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PERFORMANCE OF PAINT SYSTEMS AFTER UHP (ULTRA HIGH PRESSURE) WATERJETTING ON SHOP PRIMER COATED STEEL SUBTRATE FOR NEW CONSTRUCTION IN NAVAL INDUSTRY

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Abstract

In naval industry and even for new construction, the conventional surface preparation by abrasive cleaning becomes more and more a costly constraint due to environmental regulations.
It is felt as clearly wishable to replace it by another more friendly technique.
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 shop primed steel after abrasive cleaning (Sa2 1/2 of ISO 8501-1) and after UHP waterjetting (DHP4 of NF 35 520).
It is presented the results concerning seven paint systems after salt spray test, artificial cycling test and natural ageing on a site qualified for a C5M corrosivity category.
UHP waterjetting seems to be a promising method for flat zinc shop primed surface (excluding in particular welds areas) in new construction. Similar behaviours have been noticed between the both surface preparation methods.
In addition, the comparison between the two artificial tests is also discussed.

Keywords: UHP waterjetting, organic coating, accelerated corrosion test

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 [1-3].

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 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 with the following requirements in terms of surface quality : DHP4, Flash rust < OF1 and $Fe^{2+} < 1 g/m^2$.

If UHP waterjetting becomes more widely used for maintenance, they are however some questions on the use of this technique for new construction applications. Against this background, a project was initiated with the aims to increase the knowledge of coating systems in highly corrosive marine atmosphere and in particular to assess the performance of UHP waterjetting in comparison to classical abrasive blasting in zinc-rich shop primer coated steel. The coating systems were investigated in laboratory tests and field exposure.

Experimental

Samples

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. As shown in Table 1, steel panels (100x175mm) were grit blasted (metallic abrasives) to grade $Sa2^{1/2}$ or 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 using a robot. Table 2 gives details on the UHP waterjetting 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. More details on the surface properties may be found in reference [7].
As given in Table 3, 7 commercial paint systems for new construction, namely P1, P2, P3, P4, P5, P6 and R, were selected so that the three main properties of a coating were included e.g. barrier effect, galvanic effect and inhibiting effect, and upon the knowledge of their behaviour in marine field exposure. Among the 7 organic coatings, one reference paint system (R) composed of vinyl epoxy primer coat 100µm; vinyl epoxy intermediate layer 80µm and silicone alkyd topcoat 2x30µm was also applied. Painted samples were conditioned for 3 weeks (under laboratory conditions, e.g. at 20-25°C and 55% R.H.) before being exposed in accelerated corrosion test and in natural weathering site. Prior to exposure, a vertical scribe parallel to the longest side of 100x0.5 mm was applied using an Elcometer 1538 scribing tool equipped with a rectangular blade of 0.5mm in width. Two parallel samples were exposed in the different testing conditions.

Table 1: Description of the steel samples

Reference	**T1**	**T2**
Type of steel	DH36	DH36
Initial state	Blasted to Sa2½ and shop primer	Blasted to Sa2½ (mix grit and shot) and shop primer
Surface preparation	Blasting to Sa2½ (ISO 8501-1) Medium Grit (ISO 8503-1)	Water jetting (cf. table 2)
Roughness (Ra)	10 - 12 µm	7 µm

Table 2: Description of UHP waterjetting using a robot

Parameters	**Robot**
Degree of cleanliness according to NF T35-520	**DHP4**
Level of flash rusting according to NF T35-520	**<OF1**
Pressure of cleaning	2730 bar
Water flow	34 liter/min
Material	Rotating water jet head with 10 nozzles,
Angle of cleaning	90 degrees
Conductivity of water	400 µS/cm
Distance of jet from surface	between 20 and 30 mm

Table 3: Coating category and thickness applied on steel substrates

Paint Label	**Category of protection**			**Dry Film Thickness, µm**
	Barrier	**Cathodic (Zn)**	**Inhibiting**	
P1		X		340
P2		X		400
P3			X	340
P4			X	450
P5	X			350
P6	X			350
R			X	240

<u>Accelerated corrosion test and field exposure</u>

Corrosion performance of the different paint systems and surface preparation was performed in laboratory by ageing resistance in accordance to the test described in *Figure 1*. This test was conducted during 25 weeks, e.g. 4200 hours. This test is a modified version of ISO 20340 cycle and details on the development of the test may be found elsewhere [5]. In addition, the samples were exposed in a neutral salt spray test according to ISO 9227 for 1440 hours.
Outdoor exposure was carried out at the marine site of Brest Saint Anne which is classified in the corrosivity category of C5M for steel according to ISO 9223. Two parallel samples of each system were exposed at 45° facing south for minimum 4 years with intermediate evaluations.

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 1 : basic artificial weathering cycle used in this study [5]

<u>Evaluation</u>

Visual examination
The evaluation of the coating degradation was performed according to ISO 4628 standards in particular ISO 4628-2 for blistering, ISO 4628-3 for rusting and ISO 4628-8 for scribe creep. The degree of flaking, cracking and chalking was also evaluated when such defects were detected. Intermediate evaluations were conducted during the accelerated corrosion tests as well as in marine exposure.
Based on Hochmannova’s works [8], a parameter involving the main paint defect and called anticorrosive effect (AE) was calculated using the following equation:

$$AE = (BD+SD+2RD)/4 \qquad (1)$$

Where:
- BD is the blistering degree in accordance with ISO 4628-2 (density),
- SD is the scribe delamination (in mm) in accordance with ISO 4628-8,
- RD is the rust degree in accordance with ISO 4628-3. For Ri0, RD=0 while for Ri5 RD = 5.

In the present study, the scribe delamination corresponds to the maximum scribe creep minus the scribe width which is divided by 2.
An anticorrosive effect with a low value characterizes a good performance of the coating while high values indicate poor behaviour.

Adhesion testing by pull off

The adhesion pull off strength was determined according to ISO 4624 with a Posi-Test AT-M on the test samples before artificial ageing, at the mid-cycle (2100 hours) and after completion of the test (4200 h). Thus, one replicate was withdrawn at mid-test.

Assessment – requirements

For accelerated corrosion tests, the assessment of the panels prepared by UHP waterjetting was conducted according to the acceptance requirements which are defined in ISO 20340 (See Table 4) and compared to the performance of the reference abrasive blasting system (R).
However, the ultimate test remains the performance of coating systems in comparison to the reference coating after natural weathering in highly corrosive marine atmosphere.

Table 4: Assessment of the test panels as defined for this study.

Criteria	Standard	Thresholds of acceptance established after the weathering cycle (ISO 20340)	Remarks
Defects before and after weathering	ISO 4628-2 ISO 4628-3	0 (S0) Ri 0	Comparison with the reference on Sa2½
Delamination-corrosion from the scribe line	ISO 4628-8	• Mx < 3 mm for zinc primed coating system* • Mx < 8 mm for non zinc primed coating system*	Comparison with the reference on Sa2½
Adhesion **before** artificial weathering test C5M	ISO 4624	Minimum pull off test value: - 3 MPa for zinc primed coating system - 4 MPa for non zinc primed coating system No adhesive failure between the substrate and the first coat unless pull-off values ≥ 5 MPa	
Adhesion **after** artificial weathering test C5M	ISO 4624	Minimum pull off test value = 50% initial value with a minimum value of 2 MPa No adhesive failure between the substrate and the first coat unless pull-off values ≥ 5 MPa	

* scribe delamination corresponds to the maximum scribe creep minus the scribe width which is divided by 2.

Results

Salt spray test

Most of the coated systems presented no defects on the overall surface e.g. no rusting or blistering after 1440 hours of exposure in the salt spray test, unless paint systems P6 which showed blistering quantity 3S2 and 4S2 for blasted and hydroblasted surfaces respectively. Paint system P3T1 also presented some red rust (Ri). However, creep from the scribe line was observed with a variable extent upon coating systems (See Figure 1). The largest scribe creep was found on coating system P1 with more than 8 mm while less than 1 mm of delamination was measured on system P2, despite comparable mode of protection, both containing a zinc rich primer. For the other paint systems, the scribe creep ranges between 2 and 4 mm with insignificant differences between blasted and UHP hydroblasted surfaces. In general, a quite comparable behaviour was observed whatever the surface preparation e.g. blasted Sa2½ or UHP treated, despite a surface state slightly different in terms of roughness Ra (See Table 1). Concerning the anti-corrosive effect (AE) presented in Table 5, it should be mentioned that it was mainly based on the delamination from the scribe line, as only one system showed other damages than scribe creep. Nevertheless, this parameter is interesting to show as it summarizes in one value the main defects usually observed on painted steel in service. Similar observation as those drawn for the scribe creep may be observed. Unless paint systems including zinc rich primers, the anticorrosive effect was rather similar with however a higher AE for system P6 due to the presence of blisters.

Excluding coating systems with zinc-rich primer, the results highlighted a rather poor ability of the salt spray in discriminating different paint systems. This is in good agreement with previous works [5, 9].

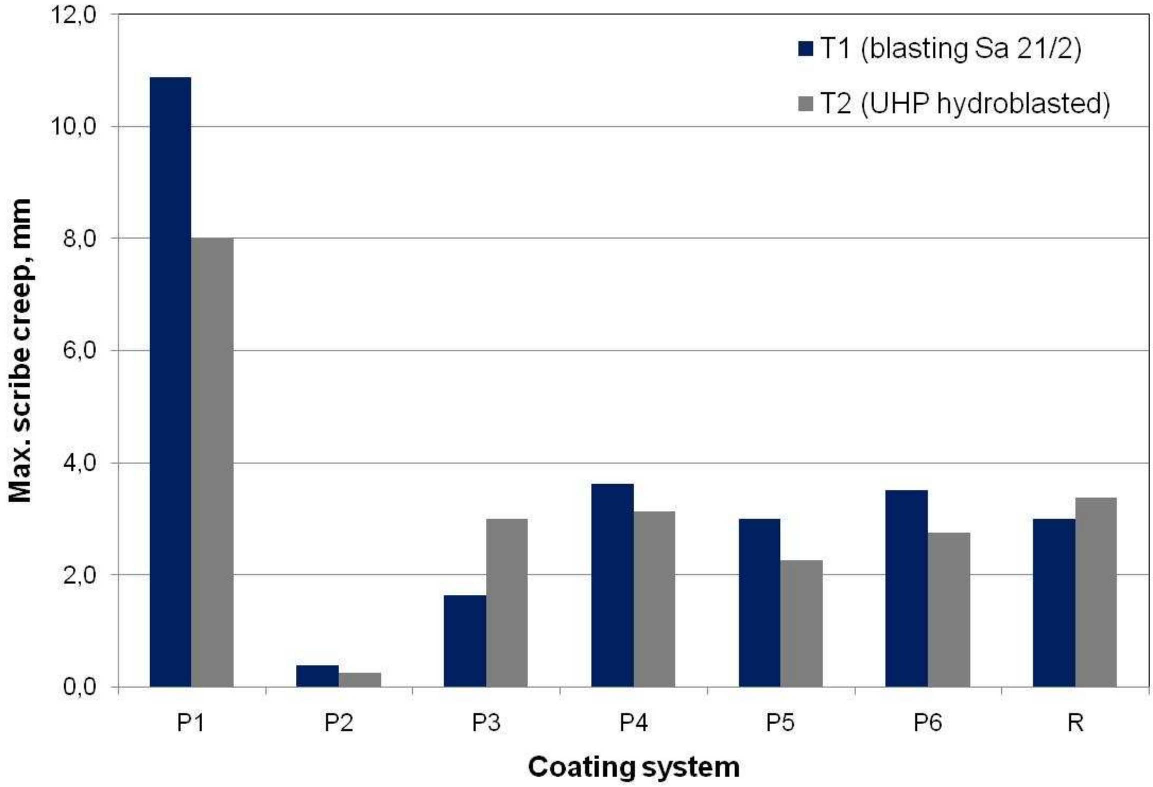

Figure 1: Effect on surface preparation on scribe creep for different coating systems after 1440 hours of salt spray test.

Table 5: Anticorrosive effect (AE) after 1440 h of salt spray test: influence of surface preparation given in Table 1.

Paint system	**Surface preparation**	
	T1 Blasting Sa2 ½	**T2 UHP waterjetting**
P1	2,7	2,0
P2	0,1	0,1
P3	0,7	1,3
P4	0,9	0,8
P5	0,8	0,6
P6	1,5	1,2
R	0,8	0,8
Mean	**1,1±0.8**	**1,0±0,6**

Cyclic corrosion test

Similar paint inspections were carried out after finishing the 4200 hours of exposure in the cyclic corrosion test and the anti-corrosive effect was calculated. The results are presented in Table 6. The coating systems P1 and P2 with zinc rich primers performed particularly well after the cyclic corrosion test. Only scribe creep was observed as defects. For system P1, comparable results were observed on blasted and UHP treated surface while a poorer behavior was observed on UHP hydroblasted panels for system P2. The AE was significantly more important for all the other paint systems using either barrier or inhibiting primers. Indeed, in addition to scribe creep, blistering and rusting were also observed on some of the systems. Regarding the influence of surface preparation, similar performance were noticed on systems P5 and P6 (barrier primers) and the reference paint R. Concerning paint systems P3 and P4, both containing an inhibiting primer, UHP treated panels were slightly more affected than the blasted ones. It is interesting to note that, in opposite to the salt spray test, the present cyclic corrosion test is able to rank the different paint systems placing both paint systems using cathodic primer as the best systems. This was not true after the salt spray test.

Adhesion was investigated by pull-off testing according to ISO 4624. All paint systems satisfied the qualification criteria, showing adhesion strengths above 5 MPa and less than 50% of reduction in the adhesion strength after the accelerated corrosion test. One exception was however observed for paint system P1 applied on UHP treated samples, where an adhesive fracture was found. For the other paint systems and for both surface preparation, mixed cohesive and adhesive fractures were detected before and after the accelerated test. In general, the effect of the surface preparation on the adhesion strength is not significant. This may be observed when considering the mean value of the adhesion strength for each surface preparation.

Table 6: Anticorrosive effect (AE) after 4200 h of cyclic corrosion test: influence of surface preparation given in Table 1

Paint system	Surface preparation	
	T1 Blasting Sa2 ½	**T2 UHP waterjetting**
P1	0,5	0,8
P2	0,5	2,8
P3	4,8	5,5
P4	5,1	6,8
P5	2,5	2,3
P6	4,0	4,0
R	3,8	3,8
Mean	**3,0±1,9**	**3,7±2,0**

*Table 7: pull-off test values after 4200 h of cyclic corrosion test. (T1: Sa2½, T2: UHP treated) *: adhesive fracture*

Paint system	Pull-off test value, MPa After ageing (Cycle C5-M)	
	T1	**T2**
P1	7,7±3,0	4,5±1,3*
P2	10,0±3,7	10,4±3,0
P3	7,2±1,1	13,6±0,6
P4	15,7±1,1	12,6±0,4
P5	12,2±3,2	10,3±1,1
P6	10,4±1,9	11,7±2,6
R	12,8±1,9	13,0±2,8
Mean	10,9±3,0	10,9±3,0

<u>Outdoor exposure in marine atmosphere C5M</u>

As indicated in the experimental section, all samples were exposed outdoor in marine atmosphere of C5M corrosivity category on steel, for a minimum duration of 4 years. The first inspection of the samples conducted after 12 months of exposure only revealed the presence of delamination from the scribe line on some coatings systems. Nevertheless, the anticorrosion effect was calculated in order to compare with data from laboratory tests and summarized in Table 8. From the results, no visual defects were observed on coating systems P1, P2 and P5 while moderate delamination was formed on paint systems P6 and R for both surface preparations. Concerning coating systems P3 and P4, more damage was found on UHP treated samples in comparison to blasted ones at least after 12 months of exposure. However, the evolution of paint degradation shall be examined after longer exposure duration. It should be mentioned that defects were already observed after 6 months of exposure on paint systems P3 and P4 which reflects the poor performance of these paint systems.

Table 8: Anticorrosive effect (AE) after 12 months of outdoor exposure in marine atmosphere C5M: influence of surface preparation given in Table 1. The scribe creep is given into brackets.

Paint system	**Surface preparation**	
	T1 Blasting Sa2½	**T2 UHP waterjetting**
P1	0	0
P2	0	0,0
P3	0,3 (1,3)	3,4 (13,5)
P4	1,2 (4,9)	3,0 (12)
P5	0	0
P6	0,9 (3,9)	0,3 (1,1)
R	0,3 (1,3)	0,2 (0,8)

The material ranking in terms of performance after 12 months of outdoor exposure was compared to that obtained after artificial ageing in neutral salt spray test and in the cyclic corrosion test (See Table 9). This was made by comparing the anticorrosion effect. The results indicate rather comparable material ranking between field exposure and the cyclic corrosion test while the salt spray test definitely gives a different classification of the coating systems. As an example, coating system P1 was the poorest one after the salt spray test while it shows very good performance on field after 12 months. These observations are in good agreement with previous works [5, 9-10]. They should however be consolidated with results from longer outdoor exposures, as it is indeed scheduled in the present work.

Table 9: material ranking after cyclic corrosion test (4200 h), salt spray test (1440 h) and 12 months of outdoor exposure in marine atmosphere

Paint system	**Cyclic corrosion test 4200h**	**Salt spray test 1440h**	**Outdoor 12 months**
P1	1	7	1
P2	2	1	1
P3	6	3	6
P4	7	5	7
P5	3	2	1
P6	5	6	5
R	4	3	4

From the first results of the present study, UHP waterjetting seems to be a rather promising technique of steel surface preparation in new construction configuration. Hydroblasting generally induces a notable reduction of soluble salts, contaminants and dust at the steel surface as a consequence of an effective water flow that can entered pores and pits and weep the contaminants away. The level of cleanliness is thus better than that obtained on blasted steel. Despite a slightly different surface state in terms of roughness, no significant differences were observed on the performance of the coatings thereafter applied. From a study aiming to characterize steel surface after UHP waterjetting of zinc primer coated steel, it has been shown that whatever the water pressure between 2560 and 3000 bar, and the hydroblatsing tool (gun or robot), traces of zinc were always detected on such steel surface [7]. Similarly, traces of zinc were also measured on grit blasted zinc primer coated steel. From the results obtained in the present work, the presence of remaining zinc on steel substrate doesn't seem to affect the performance of the coating.

This study highlights the need to adapt and improve the standardization related to surface preparation by UHP waterjetting for new construction. Indeed, most of the standards are addressed to surface preparation of painted steel for maintenance. Among standards related to UHP waterjetting, initial conditions involving zinc shop primers are defined in ISO 8501-4 (conditions PRZ) and SSPC VIS4/NACE VIS7 (condition F zinc-rich paint applied over blast cleaned steel). More details are however needed to help the operators and the Project Manager to be able to require a guarantee of the result.

If UHP waterjetting becomes more widely used for maintenance, they are however some questions on the use of this technique for new construction, in particular the influence of surface roughness which is known to be a key parameter influencing the adhesion of the coating and thus its durability. In particular, it is known that UHP waterjetting is not efficient to eliminate mill scale, which limits the use of the technique. Thus, in addition to classical abrasive blasting, the surface preparation with hydro-abrasives jets may be an alternative, but more work is needed to validate this new technique [1].

Other aspects related to real structures have to be carefully considered such as the effect of hydroblasting on welded areas and further coating performance. This work was still in progress when writing the paper. Additional results shall be available later.

Conclusions

The aims of the study were to assess the performance of different coating systems applied on UHP treated zinc-rich shop primer coated steel, e.g. in new construction configuration. The results were compared with classical grit blasted surfaces Sa2 ½. Two accelerated corrosion tests (a neutral salt spray test and a cyclic corrosion test based on C5-M corrosivity) were 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.

UHP waterjetting seems to be a rather promising technique of steel surface preparation in new construction configuration (on zinc-rich shop primer) and gives rather comparable behavior than classical abrasive blasted surface. Despite a slightly difference in roughness and the presence of remaining zinc at a similar level compared to abrasive cleaning , the performance of the coatings does not seem to be significantly affected.

The results also indicated quite similar material ranking between field exposure and the cyclic corrosion test while the salt spray test definitely gave a different classification of the paint systems confirming previous results.

Other aspects related to real structures have to be carefully considered such as the effect of hydroblasting on welded areas and further coating performance. This work was still in progress when writing the paper. Additional results shall be available later.

References

1- A. Momber, Hydroblasting & coating of steel structures 2003 *Elsevier*
2- T. Mabrouki, A. Cornier, O. Hafiz, K. Raissi, Mécanique & Industries, **5** (2004) 11.
3- P. Le Calvé, P. Meunier P, J.-M. Lacam, Protect. Coat Europe, **19 (9)** (2002) 22.
4- P. Le Calvé, P. Meunier, J.-M. Lacam, J.Protective Coatings & linings, **20 (1)** (2003) 48.
5- P. Le Calvé, J.Protective Coatings & linings, volume 24 n°8 (August 2007) 13.
6- M. Islam, W. McGaulley, M. Adams *Analitical WJTA American Waterjet Conferenc*e, August 21 -25 2005. Houston, Texas.
7- P. Le Calvé, J-P Pautasso, N Le Bozec, **Paper 8369**, Eurocorr09, September 6-10, 2009, Nice, France
8- Hochmannová, Zinc-Rich Primers With Micaceous Iron Oxide, Symposium “Protective Corrosion Industry” april-2004
9- P. Le Calvé, J-M Lacam, N Le Bozec, Protective Coating Europe, **10(7),** (2005) 29
10- D. Ward. CORROSION/08, **Paper 08003**, New Orleans, NACE (2008).