table 3**, there are corrosion results related to duplex 2205 stainless steel after electrochemical polishing and after passivation for 15 and 30 minutes in 20% (vol.) HNO_3.

Corrosion potential for non-passivated sample was equal to −182.7 ±181.5 mV_{SCE} (median: −192.5 mV_{SCE}), while the pitting corrosion potential was 1170.8 ±234.5 mV_{SCE} (median: 1192.5 mV_{SCE}). In case of passivated sample in 20% (vol.) HNO_3 for 15 minutes the corrosion potential was equal to −145 ± 179 mV_{SCE} (median: −171.5 mV_{SCE}), while pitting corrosion potential was 1203.5 ±27 mV_{SCE} (median: 1177.5 mV_{SCE}). The corrosion potential of sample passivated in 20% (vol.) HNO_3 for 30 minutes was equal to −172.5 ±69 mV_{SCE} (median: −159.5 mV_{SCE}), while pitting corrosion potential was 1224.9 ±42 mV_{SCE} (median: 1221 mV_{SCE}).

In **Fig. 10**, comparison of corrosion behavior of duplex 2205 stainless steel after different treatments: AR – as received, MP – after abrasive polishing (paper No. 500), EP – after electropolishing, are presented. Moreover, additional treatment by passivation in 20% (vol.) HNO_3 for two periods of time, 15 and 30 minutes, are given. One can observe the highest discrepancy after electropolishing (EP).

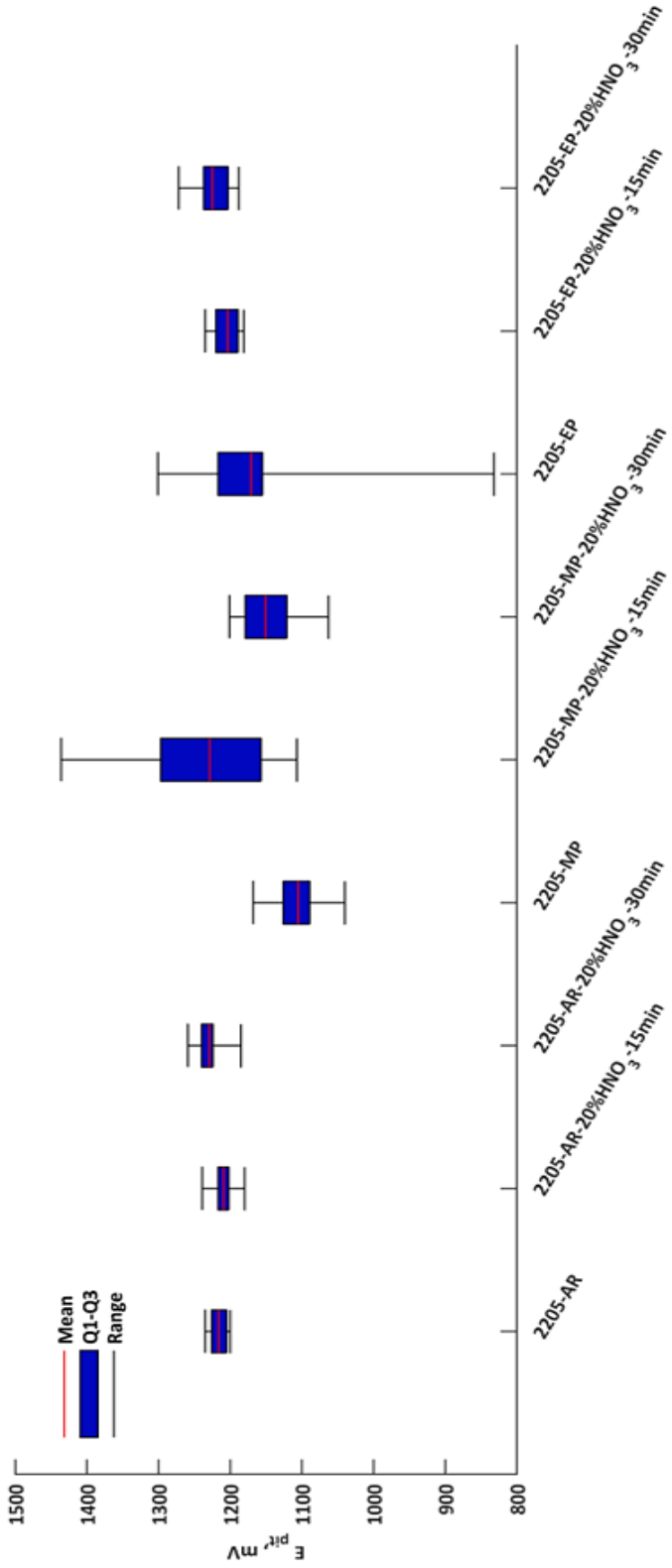

Fig. 10. Comparison of corrosion behavior of duplex 2205 stainless steel after different treatments: AR – as received, MP – after abrasive polishing, EP – after electropolishing

Table 3. Results of potentiodynamic measurements of duplex 2205 stainless steel after electrochemical polishing (EP) and passivation in 20% (vol.) HNO_3 for 15 and 30 minutes

Sample	2205-EP		2205-EP - 20% HNO_3 – 15 min		2205-EP - 20% HNO_3 – 30 min	
	E_{pit}	E_{cor}	E_{pit}	E_{cor}	E_{pit}	E_{cor}
1	832	–351	1188	144	1272	–263
2	1181	–195	1191	–206	1188	–133
3	1184	–176	1181	–208	1212	–183
4	1301	28	1220	–214	1265	–181
5	1272	–180	1189	–151	1203	–159
6	1215	–161	1235	–142	1237	–137
7	1155	–192	1193	–143	1230	–146
8	1217	–193	1221	–163	1227	–125
9	1201	–199	1197	–187	1200	–160
10	1150	–208	1220	–180	1215	–238
Average	**1170.8**	**–182.7**	**1203.5**	**–145**	**1224.9**	**–172.5**
Stand. dev.	**128.2**	**91**	**18.6**	**105.1**	**27.3**	**45.7**
Median	**1192.5**	**–192.5**	**1195**	**–171.5**	**1221**	**–159.5**
Max	**1301**	**28**	**1235**	**144**	**1272**	**–125**
Min	**832**	**–351**	**1181**	**–214**	**1188**	**–263**
Range	**469**	**379**	**54**	**358**	**84**	**138**

4. CONCLUSION

Corrosion analysis of passive layers obtained after passivation in 20% by volume nitic acid (HNO_3) without any pre-treatment (as received) as well as after abrasive and electrochemical polishing unambiguously indicates that the best pitting corrosion protection (the minimum of pitting corrosion potential in the range from 1180 mV_{SCE} up to 1200 mV_{SCE}) may be obtained after passivation of non-treated surface or after electrochemical polishing as pre-treatment. The lowest corrosion protection regarding pitting was found for abrasively polished samples (the minimum of pitting corrosion potential was equal to 1040 mV_{SCE}) and

after passivation with abrasive polishing as pre-treatment (the minimum of pitting corrosion potential in the range from 1180 mV_{SCE} up to 1200 mV_{SCE}). In summary, it should be noted that after electrochemical polishing and passivation in 20% vol. HNO_3 the obtained passive layer is uniform and its pitting corrosion resistance is very high.

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