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CHARACTERISATION OF SURFACES AFTER UHP ((ULTRA HIGH PRESSURE) WATERJETTING ON SHOP PRIMER COATED STEEL SUBSTRATE FOR NEW CONSTRUCTION IN NAVAL INDUSTRY

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Ultra-high-pressure (UHP) waterjetting is a suitable alternative to abrasive blasting for maintenance work or complete renovation. For maintenance conditions, the oxides of the surface are quantified though different levels of “flash rust”, but for new construction the characterisation of surface especially with a moderate roughness values is not available.
This study presents the results of characterisation of steel surfaces after UHP waterjetting of shop primer coated steel, using different surface analytical techniques (EDX/MEB, Mossbauer spectrometry …). The influence of cleaning parameters such as flow pressure, type of nozzles…etc, was examined. UHP waterjetting was found to remove a large part of zinc ethyl silicate on the steel surface but, whatever the cleaning parameters, a small fraction of zinc still remains on the surface. The results are compared with conventional grit blasted surfaces in terms of surface cleanness, roughness and remaining zinc on surface.

Introduction

Surface preparation processes influence the performance and lifetime of coating systems applied to steel substrates. Thus, the state of the steel surface immediately prior to painting is crucial and the main factors influencing the performance are the presence of rust and mill scale, surface contaminants including dust, salts and grease, surface profile. For aggressive environments such as marine atmospheres of C5M corrosivity category and high-performance coatings that require cleaner and/or rougher surfaces, blast cleaning is often preferred (see ISO 8501-1 or SSPC VIS1). It is well known that surface preparation using abrasive cleaning in particular can produce a considerable amount of waste mainly containing blasting media and old removed paint or rust products.

As an alternative to abrasive cleaning for maintenance work or complete renovation, ultra high pressure (UHP) waterjetting may be a promising strategy for surface preparation as long as the performances of the coatings on steel structures are not affected. UHP waterjetting technology has been described intensively [1-3].

It is crucial to characterise the surface quality of steel substrates prepared by UHP waterjetting, in terms of flash rust, salt contaminants or surface roughness etc. Previous works have been conducted by the team of Le Calvé *et al*. in order to gain more understanding on the surface preparation by UHP waterjetting and its influence on the coating performances through accelerated corrosion tests and field exposures [4, 5].

- One study was dedicated to the extraction and the measurement of iron oxides, as a function of the degree of flash rusting (OF0, OF1, OF2) as described in the standard NF T35-520 [3]. It should be remembered that original state of the support is a determining element in the concentration measured. The latter can vary between 4-6 g/m^2 for a level of flash rusting OF1 and higher than 8 g/m^2 for a level of flash rusting OF2. Similar techniques were used by Islam and co-workers [6]

-A systematic investigation about the influence of flash rust on the performance of four reference paint systems applied in new construction and maintenance configuration after UHP waterjetting preparation (hand held gun, 2100 bar) showed that the method did not lead to similar performance as classical abrasive cleaning (Sa 21/2) [4]. The study showed a drop in the coating performance as a function of increasing level of flash rust degree from OF0 to OF2, which highlights the importance of the steel surface state prior to UHP waterjetting.

- The performance of 13 different coating systems applied on UHP treated steel in maintenance configuration (robot, 2450 bars) was studied in field exposure and laboratory tests and compared to classical abrasive blasted steel [5]. 4 coating systems applied on UHP treated surfaces were found to give satisfying results comparable to a surface preparation by abrasive blasting.

If UHP waterjetting becomes more widely used for maintenance applications, they are however some questions on the use of this technique for new construction. In particular, the surface state of hydroblasted zinc-rich shop primer coated steel (in new construction configuration) is not fully described. Thus, there is a need to better assess the efficiency of hydroblasting for such application.

In the present study, the influence of cleaning parameters such as flow pressure or hydroblasting tools are examined in terms of surface cleanness, roughness and remaining zinc on surface. The results are compared with classical grit blasted surfaces

Experimental

<u>Samples and surface preparation</u>

Steel panels DH36 commonly used in naval constructions were selected with different surface preparations which represent different practical cases that may be found one a structure in the field. As shown in Table 1, steel panels (100x175mm) were grit and shot blasted (metallic abrasives) to grade $Sa2^{1/2}$ and coated with a zinc-rich shop primer (zinc silicate, 10-15µm) as initial conditions. Further surface preparation consisted in ultra high pressure (UHP) water jetting performed either using a gun or a robot for sample type 1. Table 2 gives details on the UHP waterjetting equipments and configurations to get a degree of cleanliness DHP4 according to NF T35-520 and a flash rust level less than OF1 as defined in the same standard. It should be mentioned that three different pressures were applied on samples type 1 e.g. 2560, 2800 and 3000 bar, both with the gun and the robot. Samples type 2 as references were grit blasted to Sa2½ (Medium Grit). Table 3 gives details on the sample reference as an example, label **Sa_R_2560** corresponds to: Sa = blasted surface ASa2 ½ (ISO 8501-1) Medium Grit (ISO 8503); roughness Ra = 10 – 12 µm; R = Robot; 2560 = pressure UHP waterjetting 2560 bar.

Table 1: description of steel samples and initial states

	Type 1	**Type 2**
Type of steel	DH36	
Initial states	Blasted to ASa2½ + Zinc-rich shop primer coated	
Surface preparation	UHP Waterjetting	Blasted to Sa2½ (ISO 8501-1) Medium Grit (ISO 8503-1)

Table 2: description of UHP waterjetting parameters and equipments

Parameters	**Hand held gun**	**Robot**
Degree of cleanliness according to NF T35-520	DHP4	
Level of flash rusting according to NF T35-520	<OF1	
Pressure of cleaning	from 2560 bar to 3000 bar	from 2560 bar to 3000 bar
Water flow	15 litre/min for 2500 bar	28 litre/min for 2500 bar 40 litre/min for 3000 bar
Material	“Rotorjet” with 4 nozzles 0.4 mm	Rotating water jet head with 10 nozzles,
Angle of cleaning	75 -90 degrees	90 degrees
Conductivity of water	400 µS/cm	400 µS/cm
Distance of jet from surface	50 mm	between 20 and 30 mm

Table 3: sample reference

Initial States	Waterjetting Equipment	Pressure
*Sa **Zn	R = Robot G = Gun	From 2500 bar to 3000 bar
*Sa	-	-

*Sa = blasted ASa2 ½ ISO 8501-1 Medium Grit (ISO 8503); roughness Ra = 10 – 12 µm
** Zn = blasted Asa2 ½ + zinc-rich shop primer on an automatic facility (mix grit and shot abrasive) roughness Ra = 7 µm

<u>Evaluations procedures</u>

Surface profile
A stylus instrument « Surtronic 10 Rank Taylor Hobson » was used to determine the surface roughness parameters (Ra). 20 measurements per samples were made and averaged.

Scanning Electron Microscopic Examination (SEM)
The surface microstructure of the steel was studied using a HITASHI S-3200 N SEM. The composition of the substrate and in particular the amount of zinc from residual zinc shop primer was determined using an Energy Dispersive Spectrometer (EDS) coupled to the SEM. EDS measurements were performed at 15 kV of acceleration voltage on a surface of dimension 500x400µm (X250). The depth of analysis was about 100µm. 3 measurements per samples were made and averaged

Mossbauer spectroscopy
The determination of rust composition was performed using Mossbauer spectroscopy at the Institute of materials from the Czech Science Academy. Investigation of a surface layer to depths up to 300 nm was carried out using Conversion Electron Mössbauer spectroscopy (CEMS) with gas-filled electron detector with normal incidence of the gamma radiation. The spectra were measured using ^{57}Co in an Rh source at room temperature. Calibration was done relative to pure α-Fe. The measurements were performed on an area of 10x10mm^2.

Condensation testing
A condensation chamber from Qpanel was used at 40°C to study the formation of red rust as a function of exposure time and surface preparation. Intermediate evaluations were performed after 30 minutes and every hour the first day. The test was conducted during 3 days. The extent of red rust was calculated using image analysis software (Lucia) applied on photographs of the samples. This was done on a surface of 6x6 cm^2, excluding edges.

Results

<u>Characterisation of steel surface profile</u>

UHP waterjetting differs from abrasive cleaning as it does not impart the surface profile to the substrate, since no abrasive is used in the water stream. However, it is important that the water jet removes contaminations such as dirt and rust as well as old paints, in particular in crevices or pits.

The influence of water pressure from 2560 to 3000 bar and of the hydroblasting tool (hand held gun or robot) was studied on zinc-rich shop primer coated steel substrates and the surface state was evaluated by microscopical inspections using SEM and roughness measurements. No significant differences in the surface state were observed upon the pressure and the UHP tool. However, the initial state Sa2$^{1/2}$ was not fully recovered. This is obvious on Figure 1 which compares the roughness parameter Ra measured using a stylus instrument as a function of water pressure and hydroblasting equipment. Typical Ra values of 9 to 12 µm were found for abrasive blasted steel surface, while a slightly lower roughness was found after UHP waterjetting applied on zinc primer coated steel. One question is how this difference in the surface roughness may affect the coating performance on such surface state? [7].

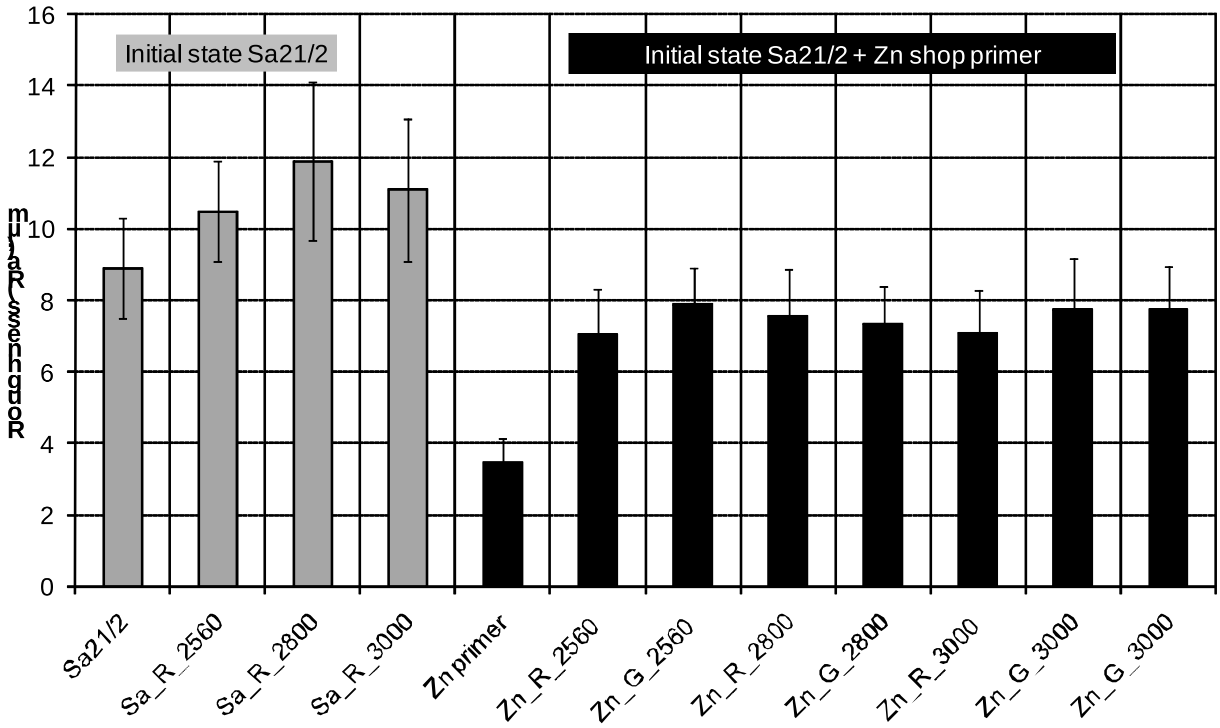

Figure 1: Influence of UHP waterjetting pressure and tools on the surface roughness (Ra) of grit – blasted steel Sa2½ (Sa) with and without zinc shop-primer (Zn). R: Robot, G: gun.

<u>Surface steel composition</u>

SEM/EDS technique has been used to analyse the remaining zinc after UHP water-jetting of zinc shop primer coated steel and thus evaluate the efficiency of UHP waterjetting in cleaning steel surface as a function of water pressure and equipment. It shall be highlighted that the depth of analysis are different upon the technique with about 100µm with SEM/EDS.

Figure 2 presents the ratio Zn/Fe calculated from EDS spectra for the different surface state studied. The results clearly indicate that zinc remains on the steel surface whatever the pressure between 2560 and 3000 bar or the hydroblasting equipment, hand held gun or robot. However, a better efficiency of the robot in comparison to the gun in removing zinc was observed for water pressures of 2560 and 3000 bar. No significant influence of the pressure was noticed regarding the deviation. It is interesting to notice that traces of zinc also remain on steel surface after abrasive blasting. SEM/EDS inspection of abrasive blasted surface showed the presence of dust from abrasives on steel in contrary to UHP waterjetted surfaces, where no debris were observed on the surface.

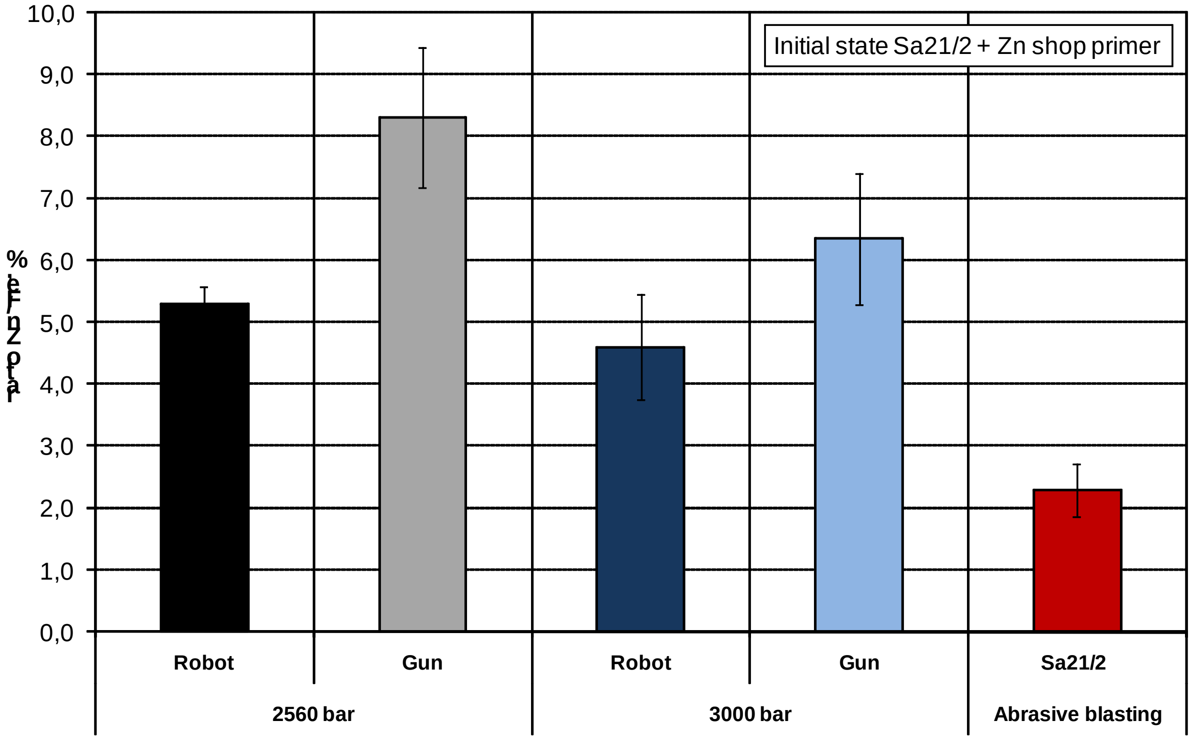

Figure 2 : Influence of UHP waterjetting pressure and tool on the removal of zinc from zinc shop primer coat. Ratio Zn/Fe in weight from SEM/EDS measurements.

Mossbauer spectroscopy analysis was conducted directly on steel surface in order to assess the relative amount of iron phases in a surface layer of approximately 300 nm in thickness. The results are presented in Figure 3 for the 6 different surface states inspected. It can be observed that a large part of iron is present in its metallic form (Fe (α)) in particular for abrasive blasted surface Sa2½ only or with a further UHP hydroblasting cleaning. In addition, the oxide thickness is rather thin on these samples when comparing the one on steel initially covered with a zinc shop primer. On reference steel Sa2 ½, iron oxides are composed of magnetite (0.03) and Fe^{3+} (FeOOH) in equal proportion. No significant influence of UHP waterjetting may be observed on the composition of iron oxides at least between 2560 and 3000 bar. However, it seems that UHP waterjetting applied on abrasive blasted steel favored the formation of Fe^{2+}. The results should however be considered with cautions as the relative amount is quite low and the surface of analysis restricted.
Regarding steel surface initially covered with zinc-rich shop primer and further cleaned using hydroblasting, the thickness of the oxide layer is indeed more important and composed of FeII, FeIII, magnetite and a mixed oxide type FeX_2O_4 (where X = Si, Zn ..). There is however one exception for the samples hydroblasted with the robot at 2560 bar where the oxide layer is purely composed of magnetite. Deeper investigations should be made to confirm the results. On the other hydrosblasted surfaces, magnetite represents between 6 and 8 %. No significant effect of the hydroblasting pressure and tool was noticed. Nevertheless, it cannot be excluded that remaining zinc silicate doesn't disturb the measurements.
Results from Mossbauer spectroscopy did not show any systematic trends in the composition of the oxide film upon hydroblasting parameters and tool. Only differences in the oxides thickness were observed upon the initial state e.g. surface covered with a zinc rich primer or blasted steel Sa2½.

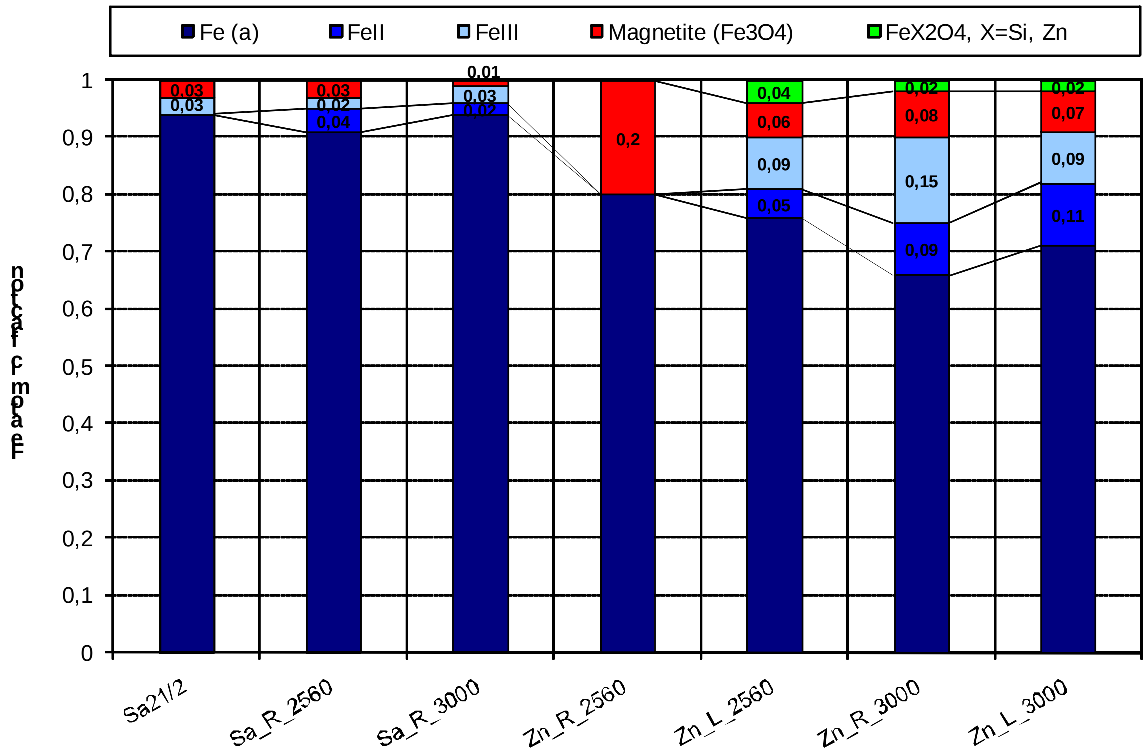

Figure 3 : Distribution of iron phases as a function of UHP waterjetting parameters pressure and tools applied on zinc-rich primer coated steel (Zn) – Comparison with abrasive steel Sa2½ (Sa). R = robot, G = Gun; CEMS Mode (Mossbauer spectroscopy).

<u>Condensation test</u>

A condensation test at 40°C was performed on steel samples with the different surface preparation in order to evaluate the rate of rust formation. As described in the experimental section, the influence of hydroblasting pressure and equipment was assessed on two initial surface state Sa2 ½ with or without zinc shop primer. The evolution of the percentage of red rust was plotted as a function of exposure time in condensation test on Figure 4. From the results, it may be observed that abrasive blasted steel (Sa2 ½) further cleaned or not with UHP waterjetting are more sensitive to red rust formation than similar steel samples initially covered with a zinc shop primer. This is in good agreement the presence of remaining zinc on the hydroblasted steel surface initially covered with zinc shop primer. The presence of small amount zinc delayed the formation of red oxidation during the first stage of exposure. A slight effect of the hydroblasting pressure may be observed on abrasive blasted surface after 72 hours of test where the extent of red rust increases in the following order: Sa_R_3000 < Sa_R_2800 < Sa_R_2560 < Sa. The extent of red rust was about 80% on steel cleaned at 3000 bar while it covered more than 95% on the initial abrasive blasted state.

On surfaces initially covered with a zinc shop primer and further hydroblasted, the extent of red rust ranged between 60 and 70% of the surface and a slight influence of the water pressure may be noticed, again in quite good agreement with the amount of remaining zinc (See Figure 2). It is likely that additional exposure to condensation test would result in full coverage of red rust when remaining zinc had been completely consumed.

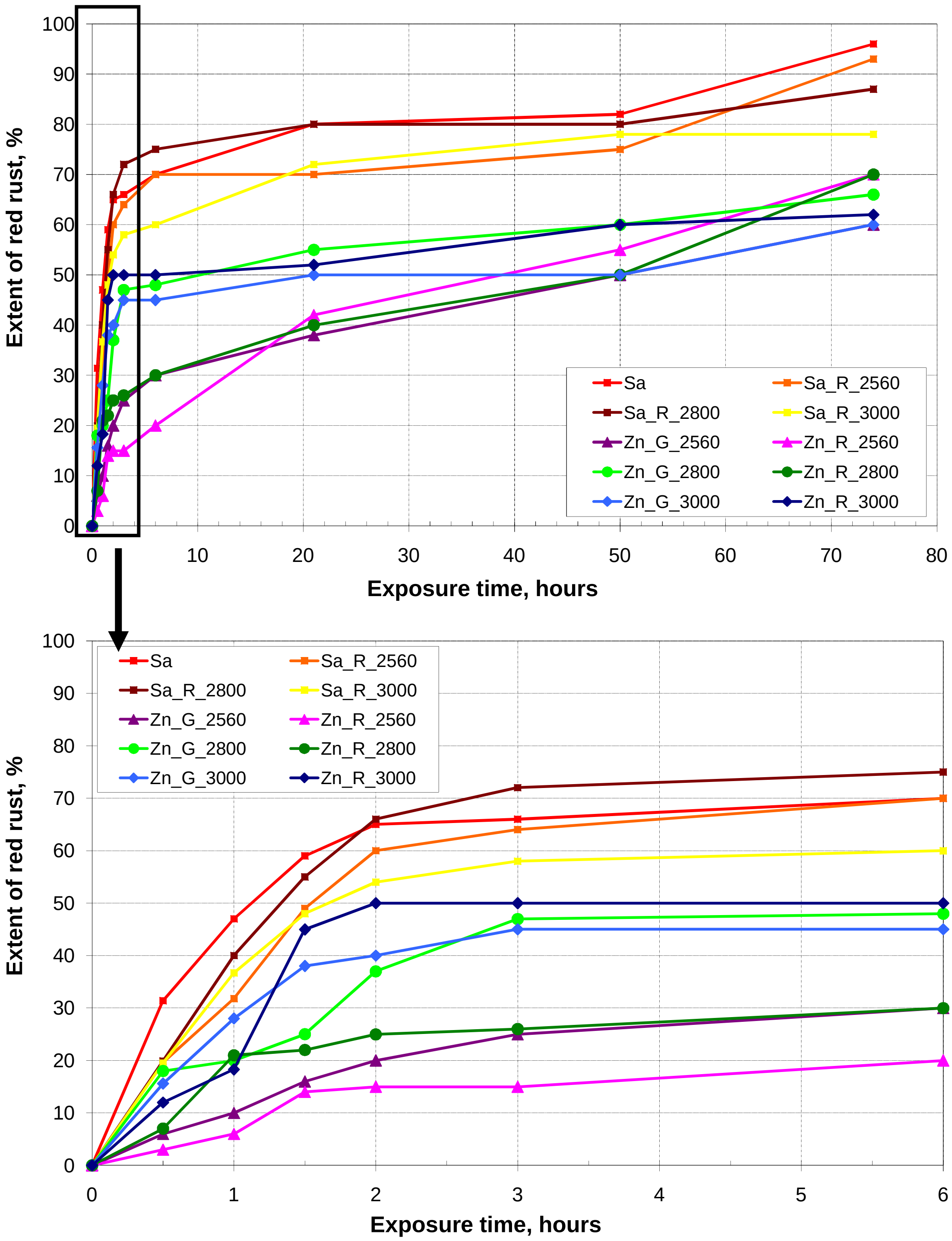

Figure 4 : Extent of red rust on steel panels with different surface preparation as a function of exposure time in condensation test at 40°C. Sa : Initial state : Sa=Sa2 ½ ; Zn: zinc shop primer coat. Hydroblasting with a robot (R) or a hand held gun (G).

Conclusions

The aims of the study were to characterize zinc-rich shop primer coated steel surfaces after UHP waterjetting of (in new construction configuration), in terms of surface roughness and cleanliness. The influence of cleaning parameters such as flow pressure between 2560 and 3000 bars or hydroblasting tool e.g. hand held gun or robot was examined. The results were compared with conventional grit blasted surfaces as initial states.

From the results, the following conclusions may be drawn:

- No significant effect of UHP waterjetting tool (hand held gun and robot) and water pressure between 2560 to 3000 bar on the surface profile was observed.Typical roughness parameters were measured on Sa2 ½ steel surface while a slightly lower Ra was found after hydroblasting of zinc-rich shop primer coated steel panels.
- Whatever the parameters of hydroblasting (hand held gun or robot, water pressure from 2560 and 3000 bar) applied on zinc-rich shop primer coated steel, traces of zinc and silice were found on steel surface. Same observation was also found after conventional abrasive blasting. In addition, a mixte oxyde type FeX_2O_4 (X= Zn, Si..) was detected using Mossbauer spectroscopy, again whatever the hydroblasting parameters selected in the present study. It is however not known whether traces of zinc may affect further coating performance.
- The presence of remaining zinc on hydroblasted steel resulted in a longer delay before formation of red oxidation observed in a condensation test, as expected. About 70% of UHP treated samples initially covered with a zinc-rich shop primer were rusted while red rust covered 100% of UHP treated abrasive blasted panels.

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