EUROPEAN COMMISSION

ECSC Research Project RFS-PR-09032
Executive Committee TGS8

"STRUCTURAL APPLICATIONS OF FERRITIC STAINLESS STEELS"

State of the art (WP7.1)

EUROPEAN COMMISSION

ECSC Sponsored Research Project
Directorate General XII. Science, Research and Development

CONFIDENTIAL

Title of Research Project:	Structural Application of Ferritic Stainless Steels
Executive Committee:	TGS8
Contract:	RFSR-PR-09032
Commencement of Research:	July 01, 2010
Scheduled Completion Date:	June 30, 2013
Beneficiary:	Acerinox Europa S.A.U. Santiago de Compostela 100, 4ºD 28035-Madrid-SPAIN
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STATE OF THE ART

1. Introduction

In a simple way, corrosion can be defined as the deterioration of material, usually a metal, that results from a chemical or electrochemical reaction with its environment. The majority of materials should be expected to deteriorate, to some extent, with time when exposed to the elements because corrosion is a natural process [80].

The corrosion resistance of stainless steel results from the formation of a chromium oxide film on metal surface. The film is hard and generally invisible. If the film is accidentally removed, a new one is created in order to continue the protection (self-passivating). The various stainless steels possess different degrees of corrosion resistance, owing to the amount of chromium and other alloying elements.

The addition of different elements from chromium is related with the wide range of ferritic grades, suitable for many applications. The choice of a ferritic grade depends on the characteristics of the service environment [50].

2. Design and ferritic properties

Good architectural design requires not only knowledge of the characteristics of the material used, but also an understanding of how they are shaped and formed for use. It must be known its composition and properties, the shape and size in which is available, how it is fabricated, and how it is finished. Good designers employ a material in a manner which permits the most effective use of its outstanding properties. The designers must know his material before they start designing.

For most architectural applications, stainless steel is used in the form of sheet, ship or plate, although other forms such as bar, tubing and even extrusions find many uses. Both, chemically and aesthetically, stainless steel is comparable with almost all common building materials. It can be used safety in contact with, or even imbibed in concrete, masonry or plaster. Because of the feature of stainless, it performs best when boldly exposed to the rain and weather as well.

Although the accumulation of dirt pockets sometimes can cause corrosion, it has been shown that the corrosion behavior, reflection behavior and sensitivity to dirt of stainless steel surfaces can be influenced and optimized by appropriate "surface design"[15]. So, it is important to design in order to minimize the possible retention areas. There is a critical surface roughness of approximately 0.5 µm Ra, below this value surfaces are less susceptible to corrosion [77]. The most corrosion resistant, mechanically finished surface is a mirror polish (ASTM A480, No 8 or EN 10088-2 Class 2P). It is very smoothing, resistant to salt accumulation and easy to clean [78].

As it has been commented before, the most striking characteristics of stainless steel are its outstanding resistance to corrosion, great strength and enduring beauty. Furthermore ductility, flexibility, elasticity, weldability, low thermal expansion and high strength at high temperature make of stainless steel a good election.

Stainless steels can be welded or joined mechanically by means of screws, bolts or rivets. It could be considered that its relatively low coefficient of thermal expansion means that fewer expansion joints are required.

3. Service life

On the other hand, atmospheric corrosion, tarnishing, pitting, crevice corrosion, embedded iron, erosion/corrosion, galvanic corrosion and stress corrosion cracking can impact the performance and appearance of building materials. As J.A.Careu, A.Abdullah said, any breakdown in the passive film on the metal surface can lead to dangerous localized corrosion [4]. It is known that stress corrosion cracking can occur in medium that have an extremely high chloride concentration [20].

It is very important to know the environment where the stainless steels are going to be exposed. Relative humidity, temperature, rain and wind are some of the parameters that can influence on the behavior of the stainless surface. Polluting elements as SO_2 and chloride will have a large effect over the steel. For general exposure with infrequent cleaning, EN 1.4301/1.4401 (AISI 304/316) steels have been found satisfactory. Steels containing nickel are required for satisfactory services outdoors[2]. Type EN 1.4016 (AISI 430) is less corrosion resistance and less frequently used in exterior applications but it has been found suitable for interior applications[2,9,11], and for exterior applications that receive frequent maintenance [5]:

- *Rural sites*: EN 1.4016 (AISI 430) will suffer light to moderate staining and rusting on both exposed and sheltering surfaces. Smoother surface finishes and regular washing help reducing corrosion, although should be expected some lost of brightness.
- *Urban sites*: EN 1.4016 (AISI 430) become quite heavily rusted, especially in sheltered areas where pollutants are not washed off by rain. Neither surface finish nor regular washing has a significant effect on performance.
- *Industrial sites*: EN 1.4016 (AISI 430) is normally attacked quite severely. A smoother finish or/and a periodic washing is unlikely to produce a significant improvement.
- *Coastal and marine sites*: EN 1.4016 (AISI 430) experiences severe rusting over a large proportion of its surface and are unsuitable for marine exposure.

It should be noted that discoloration of stainless steel is not automatically the result of atmospheric corrosion of the stainless steel or even corrosion attack. It can be a discoloration from dirt or extraneous rust, not affecting the stainless steel[18].

Although stainless steels are a low maintenance material, it is not generally maintenance free. All architectural stainless steel materials are supplied in a passivated corrosion resistance condition. They require periodic cleaning just as other materials do when in service [6]. A light and regular wash is best but in some cases natural rain washing may be enough [78].

4. The stainless steel choice

Most of structures in building, when corrosion is a problem, will make use of either, the austenitic or ferritic types of stainless steel. One reason in order to select a stainless steel would be that thermal expansion coefficient of ferritic steel grades is smaller than ones of austenitic steels and the value corresponds to carbon steels. In the case of ferritic, their impact strength at low temperature and elongation after fracture are lower than those of austenitic steel grades. On the other hand, ferritic stainless steel grades are not susceptible to stress corrosion cracking. Simultaneous consideration of the mechanical strength, formability, and corrosion resistance must be taken into account [21].

Atmospheric corrosion is implied both in architecture uses and in structural uses. There is a very important difference between the uses. In the case of architecture, exterior appearance of the stainless steel is essential, while in the case of structural uses resistance is more important where discoloration is not a problem but corrosion attack is very important. Visual durability is needed in most architectural applications to retain the architect´s aesthetic concept [76].

It is very important to know accurately the place where materials are going to be used. The environment is essential in order to define the behavior of metals. In table 1, as the result of an atmospheric essay, it can be observed the different corrosion rate according to the corrosiveness of the atmosphere. These data are referred to samples of carbon steel, but it can be used to consider the different behavior depending on the location [72].

Test Site	Atmosphere	Corrosion rate	
		mils/year	mm/year
United States			
Phoenix Arizona	Rural arid	0.18	0.005
Point Reyes. California	Marine	19.71	0.500
Waterbury, Connecticut	Industrial	0.89	0.023
Cape Canaveral, Florida 0.8 Km (0.5 mi) from ocean 55 m (180 ft.) from ocean elevation 18 m (60 ft.) elevation 9 m (30 ft.) ground level Beach	Marine	 3.39 6.48 17.37 5.17 42.0	 0.086 0.165 0.440 0.131 1.070
Daytona Beach, Florida	Marine	11.63	0.295
East Chicago, Indiana	Industrial	3.30	0.084
Detroit, Michigan	Industrial	0.57	0.015
Durham, New Hampshire	Rural	1.10	0.028
Kure Beach, North Carolina 250 m (800 ft.) from ocean 25 m (80 ft.) from ocean	Marine	 5.73 21.0	 0.145 0.530
Bayonne, New Jersey	Industrial	3.10	0.079
Cleveland, Ohio	Industrial	1.50	0.038
Middletown, Ohio	Semi-Industrial	1.10	0.028
Bethlehem, Pennsylvania	Industrial	1.50	0.038
State College, Pennsylvania	Rural	0.90	0.023
Pittsburgh, Pennsylvania	Industrial	1.20	0.030
Potter County, Pennsylvania	Rural	0.80	0.020
Brazos River, Texas	Industrial marine	3.70	0.094
Canada			
Norman Wells, North West Territory	Polar	0.03	0.001
Montreal, Quebec	Urban	0.90	0.023
Trail, British Columbia	Industrial	1.30	0.033
England			
Dungeness	Industrial marine	19.22	0.490
Pilsey Island	Industrial marine	4.04	0.103
London, Battersea	Industrial	1.80	0.046
Panama			
Mirafores	Tropical marine	1.69	0.043
South Africa			
Durban, Salisburg Island	Marine	2.20	0.056
Durban Bluff	Severe marine	10.22	0.260
Cape Town Docks	Mild marine	1.84	0.047
Walvis Bay military base	Severe marine	4.33	0.110

Table 1. - Corrosion rates of carbon steel calibrating samples at various test sites

Stainless steels show a very low weight loss in comparison with other metals. In table 2, the annual corrosion rate of different metals in South Africa after 20 years [5] is shown.

	Pretoria-CSIR	Durban Bay	Cape Town Docks	Durban Bluff	Walvis Bay	Sasolburg
Environment						
Location Type	rural, very low pollution	marine, moderate pollution	marine, moderate pollution	severe marine, moderate/ low pollution	severe marine, low pollution	industrial, high pollution
SO_2 Range µg/m^3	6-20	10-55	19-39	10-47	NA	NA
Fog days/year	NA	NA	NA	NA	113.2	NA
Avg.rainfall, in/year (mm/year)	29.4 (746)	40 (1,018)	20 (508)	40 (1,018)	0.31 (8)	26.7 (677)
Relative humidity range %	26-76	54-84	52-90	54-84	69-96	49-74
Temp. range F (C)	43-79 (6-26)	61-80 (16-27)	48-77 (9-25)	61-80 (16-27)	50-68 (10-20)	41-67 (5-20)
Unpainted galvanized steel life, years*	5-15	3-5				
Stainless steels	**Annual Corrosion Rate mils/year (mm/year)**					
EN 1.4401 (AISI 316)	0.001 (0.000025)	0.001 (0.000025)	0.001 (0.000025)	0.01 (0.000279)	0.004 (0.000102)	NA
EN 1.4301 (AISI 304)	0.001 (0.000025)	0.003 (0.000076)	0.005 (0.000127)	0.02 (0.000406)	0.004 (0.000102)	NA
EN 1.4016 (AISI 430)	0.001 (0.000025)	0.02 (0.000406)	0.01 (0.000381)	0.07 (0.001727)	0.02 (0.000559)	0.004 (0.000107)
Aluminium alloys	**Annual Corrosion Rate mils/year (mm/year)**					
AA 93103	0.01 (0.00028)	0.21 (0.00546)	0.17 (0.00424)	0.77 (0.01946)	0.18 (0.00457)	0.11 (0.00281)
AA 95251	0.01 (0.00033)	0.14 (0.00353)	0.15 (0.00371)	0.66 (0.01676)	0.16 (0.00417)	NA
AA 96063	0.01 (0.00028)	0.12 (0.00315)	0.14 (0.00366)	0.79 (0.020)	0.19 (0.00495)	NA
AA 96082	0.01 (0.00033)	0.14 (0.00366)	0.13 (0.0034)	1.09 (0.02761)	0.23 (0.000587)	NA
AA 96261	NA	NA	NA	0.93 (0.02364)	0.15 (0.00375)	0.12 (0.00317)
Copper	0.22 (0.00559)	0.37 (0.0094)	0.28 (0.00711)	0.97 (0.0246)	1.51 (0.0384)	0.55 (0.014)
Zinc	0.13 (0.0033)	0.91 (0.0231)	1.14 (0.029)	4.37 (0.111)	NA	0.60 (0.0152)
Weathering steel	0.9 (0.0229)	8.35 (0.212)	3.60 (0.0914)	31.89 (0.810)	45.28 (1.150)	4.21 (0.107)
Mild steel	1.70 (0.0432)	14.61 (0.371)	10.12 (0.257)	86.22 (2.190)	33.81 (0.846)	5.91 (0.150)

Table 2. - Average annual corrosion rate after 20 years exposure in South Africa

In all the test sites the ferritic grade 430 annual corrosion rates are lower than the obtained from mild steel, weathering steel, zinc, copper and even aluminium alloys.

The long-term durability and very low dissolution rates of metal ion make stainless steels a very environment-friendly choice of material with low life-cycle costs [18].

The move towards sustainable development will be propelled by legislation in most countries, forcing developers to place greater emphasis on life cycle costs rather than initial cost of a building or construction. Use of stainless steels depends on architects now, and in the future, knowing how to design and specify it correctly [76].

In ENV 1993-1-4 (Europe standard) an annex contains a conservative approach for designing ferritic grades of stainless steel. In US standard three grades of ferritic stainless steels are included (EN 1.4512 (AISI 409), EN 1.4016 (AISI 430) and EN 1.4510 (AISI 439)) only in annealed condition [7].

The designers can compensate for the higher initial unit cost of stainless by utilizing its high strength and corrosion resistance to reduce the thickness of the sections or to eliminate the need of secondary framing. Any comparison of the cost of stainless steels with the cost of other architectural metals should take the minimal maintenance requirements of stainless steel into account. The designers are able to achieve economies which further justify the use of stainless steels in place of other metals [1].

Some architects choose stainless steel because the lower dead load in some uses allows to reduce the volume of material required [76] being an ideal material for lightweight architectural design [14] .Stainless steels have successfully met the requirements of architects for over eighty years, and yet is continuously development to keep its place as the premier material to meet architecture challenger.

Design, finish, orientation, dimensions of the installation, climatic variation, contaminants and maintenance are important variables to know in order to select the most suitable stainless steel.

5. Published studies with conclusions

- There is a growing interest in extending the service life of concrete structures. Numerous field and laboratory tests of metal have been carried out. They conclude that stainless steels should be considered for installations where corrosion induced damage is difficult or costly to repair, such as parking garages, sea walls, piers, tunnels and bridges with high traffic volumes [72].

- Some authors indicate EN 1.4003 is a low chromium stainless steel which mechanical properties and weldability are excellent. EN 1.4016 has good corrosion resistance in mildly corrosive environment [13]. Others authors indicate that ferritic steels EN 1.4003 and EN 1.4509 are available mainly for specialist applications. The use of steel grade EN 1.4003 unprotected in outdoor applications is suitable with modest requirements for surface appearance. The most typical application of hollow sections made of this steel grade, is the load-bearing body and enclosure structures of buses [21]. 3CR12 is suitable for the structural designers when structures have to be designed subjected to relatively aggressive corrosive environments such as found at the coast and/or wet abrasive environments or in applications where general corrosive repair is uneconomical [17].

- Ferritic are employed in exterior roof application with an exterior tin layer [10, 11]. Otherwise, the ferritic grades are generally better suited for indoor use, but with some caution and the right measures they may be used in some outdoor environments, especially the molybdenum alloyed 1.4521[18]. This grade has a resistance to pitting and crevice corrosion similar to austenitic grades, and it is not prone to stress corrosion cracking [50].

- In the *preliminary study on the use of ferritic stainless steel grades in building industry* [23], they concluded that ferritic grades are used in facades (cladding, roofing) as bare and coated surface finishes. Fabricators of structural hollow sections and profiles are marketing ferritic grades, but their share in building industry application is unclear. They resume that in standard EN 1993-1-4 should include all ferritic grades according to standards EN 10088-4 and 5. The ferritic grades EN 1.4003 and 3CR12 are recommended for structural purpose because of their good weldability. EN 1.4016 (AISI 430) and EN 1.4512 (AISI 409) are weldable up to thicknesses 3.2 and 3.8 mm. Standard EN 1993-1-4 does not give information on the weldability of ferritic grades for structural purposes.

- In *Stainless steel in bus construction* [43] in order to clarify how different stainless steels can tolerate the corrosive attach in road environment, accelerated laboratory and under buses field test were performed. EN 1.4003 colored very heavily in all laboratory and field test. It is concluded that EN 1.4003 cannot be recommended to be used without any corrosive protection (for instance painting) as bus material in the atmosphere where chlorides are presents.

- Some publications give more information on 22Cr steel. This steel combines additions of small amount of niobium, titanium and aluminum having high pitting potential after pickling treatment. The developed steel has high corrosion resistance in an atmospheric environment [3].

- Pitting corrosion in electrochemical test and salt spray test [32] has shown that ferritic stainless steel exhibit a good relation with PRE value. Grades with stabilized alloying elements and molybdenum content show the best behavior.

- After two years of exposure [44], EN 1.4016 and EN 1.4509 have not suffered cosmetic changes in samples installed in less aggressive atmospheres (urban and rural). This fact is due to the effect of environments with very low sulfur dioxide and chloride concentrations, the weather variations do not affect the behavior of stainless steel [69]. In marine and marine-industrial atmospheres, there is a considerable deterioration of the surface appearance in the test specimens.

- In October 1993 and interesting paper was published [65] where a correlation was established between the Pitting Index (%Cr+3%Mo) and the rust area. Different austenitic, ferritic and duplex stainless steels, were tested in atmospheric corrosion evaluating their appearance after 1.5 years exposed near seaside of Shionomisaki. The pitting potential obtained in a sodium chloride solution at 70ºC was used to establish this relationship. It was a quick criterion to evaluate the materials and obtain a simple selection. As a result, a pitting index above 30, or a pitting potential above 450mV is necessary for an exterior stainless steel in order to be used in this environment. The ferritic stainless steel SUS447J1 (30Cr-2Mo) showed a very good atmospheric behavior.

- Baosteel has developed a high chromium ferritic stainless steel B445R for architectural roofing [67] (22.5Cr-1.5%Mo). Niobium and titanium have been added to suppress the precipitation of chromium carbide and nitride and to avoid intergranular corrosion (in view of improving toughness, addition of niobium is preferred). This steel provides pitting and atmospheric corrosion resistance superior to austenitic EN 1.4404 (AISI 316L). Dull-finished have been employed as roofing material for Guangzhou Asian Games Stadium. It was completed in June 2010. Very similar results were obtained by Nisshin Steel (Japan) with a 22Cr-1.2Mo ferritic stainless steel for roofs and curtain walls [3, 68]. This steel with addition of titanium, niobium and aluminum has high corrosion resistance in atmospheric environment and again with better behavior than EN 1.4401 (AISI 316).

- Superior corrosion resistance has been confirmed in a long-term exposure test [70] of NSS445M2 (22Cr-1Mo-Nb, Ti) and NSS447M1 (30Cr-2Mo-Nb, Ti). After 15 years exposure test in a marine environment in Okinawa, the surfaces of EN 1.4301 (SUS304) and EN 1.4401 (SUS316) were covered with light rust, while 445M2 corroded only partially, and NSS447M1 has scarcely corroded at all.

- Ferritics with aluminized layer [70] (Alstar) has excellent anticorrosion properties. The layer provides galvanic protection to the stainless steel. It can be expected that Alstar have exceptional long-term atmospheric corrosion resistance. They have been successfully used for roofs in several environments. On the other hand, Tough-tain Z is ferritic steel with a zinc coat. This steel has a dark grayish appearance. The corrosion product of zinc adhering to the surface, reduce the cathodic process of oxygen and prevent an increase in potential. The zinc corrosion products formed on stainless steel provides resistance to pitting corrosion.

There are numerous applications in architecture where stainless steel is used with guarantee of its right election and performance. Although ferritic stainless steel use is not very widespread, it can be considered as the best election for specific applications.

6. Summary tables

Reference	Title	Subject	Application	Material	Observation
N1	Stainless steel uses in architecture	General rules stainless steel in architecture	Architecture	Stainless steel	--
N2	Stainless steel in architecture, building and construction. Guidelines for building exteriors	Guidelines for building exteriors	Architecture	Stainless steel	--
N3	Development of atmospheric corrosion resistant 22cr ferritic stainless for roofs and curtain walls	Characterization	Roof Curtain walls	22Cr	Addition Al, Nb and Ti
N4	The influence of heat treatment on the corrosion behaviour of ferritic stainless steel solar panels in hot municipal water	Water	Solar panel	Ferritic	Cooling influence
N5	Stainless steel in architecture, building and construction. Guidelines for corrosion prevention	Guideline for corrosion prevention	Architecture	Stainless steel Carbon steel	Vcorr (carbon steel)
N6	Stainless steel in architecture		Architecture	Stainless steel	--
N7	A comparison of structural stainless steel design standards	Structural stainless steel design	Cross sections	Stainless steel Carbon steel	--
N8	Design Manual for Structural Stainless Steels	Design Manual for Structural Stainless Steels	Architecture	Stainless steel	--
N9	Guía del acero inoxidable para arquitectos	Manual	Architecture	Stainless steel	--
N10	Guía técnica tejados en acero inoxidable	Manual	Roof	Stainless steel EN 1.4510+Sn	--
N11	La correcta fabricación del acero inoxidable para arquitectura	Manual	Architecture	Stainless steel	--

Reference	Title	Subject	Application	Material	Observation
N12	Manual de diseño para acero inoxidable estructural	Design Manual for Structural Stainless Steels	Architecture	Stainless steel	--
N13	Material properties of stainless steel for lightweight architectural design	--	Architecture	Stainless steel EN 1.4003 EN 1.4016	--
N14	Stainless steels as a light metal	Manual	Architecture	Stainless steel EN 1.4116 (430) EN 1.4510 (439)	--
N15	Stainless steel and the changes of time	Surface design	Architecture	Stainless steel	--
N16	Stainless steel-A material for architectural visions	--	Architecture	Stainless steel	--
N17	Structural design in hot-rolled 3CR12 sections	Structural design	Architecture	3CR12	--
N18	Corrosion Handbook	General Information	--	Stainless steel	
N19	Guía del uso del acero inoxidable	General information	--	Stainless steel	Eurocode
N20	Stress corrosion cracking behaviour of the stainless steel with respect to their use in architecture.	Stress corrosion cracking	Swimming pool	Stainless steel (EN 1.5422)	--
N21	Stainless steel hollow sections handbook	Structural stainless steel design	Design of building	Stainless steel	--
N22	Life-Cycle	--	--	--	--
N23	Preliminary study of ferritic stainless steels in building industry	Building industry	Building industry	Ferritic	Mechanical properties
N24	Answer for architects	--	Architecture	--	--
N25	Aplicación de los aceros inoxidables para superficies exteriores en la industria de la construcción	Building industry	Outdoor	--	--

Reference	Title	Subject	Application	Material	Observation
N26	Development of the use of stainless steel in construction	Bolted connections	Material characterization	--	RFCS project
N27	Ferritic stainless steel	Testing mechanical properties	Design rules	Stainless steels	RFCS project
N28	Preliminary European Recommendations for the Testing and Design of Fastenings for Sandwich Panels	Testing and Design	Fastenings for Sandwich Panels	--	--
N29	Design of steel Structures in Seismic Zones	Seismic Zones	--	--	--
N30	Commentary and worked examples to EN 1993-1-10 Material toughness and through thickness properties	Toughness	--	--	--
N31	Assessment of Existing Steel Structures. Recommendations for Estimation of Remaining Fatigue Life	Fatigue in structures	Development of Eurocodes	--	--
N32	Estudio comparativo de la Resistencia a la corrosión de aceros inoxidables ferríticos	Electrochemical and salt spray tests	--	EN 1.4016 EN 1.4509 EN 1.4521	--
N33	The Testing of Connections with Mechanical Fasteners in Steel Sheeting and Sections	--	Connection	--	--
N34	Surface Protection Guide for steelwork exposed to Atmospheric Environments	Design	--	--	--
N35	Protection against Corrosion inside Buildings	Protection	--	--	--

Reference	Title	Subject	Application	Material	Observation
N36	European Recommendations for Bolted Connections with Injection Bolts	--	Bolted connections	--	--
N37	Connections and Frame Design for Economy	Semi-rigid connections	Connections design	--	--
N38	Commentary and worked examples to EN 1993-1-5 Plated structural elements	--	Structural elements	--	--
N39	5th International Symposium on steel bridges	--	Bridges	--	--
N40	2nd European Conference on steel structures Eurosteel´99	--	Structures Bridges Connections Composite structures codes	--	--
N41	The Design and Testing of Connections in Steel Sheeting and Sections	--	Connections	--	--
N42	Protection of steel Structures against Corrosion by Coating	Corrosive environments Protection Surface preparation painting	--	--	--
N43	Stainless steels in bus construction	--	Buses	--	RFCS project
N44	Corrosión atmosférica de aceros inoxidables ferríticos	Atmospheric test	--	EN 1.4016 EN 1.4509	
N45	Atmospheric corrosion resistance of high-Cr ferritic stainless steels for architectural exterior applications.	Atmospheric corrosion resistance	Finish, stainless steel comparison	Stainless steel	Atmospheric
N46	Resistance of stainless steels to atmospheric corrosion	Atmospheric test	--	Stainless steel	10 years. Washing effect and surface finish

Reference	Title	Subject	Application	Material	Observation
N47	Atmospheric corrosion behavior of stainless steels and nickel alloys	Atmospheric test	Materials behavior	Stainless steel and nickel alloys	Finish: 2B, dull, polished and electropolished
N48	Application of stainless steel to the architectural exterior materials	Stainless steel behavior	--	--	Atmospheric and electrochemical tests
N49	Case study of Atmospheric corrosion and controlling factors	Atmospheric corrosion resistance	Outdoor and indoor	Stainless steel	Analysis of previous studies. Accelerated test
N50	Corrosion atmosférica de aceros inoxidables ferríticos	Atmospheric corrosion	Atmospheric corrosion	EN 1.4016 EN 1.4511 EN 1.4113 EN 1.4513 EN 1.4509 EN 1.4301	Finishes SB, 2B
N51	SKFM observation of Pit Initiation on Stainless steels	Super Kelvin Force Microscope and pitting corrosion	Pitting corrosion	EN 1.4301 (304) EN 1.4016 (430)	--
N52	Atmospheric corrosion behavior of stainless steels and its estimation method.	Atmospheric corrosion resistance	Marine environments	Stainless steel	--
N53	Effect of alloying elements on atmospheric corrosion resistance of ferritic stainless steels	Atmospheric corrosion resistance	Influence alloying elements Cr, Mo, Cu	Ferritic	Atmospheric, salt spray and electrochemical tests
N54	Effects of niobium and copper addition on corrosion behavior of ferritic stainless steels	Niobium and copper addition	Improvement of corrosion resistance	17%Cr ferritic stainless steel	--
N55	Atmospheric corrosion resistance of stainless steels	Atmospheric corrosion resistance	--	Stainless steel	Atmospheric and electrochemical tests. Finishes : 2B, N4, BA
N56	Electrochemical method to evaluate atmospheric corrosion	Atmospheric corrosion resistance	Lifetime prediction	Stainless steel	Atmospheric and accelerated test

Reference	Title	Subject	Application	Material	Observation
N57	Atmospheric Corrosion Testing in Southern Africa-Results of a Twenty Year Exposure Programme.	Atmospheric corrosion test	Atmospheric corrosion	Aluminium alloys Mild steel COR-TEN Zinc Copper 302 EN 1.4301 (304) EN 1.4401 (316) 3CR12 EN 1.4016 (430)	--
N58	Corrosion and the Environment	Corrosion	--	--	--
N59	Long term atmospheric exposure of stabilized ferritic stainless steels	Atmospheric test	--	Stainless steel	Ferritic 17-18%Cr with addition >2%Mo, better performance than EN 1.4301 (304)
N60	Protección de metales en las atmósferas de Iberoamerica. Parte II- Protección anticorrosiva de metales en las atmósferas de iberoamerica	Atmospheric variables	--	--	--
N61	Principles of corrosion engineering and corrosion control	Atmospheric corrosion electrochemistry	--	--	--
N62	Corrosión atmosférica del acero en intemperie y bajo techo en un ambiente urbano	Selection field test	--	--	--
N63	Predicción a corto y largo plazo de la corrosión atmosférica de metales	Electrochemistry Atmospheric contaminant	--	--	--
N64	Comparación entre algunos métodos utilizados para la determinación de contaminantes en las investigaciones de corrosión atmosférica	Atmospheric contaminant Cl- SO_2	--	--	--

Reference	Title	Subject	Application	Material	Observation
N65	Application of stainless steel to the architectural exterior materials	Atmospheric corrosion	Architecture	SUS447J1 30Cr-2Mo	Ep vs PRE Ep vs rust area
N66	El acero inoxidable y su empleo en arquitectura.	General	Architecture	--	--
N67	Baosteel Ferritic Stainless Steel B445R for Architectural Applications	Characterization	Architectural roofing	B445R 22.5Cr 1.5Mo	What about crevice corrosion?
N68	Development of atmospheric Corrosion resistant ferritic stainless steel NSS445M2	Characterization	Roofs and curtain walls	NSS445M2	What about crevice corrosion?
N69	Mapa Iberoamericano de corrosividad atmosférica. Primeros resultados	Corrosivity maps	Atmospheric corrosion	Metals	--
N70	Nisshin steel´s Development of Corrosion Resistant Stainless Steel for Roofing and Facings	Characterization	Roofing And Facings	NSS445M2 (SUS445J1) NSS447M1 (SUS447J1) Alstar Tough-TainZ	Coating
N71	Contaminación atmosférica y corrosión	Behavior	Atmospheric corrosion	--	--
N72	Metals for corrosion resistance Part II	Behavior	Atmospheric, soil, and concrete corrosion	--	V_{corr}
N73	Surface protection guide for steelwork exposed to atmospheric environments	Coating	--	--	--
N74	Characteristics and potential impacts of under-ice river plumes in seasonally ice-covered Bothnian Bay (Baltic Sea).	Marine environment	--	--	Baltic sea 0.2-0.4% salt
N75	Preventing Coastal Corrosion. February 2006	Preventing	--	EN 1.4301 (304) EN 1.4401 (316) EN 1.4462 (2205)	Roughness effect

Reference	Title	Subject	Application	Material	Material
N76	Stainless steel and sustainable construction. Case studie from Europe and North America	--	Construction	EN 1.4016 EN 1.4301 EN 1.4372 EN 1.4401	--
N77	The Atmospheric Corrosion Resistance of Stainless Steels	--	--	3Cr12 EN 1.4016 (430) EN 1.4401 (316) Corten Zinc copper	--
N78	Preventing Coastal Corrosion. February 2010	Preventing		EN 1.4301 (304) EN 1.4401 (316) EN 1.4462 (2205)	

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