Properties of naval steel after non-thermal plasma treatment

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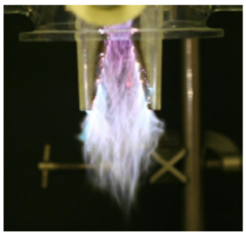
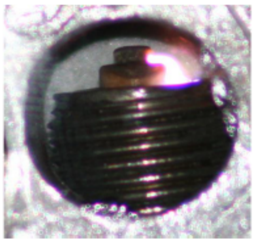
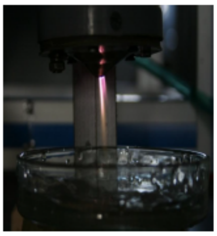
Improving corrosion resistance represents a highly interesting topic in the maritime field, having important economic consequences by reducing the maintenance costs or increasing the life expectancy of the final products and by imposing significant environmental impact. In accordance with new IMO (International Maritime Organization) regulations, different new clean technologies have been proposed for solving this particular issue, among them being also considered the technology based on plasma discharges, generally produced at reduced pressure. The proposed study concerns the opportunity of atmospheric plasma treatment for naval steel preparation or conditioning. Five different treatments, with three types of plasma working under different gases, have been used. Their effects were evaluated based on surface modification analysis. These analyses concern the roughness of the samples and the surface hydrophobicity at two different moments of time. There were used three types of reactors producing non-thermal plasma: GlidArc, Gliding Spark and Minitorch.

EXPERIMENTAL SET-UP


GlidArc reactor

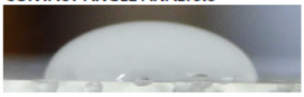

Gliding Spark reactor


Minitorch reactor

Experimental conditions:
- maximum 45° for treated surface
- power supply at 5 kV/ 100 mA (50 Hz)
- time of treatment: 10 minutes

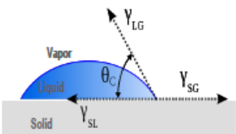
Distance between the top of the electrodes and the samples:
- 2.5 cm for Sample A and Sample B
- 5.5 cm for Sample C
- 2 cm for sample D
- 1.25 cm for sample E

CONTACT ANGLE ANALYSIS



5' GlidArc treatment

High increase in the hydrophilic nature of the surfaces by the treatment after a short time



Young's equation → $g_{SG} - g_{SL} - g_{LG} \cdot \cos q_c \approx 0$

q_c : Equilibrium contact angle
g_{SG} : Solid–vapor interfacial energy
g_{SL} : Solid–liquid interfacial energy
g_{LG} $\equiv g$: Surface tension (liquid–vapor interfacial energy)

Young-Dupré eq. → $W_{SL} = g_{SG} + g_{LG} - g_{SL} \approx g_{LG}\,(1+\cos q_c)$

W_{SL} : Work of adhesion (solid - liquid adhesion energy per unit area)

Signification of the sampless and Roughness parameters

Signification of the samples:

- Sample 0 – Model / Witness
- Sample A – GlidArc reactor using dry air, 65 L/min gas flow
- Sample B – Gliding Spark Reactor using dry air, 65 L/min gas flow
- Sample C – GlidArc reactor with humid air, 65 L/min gas flow
- Sample D – GlidArc reactor with CO_2, 20 L/min gas flow
- Sample E – Minitorch reactor with dry air, 65 L/min gas flow.

Roughness parameters:

- R_a - the arithmetic mean of deviations of the roughness profile from the average line
- R_z - average of all R_t values that come from each sample. This parameter has similar uses to R_t, but is not subject to large variations due to scratches.
- R_t - the total height of the profile, i.e. the height between the minimum and maximum points over the entire length of the evaluation
- R_{max} - the maximum profile height

DISCUSSION

-The results are the average of the 5 measurements. The minimal adhesion was observed for sample D (under the action of GlidArc with CO_2 action) at Ra =0.128 μm, followed by Sample E (under Mini-torch plasma action) at Ra=0.257 μm, while maximum adhesion was observed at sample B (by Gliding Spark action) which had the highest roughness with Ra=0.745 μm.
- According to the water contact angle sheet, samples B to E were more hydrophobic than control sample, whereas sample A was less hydrophobic than control sample.
- Also the heterogeneity of the hydrophobicity was higher for control sample and sample C than for the other samples.
- From Table 2 it could be observed that the biggest water contact angles are obtained for Sample D and Sample E which is consistent with the values from Table 1.

CONCLUSIONS

- The hydrophobic feature represents an important element in stimulating the biofilm formation, the result obtained for the samples C, D and E, having water contact angles between 83°-86° (compared to sample A, whic has the angle 66°) rushed biofilm formation in the first 24 hours. Thus, the cumulative effect of the hydrophobicit and also the chemical effect due to non-thermal plasma treatment were felt in the bacterial density fluctuatio between 24 and 48 hours.
- Taking into consideration the physical properties of the contact surfaces (roughness, water contact angle measurements) there was a direct correlation between them and the adherence of microorganisms and also i biofilm formation. For the samples treated with GlidArc with dry air and Gliding Spark, the good adhesion degre could be attributed to the increase of the surface roughness, within a relatively constant hydrophobicity of all th experimental samples.

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EXPERIMENTAL RESULTS

Roughness of the samples

Material	Zone	Direction	Ra (μm)	Rz (μm)	Rmax (μm)
Sample O (control)			0.241	2.17	3.31
			0.187	1.59	1.94
			0.359	2.72	5.91
Sample A			0.557	6.66	13.5
			0.572	4.88	5.69
			0.642	5.71	6.33
Sample B			0.745	7.73	10.7
			1.086	8.79	12.6
			1.374	9.94	15.1
Sample C			0.128	1.29	1.83
			0.275	3.17	6.48
			0.237	1.9	4.93
Sample D			0.174	1.28	1.91
			0.169	1.61	2.26
			0.292	1.88	2.44
Sample E			0.257	2.61	3.58
			0.165	1.93	2.47
			0.280	2.42	5.21

Water contact angles measured with Krüss DSA 100 type microgoniometer (100 pL per drop)

Sample	Control O	Sample A	Sample B	Sample C	Sample D	Sample E
Water contact angle [°]	77 ± 2	66 ± 5	80 ± 5	83 ± 2	85 ± 5	86 ± 4

Photos of measurements for water contact angles