Influence of UHP (Ultra high pressure) waterjetting on shop primer coated steel substrate for new construction in naval Industry

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Summary

Ultra-high-pressure (UHP) waterjetting is a suitable alternative to abrasive blasting for maintenance work or complete renovation. For new construction, the performance of paint systems after ultra high pressure waterjetting on shop primer steel substrate values is not available.

In naval industry and even for new construction, the conventional surface preparation by abrasive blasting becomes more and more a costly constraint due to environmental regulations. Among the alternative methods the UHP waterjetting appears as the most promising one. The problem arisen is what about the durability of commonly used paint systems on a new state of surface preparation? The aim of this paper is to compare the behaviour of commonly used paint systems for the protection of ship exterior topsides applied on zinc-rich shop primed steel after abrasive blasting (Sa2 1/2) and after UHP waterjetting (DHP4 and DHP1) using new designed samples. The results from three paint systems after artificial cycling test and natural ageing on a site qualified for a C5M corrosivity category are presented. From the results, UHP waterjetting seems to be a promising method for flat zinc shop primed surface in new construction including in particular welded areas and with a moderate roughness. Similar behaviours have been noticed between both surface preparation methods. In addition, the comparison between the artificial test and natural ageing is also discussed.

1 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, old removed paint and 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 in previous papers [1-6]. Even if UHP waterjetting is more and more used for maintenance [3-6], some pending questions remain on the use of this technique within the scope of new naval constructions.

From this statement of fact, a project has been started with the purpose of reinforcing the knowledge on the behaviour of different paint systems for highly corrosive marine environments (C5M) and more particularly assessing UHP waterjetting performance in relation to abrasive blasting on steel coated with a zinc-rich shop primer (ZRP) [7-10].

In a first stage, the performance of 7 paint systems applied on UHP (DHP 4) treated ZRP coated steel flat panels and welded panels was studied in laboratory and field tests [10]. The results were compared with conventional abrasive blasted (Sa 2.5 MG) surfaces. UHP waterjetting technique seems to be a rather promising technique for steel surface preparation within the scope of new constructions (on ZRP coated steel). Indeed, the results showed a rather comparable behaviour of UHP waterjetting with standard surface after abrasive blasting. Despite a slight difference as regards the roughness and the residual presence of zinc in similar proportions as after abrasive blasting, coating performance did not seem to be affected. However, some results remained inconclusive regarding welded panels as a consequence of inhomogeneous weld area.

Thus, in a second stage of the work which is presented in this study, efforts were carried out on one hand to design an appropriate welded sample further rectified including a mixed zone at periphery of the weld seam cleaned by UHP waterjetting to get a surface cleanliness DHP4. On the other hand, partial ZRP coated steel flat panels also UHP treated to get a DHP1 cleanliness were considered. This was compared to conventional blasted surface (Sa2,5, MG). Three different paint systems were applied on the various panels design and roughness and exposed to cyclic corrosion tests.

2 Experimental conditions

2.1 Test panels, surface preparation and coating

Steel plates (DH36) generally used in naval constructions have been selected with different surface preparations representing the different practices used on a structure. As mentioned in Table 1, the steel plates have been first grit blasted (metal abrasives) up to grade Sa 2.5 and covered with a zinc-rich primer (zinc silicate, 10-15 µm) to create the initial conditions (steelmaker delivery standard). Two designs of test panels were considered namely flat panels (100x175mm) and welded panels (320x250mm).

The **flat test pieces** have then been cleaned by UHP waterjetting, only on one side, with treatment degree DHP1 light cleaning according to NF T 35-520 standard e.g. “surface shall be free from oil, mud, grease, caking, poorly adhering former paint, poorly adhering rust and mill scale, former coatings and any foreign matter. At this treatment degree, 70% of the surface is still partially covered by former coatings”. Details on the UHP waterjetting parameters are given in Table 2. It should be mentioned that all cleaning operations have been performed using UHP waterjetting associated with a numerical control [2].

Table 1: Description of steel samples

Test piece reference	**T1**		**T3**
Steel grade	DH36		
Initial state	Cleaning up to Sa 2.5 (grit and shot mixing) + Zinc rich primer (10-15µm)		
Test piece configuration	Welded panel (320x250mm, 10-mm thick)		Flat panel (175x100mm,5.5-mm thick)
6-month natural ageing	Yes	Yes	Yes
Surface preparation	Grit blasting Sa 2.5 (ISO 8501-1) ; MG (ISO 8503-1)	UHP waterjetting DHP4 : complete ZRP cleaning and oxide removal in the mixed zone at weld are periphery	UHP waterjetting DHP1: partial ZRP cleaning

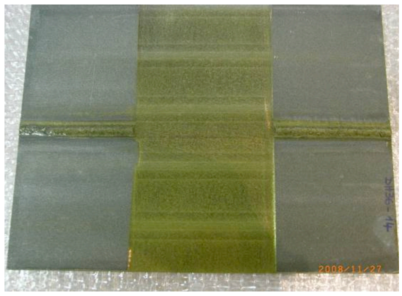
Table 2: Selected UHP waterjetting parameters (according to NF T35 520)

UHP WATERJETTING – REQUIREMENT NF T35 520	**DHP4**	**DHP1**
Test piece configuration	Welded test pieces	Flat test pieces
Cleaning parameters	Pressure: 2400 bars Progression: 1 m/min Distance: 50 mm Rate : 13 l/min	Pressure : 1125 bars Progression: 1.5 m/min Distance : 70 mm Rate : 17l/min

The **welded samples** consisted of two panels assembled together by conventional welding for ship construction. The centre of the welded panels was machined on a width of 120mm along the 250 mm long side and perpendicular to the weld as shown on photographs of Figure 1. Then, in order to mimic shipyard conditions when the ZRP is consumed during construction phases, the welded panels have been outdoor exposed for 6 months in the shipyard of Lorient before surface preparation and painting (The site is classified C2 on steel: 195.8 +- 4.6 g/m² per year, i.e. 24.9 +-0.6 µm/year).
Then, half of the panels have been abrasive blasted to Sa2,5 grade while the other half have been cleaned by UHP waterjetting on one side to get a surface cleanliness DHP4, OF1 according to the NF T 35-520 standard e.g. “surface shall be free from oil, mud, grease, caking, poorly adhering former paint, poorly adhering rust and mill scale and any former coatings or foreign matter. The exposed steel must be uniform and have an “original metallic colour”. Photographs of the different steps in the preparation of welded samples may be observed in Figure 1.

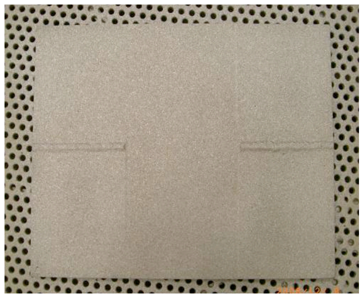
(a) Welded test piece before natural ageing

(b) Welded test piece after outdoor exposure



(c) Welded test piece after DHP4, OF1 UHP cleaning

(e) Flat test piece DHP1



(d) Welded test piece after grit blasting Sa 21/2

Figure 1: photographs of the welded panels (a-d) as a function of surface preparation stages and flat test panel DHP1 (e).

The roughness of the different area of the welded panels have been measured after the UHP waterjetting (DHP4) and is summarized in Table 3. It should be reminded that after abrasive blasting Sa 2.5 MG, the measured roughness Ra ranges between 9 to 12 µm while the machined area roughness (after machining and before rusting) was between 0.3 to 0.7 µm (Ra).

Table 3: Surface roughness of the pre-rusted welded panel according to surface area after UHP waterjetting

Location on welded panel	Ra (µm)
Area 1: machined steel (central section)	4.4 ± 1.1
Area 2: ZRP DHP4	7.1 ± 0.9
Area 3: Machined weld	6.4 ± 1.9

Once cleaned either by UHP waterjetting or by sand blasting, flat and welded samples have been painted using three different commercial paint systems selected from the preliminary phase of this study [10]. As indicated in Table 4, two of them were based on an inhibiting protection while the other operated as a barrier effect.

Table 4: Paint and category protection system.

Primer Nature	Protection category		Dry film thickness µm
	Barrier effect	Inhibitor effect	
S1		X	350
S2	X		350
R		X	240

Prior to testing, scribes down to steel substrate were applied using an Elcometer 1538 scribing tool equipped with a rectangular blade of 0.5 mm. On flat samples, a vertical scribe parallel to the longest side of 100x0.5mm was made in compliance with the previous phase of the study [10].

For the welded test panel, several areas were considered and therefore 5 scribes have been made as shown on Figure 2.

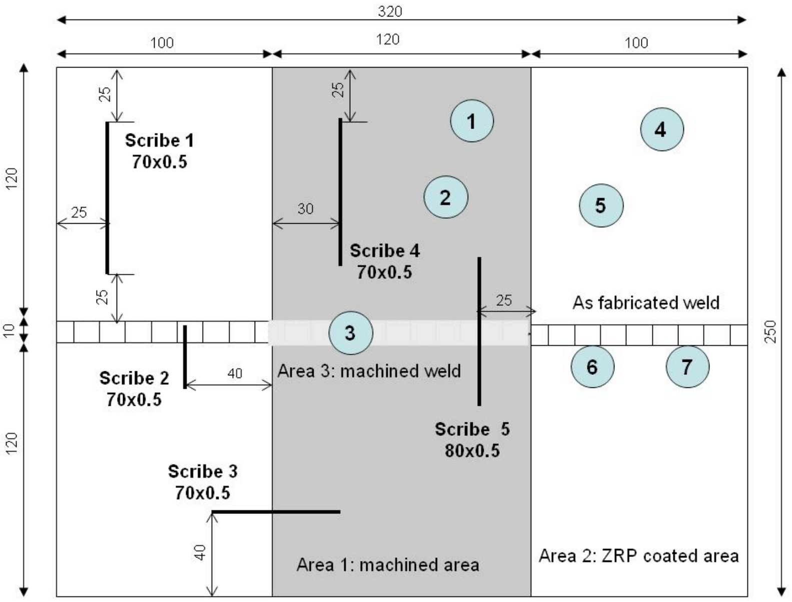


Figure 2: Position of the scribes and pull-off test dollies on the welded test panel (dimensions are given in mm)

2.2 Artificial ageing test and field test

The corrosion performance of the paint systems as a function of surface preparation was carried out in laboratory according to the C5M test cycle described in Figure 3, test w... the t...

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
UV/Condensation ISO 11507		Neutral Salt Spray Test NaCl 1wt% - 35°C			Ambiant 22°C, 55%RH	Low temperature -20°C

Figure 2: C5M cycle description over a week

Figure 3: basic artificial weathering cycle used in the study

Outdoor exposure was carried out at the marine site of Brest (classified C5M on steel according to ISO 9223). Two parallel samples per system unless abrasive blasted welded samples were exposed at 45° south for minimum 4 years with intermediate inspections. When writing the paper, 2 years' evaluations were available.

2.3 Assessments

Visual assessment

ISO 4628-2 to -6 standards have been used to assess paint defects, such as blistering, rusting, cracking, and chalking. As regards delamination measurement from the scribes, 2 methods have been used as described and illustrated in Figure 4.

M1=(V-scribe width)/2

This measurement method has been used for intermediate measurements in particular.

M4=(C'-scribe)/2
where $C' = \sum C'_n/n$

This measurement has been used after removal of the coating once C5M test was completed.

Figure 4: Assessment of scribe creep

Pull-off adhesion test

The pull-off adhesion tests have been carried out according to ISO 4624 standard using a hydraulic pull-off device (Posi-Test AT-M) on unexposed references and after completion of the C5M cycle.20 mm diameter dollies previously glued to the coating were used and the tests have been carried out in laboratory conditions (23.8°C – 45.1%RH). Figure 2 indicates the position of the dollies as a function of the area on the welded test pieces.

Assessment requirements

For accelerated corrosion tests, the assessment of test pieces cleaned by UHP waterjetting have been carried out meeting acceptance requirements defined in ISO 20340 (see table 5) and compared to abrasive blasting performance.

Tableau 5: Assessment criteria according to ISO 20340 standard

Criteria	Standard	Acceptance thresholds established at the end of the ageing cycle (ISO 20340)
Defects before and after ageing	ISO 4628-2 ISO 4628-3	0 (S0) Ri 0
Peeling-corrosion around the scribe	ISO 4628-8 and ISO 20340	Max < 8 mm for the coating system with zinc-free primer
Adhesion **before** C5M weathering test	ISO 4624	Minimum pull-off test value: 4 MPa for the coating system with zinc-free primer No adhesion defect between the substrate and the first layer except if pull-off values exceed or equal 5 MPa
Adhesion **after** C5M weathering test	ISO 4624	Minimum pull-off test value = 50% of the initial value with a minimum value of 2 MPa No adhesion defect between the substrate and the first layer except if pull-off values exceed or equal 5 MPa

3 Results

3.1 Cyclic corrosion test C5M

Flat test panels

No degradation such as blistering, rusting, cracking and chalking have been observed on any of the paint systems. However, a loss of brightness has been observed on S2 paint system. Visible degradations for all test pieces were red rust drips from the scribes.

Regarding flat test panels in DHP1 surface grade, creep from the scribe line was observed with a variable extent upon the paint systems as shown in Figure 5. Thus, paint system S1 was clearly less efficient than the 2 other systems S2 and R. This has already been observed in a previous study where the same system (except for the first layer) was tested [10]. For the 2 other paint systems (S2 and R), the results were rather comparable with UHP treated DPH4 and grit blasted Sa 2.5 surface state.

Paint system adhesion has been studied using pull-off test according to ISO 4624 and the data are summarized in Table 6. The results indicated a satisfying behaviour of paint systems S2 and R on ZRP UHP waterjetted DHP1 surface state. The behaviour was the same as for the abrasive blasted surface (data from a previous study), indicating no alteration of the coating performance on ZRP complete (DHP4) or partial (DHP1) cleaning steel surface. Nevertheless, the results highlighted the poor behaviour of system 1.

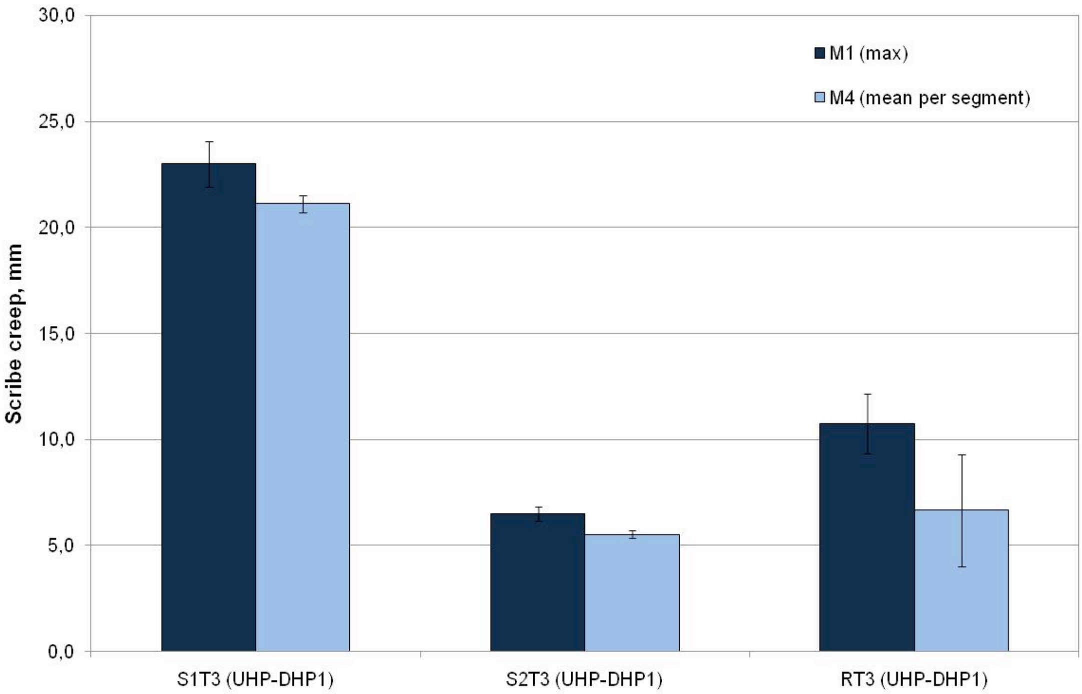


Figure 5: Delamination from the scribes on flat test pieces after 6 months of C5M test.

Table 6: pull-off test values on flat samples after 6 months of C5M cycle corrosion test (T1: Sa 21/2, T3: DHP1). Data on T1 surface state from Ref 10

Paint system	Pull-off test value, MPa	
	T1 (Sa 2 ½)	**T3 (DHP1)**
S1	15.7±1.1	11.0±2.3
S2	12.2±3.2	14.6±1.2
R	12.8±1.9	9.4±1.9

Welded test panels

As for flat test panels, no degradation such as blistering, rusting, cracking and chalking have been observed on any of the paint systems. Only corrosion from the scribes were formed. Figure 6 presents the scribe creep measured on the welded test panels after 6 months of C5M test for both Sa2,5 abrasive blasted surface (T1) and DHP4 UHP treated samples (T3). As mentioned in the experimental section regarding the design of the welded samples, 5 scribe lines were applied in order to assess the coating performance upon the surface properties. From the results, abrasive blasting gives rather satisfying behaviour whatever the locations on the welded sample, in particular when considering systems S2 and R. It is interesting to note that the weld area periphery (scribes 2 and 5) or machined area (scribe 3, 4 and 5) are not significantly more affected than reference surface (scribe 1).
This test also clearly highlights the difference in behaviour between the 3 paint systems applied on abrasive blasted samples. Only system S1 did not satisfy the ageing resistance criteria defined in Table 5. Indeed, the average scribe creep after coating removal of the 5 scribes gives the following values per paint system: S1 = 11 mm ; S2 = 7.8 mm; S3 = 2.2 mm.

Regarding UHP waterjetted (DHP4) samples, system S1 gave again unsatisfying results, even worse than abrasive blasted surface. Nevertheless, for the two other paint systems S2 and R, there is no significant evolution between the two surface preparation modes. The average scribe creep after coating removal of the 5 scribes was the following: S1 = 17.4 mm; S2 = 7.6 mm; S3 =3 mm. It should however be noted that on paint system S2, an unsatisfying value of scribe creep was measured on scribe 2 located on the as fabricated weld area with an average value of 13 mm. This may be observed on the photographs of Figure 7. They also clearly highlight the aspect and extent of corrosion upon the surface state, with an obvious remarkable behaviour of the UHP DHP4 machined area in the centre of the samples.

Paint system R presented a remarkable and constant behaviour no matter the scribe location, whereas extremely different roughness and surface profile levels were tested. The scribe creep was far below the requirements (< 8 mm).

As for flat samples, adhesion properties were investigated in accordance to ISO 4624 in different areas of the welded panels which differ by their surface roughness and profile. These areas are labelled as follows: area 1 corresponds to machined steel surface, area 2 to ZRP coated steel surface (not machined) and area 3 to machined welded area. The adhesion was also investigated in the vicinity of the as-fabricated weld (dollies 6 and 7 in Figure 2). However, due to the deformation of the weld, the results were very scattered and thus not conclusive. However, for the other locations on the test panels, the results indicated no adhesive failure. Figure 8 presents the adhesion strength as a function of the paint systems and surface preparation, where it may be observed rather satisfying results whatever the paint systems and the surface roughness and cleanliness. In particular, it is interesting to note that despite the low roughness (Ra 4,4µm) obtained on UHP waterjetted (DHP4) pre-rusted machined area (central section), comparable adhesion properties as for abrasive blasted surface may be observed. This obviously underlines the importance of surface cleanliness level which is achieved after UHP waterjetting to level DHP4.

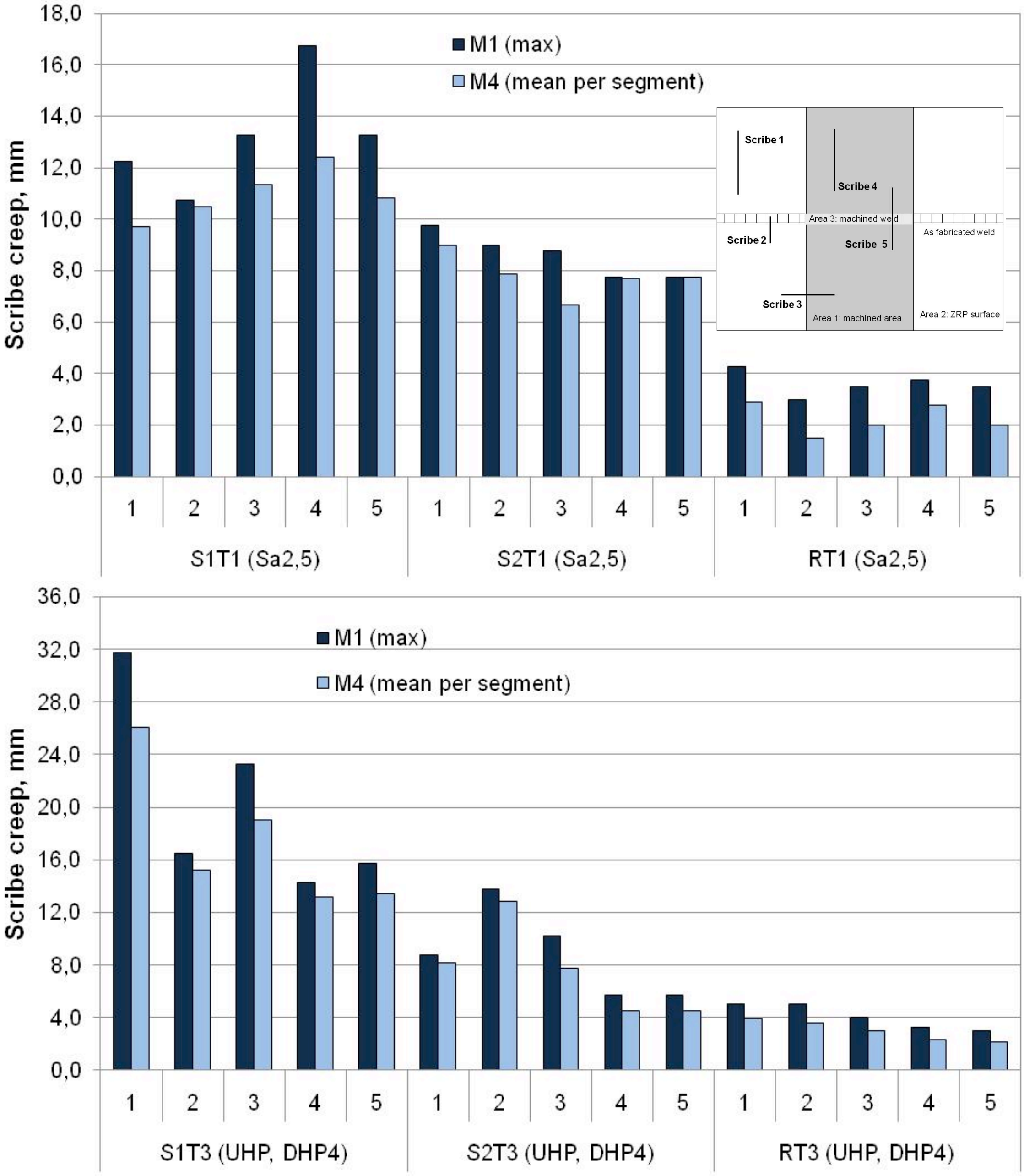
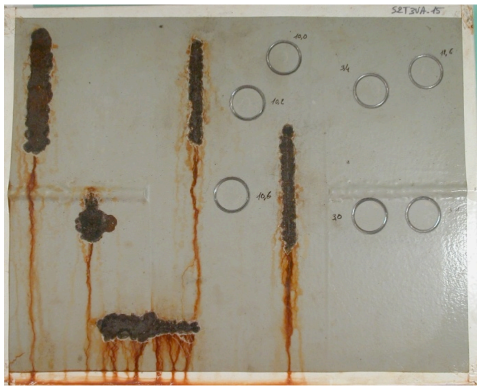


Figure 6: Influence of surface preparation (top: abrasive blasting Sa2,5 - T1; bottom: UHP watterjetting DHP4 – T3) of welded test pieces on the delamination from the scribes after 6 months of C5M cycle test. The labels 1 to 5 refer to the 5 scribes as shown on the scheme on the upper graph.

(a)



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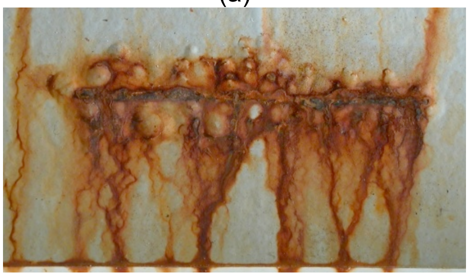
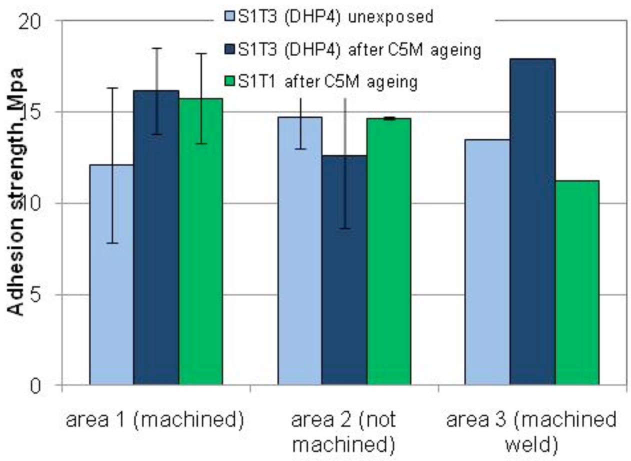
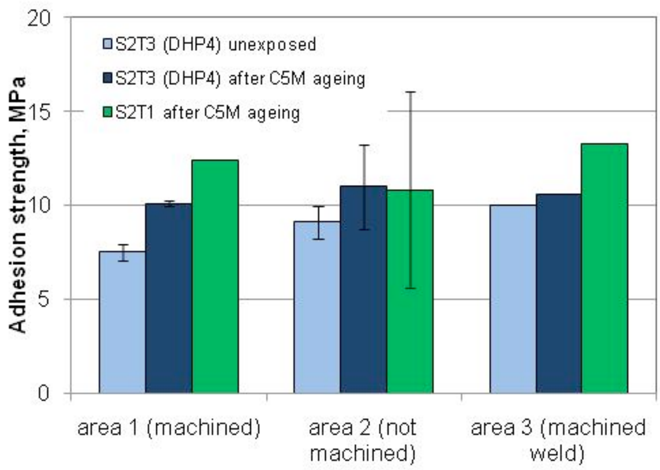


(c)

Figure 7: Photographs of test panels S2T3 (DHP4) after 6 months of C5M test – (a): before coating removal around the scribe, (b): details of scribe 3 and (c) after coating removal.



(a)



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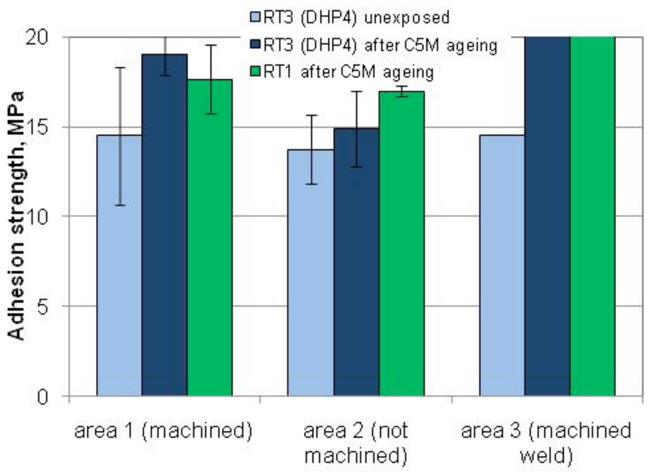


(c)

Area 1: machined area (dollies 1 and 2)
Area 2: ZRP coated steel (dollies 4 and 5)
Area 3: machined weld (dolly 3)

Figure 8: Influence of surface preparation on coating adhesion before and after 6 months of C5M corrosion test for paint system (a): S1, (b): S2 and (c): R. Surface state: T3 = UHP DHP4, T1 = abrasive blasting Sa 2.5.

The different tests carried out on the welded test pieces, presenting roughness and surface profile levels far from known standards give the following results:

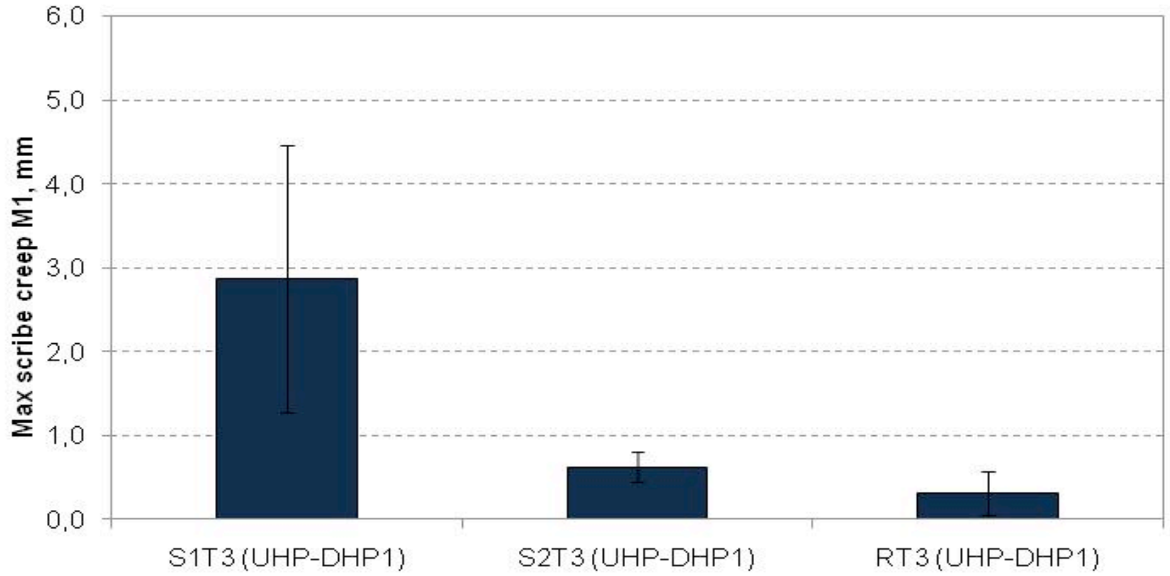
- For all tested configurations including test piece types and UHP waterjetting cleaning requirement (DHP4), no blistering, rusting, cracking and chalking defects were observed. These results constituted an important point demonstrating the relative level of performance of the tested paint systems. Mainly at scribe periphery, paint system 1 did not meet the requirement (< 8mm) and this after only a 4.5-month ageing on Sa 2.5. Systems S2 and R showed satisfactory behaviours which are respectively close to the value of 8 mm and clearly below the requirement. All these remarks are valid for all scribe locations on the welded test piece.

- Pull-off adhesion test in 7 different locations revealed variations in system behaviour according to the different surface profiles. Due to study conditions, all adhesion results do not make it possible to define that roughness and the proximity of the weld area which presented a brittle point for tested systems. The behaviour of test pieces cleaned with the UHP waterjetting method was rather similar to that obtained after abrasive blasting (Sa 2.5) where all singularities have been evened by abrasive blasting.

Such behaviour confirms the conclusions of the previous study and thus gives credibility to the thesis that surface cleanliness quality level associated with a roughness level are key elements to guarantee the performance of paint systems. The cleanliness level required is indeed obtained using UHP waterjetting. Specific work on required roughness levels will be undertaken in the on-going programme “Anticor”.

3.2 Natural ageing

After 2 years of natural ageing in marine atmosphere, the inspection revealed no blistering and rusting defects, but only delamination from the scribe line as shown in Figure 9 which presents the maximum scribe creep on flat and welded samples. In good agreement with the results from the accelerated corrosion test, more important damages were generally observed on paint system S1 considering both DHP1 and DHP4 surfaces, in comparison to system S2 and R. Important scribe creep was formed in ZRP coated steel DHP4 (scribe 1 and 3) in comparison to machined surface (scribe 4 and 5) when considering paint system 1. The extent of scribe creep was between 1 and 2 mm for paint system 2 with no major difference upon the surface roughness. The same observation may be drawn for paint system R with however less scribe creep (below 1 mm). Thus, these observations are rather consistent with artificial ageing trends and demonstrate the necessity to carry out specific additional work on paint system roughness and stability.



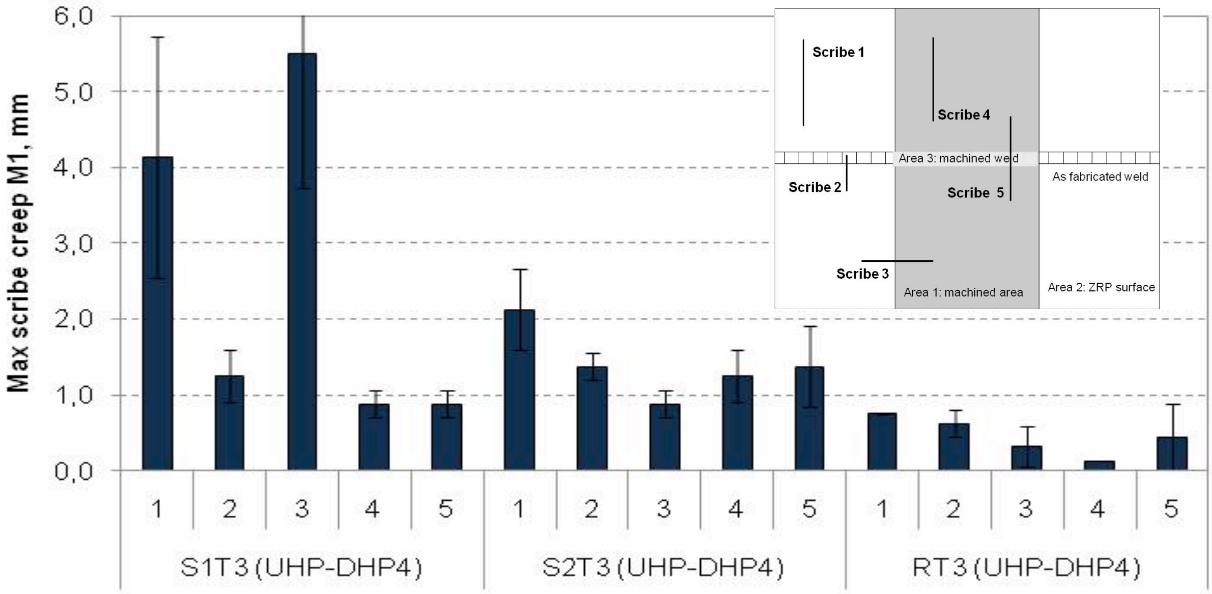


Figure 9: Influence of surface preparation (top: flat test panels UHP-DHP1; bottom: welded test panels UHP DHP4) on the delamination from the scribes after 24months of exposure in marine atmosphere.

Conclusions

The aims of the study were to assess the performance of three different coating systems applied on UHP treated zinc-rich shop primer coated steel (e.g. in new construction configuration) considering different surface states (roughness and cleanliness DHP1 and DHP4). Thus, in addition to conventional flat panels, welded panels including as fabricated and machined welded area were considered. The results were compared with classical grit blasted surfaces Sa2.5. A cyclic corrosion test based on C5-M corrosivity was carried out in order to evaluate the performance of the coatings. The results were compared to field data obtained on a natural ageing site qualified for a C5M corrosivity category.

From the results, the following conclusions were drawn:

Flat panels, DHP1 cleaning:
On the basis of corrosion from scribe and pull-off adhesion results, UHP waterjetting on ZRP (DHP1) was efficient for S2 and R paint systems, showing rather comparable behaviour as with abrasive blasting. Both ZRP complete (DHP4) or partial (DHP1) cleaning generated satisfying results.
Welded panels, DHP4 cleaning:
For paint systems S2 and R, UHP waterjetting (DHP4) gives rather comparable behavior than classical abrasive blasted surface, with an optimised performance in the low roughness area (machined area and machined weld).

Comparable observations may be drawn from 24 months of natural ageing in marine C5M atmosphere. The results will however be consolidated after longer exposure durations in the coming years.

The conclusions were in good agreement with a previous study for maintenance configuration where a reinforcement of the surface cleanliness obtained after UHP waterjetting in relation to the abrasive blasting was noticed. One of the major advantages of UHP waterjetting is the complete removal of non-visible contaminations. They include water-soluble substances such as salts (chlorides, sulphates, soluble iron oxides), alkaline residuals (from lyes), welding fume deposits, and also water insoluble matter such as oils, greases, silicones, dust, abrasive material inclusions, etc. This good performance level has been obtained in a previous investigations with controlled flash rusting levels (< 1 g/m^2) where the surface cleanliness level was found to be a key parameter in the paint durability [6]. It is undeniable that this approach can include an important notion relative to roughness. Within this scope, a specific work has begun taking into account both surface preparation types and associated cleanliness levels, particularly reached using UHP waterjetting.

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