



ACCESSIBILITY & TRANSPORTS

Project nr 2008-1/049

duratiNet

# Durable Transport Infrastructures in the Atlantic Area Network

2009-2011



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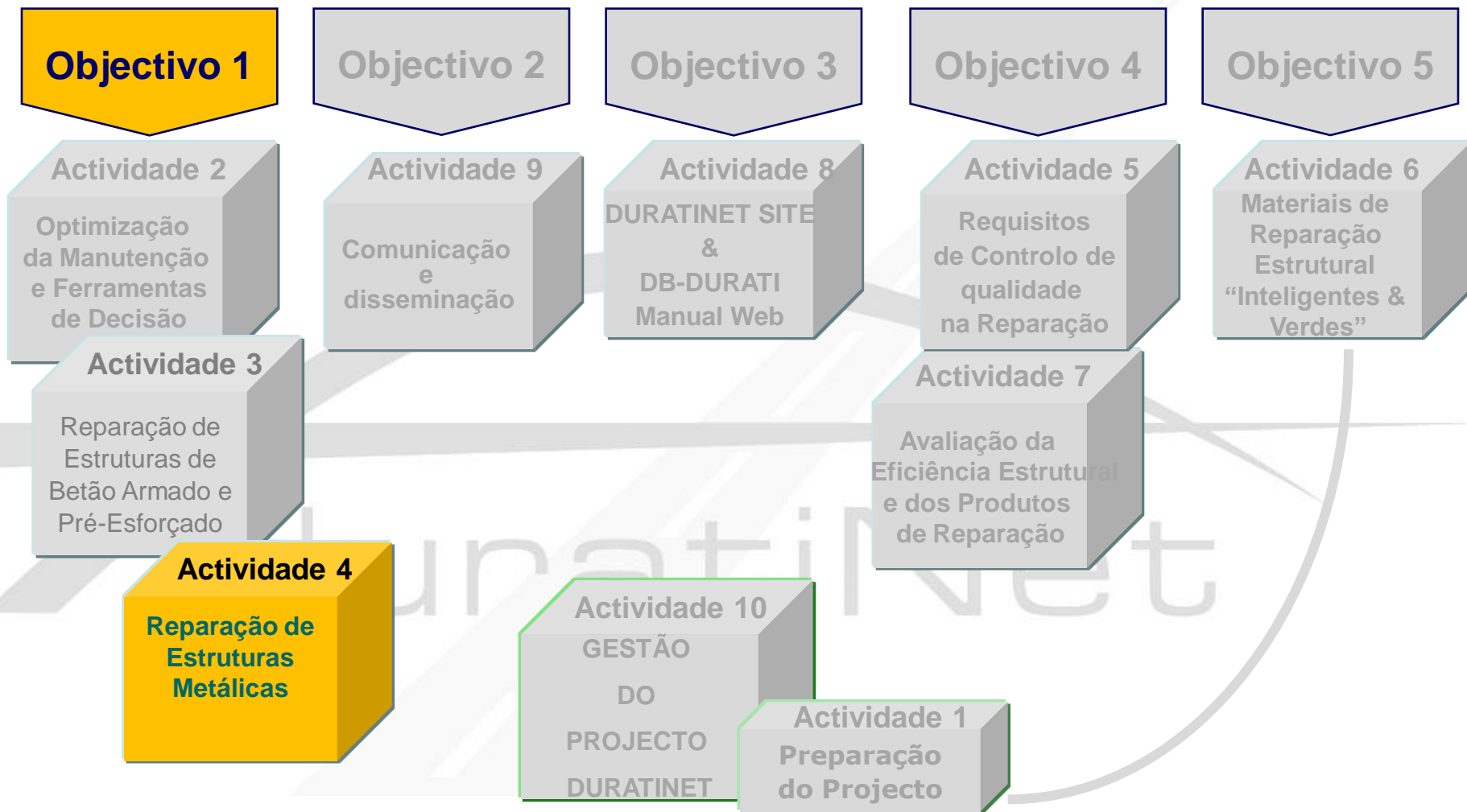
Investing in our common future





**ACTIVIDADE 4  
REPARAÇÃO DE  
ESTRUTURAS METÁLICAS**

# ACTIVIDADES DO PROJECTO



## Grupo de Trabalho 4

### > Reparação de estruturas metálicas *Leader U.Nantes*

- Actividade 4.1 - Mecanismos de Degradação  
*REFER, Rede Ferroviária Nacional*
- Actividade 4.2 – Ensaios Não Destrutivos. Aplicabilidade prática  
*LCPC – Laboratoire central des Ponts et Chaussées*
- Actividade 4.3 – Reabilitação e Sistemas de protecção de aço estrutural  
*LNEC – Laboratório Nacional de Engenharia Civil*

Parceiros activos: U.Nantes, REFER, LCPC, EP, BEL



# 4.1 MECANISMOS DE DEGRADAÇÃO

## > Defeitos

- Podem ser usados 3 critérios para a classificação dos defeitos:

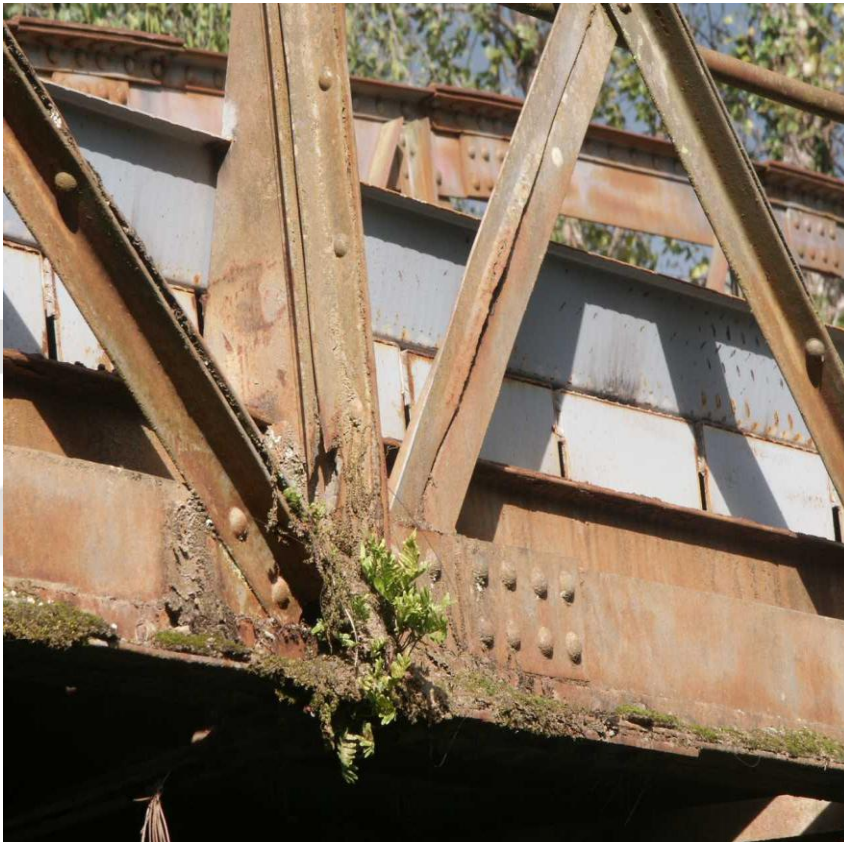
- *Causa do defeito*

- *Causa-efeito*

- *Efeito*

# Defeitos Básicos

## Contaminação



## Deformação



# Defeitos Básicos

## Deslocamento



## Descontinuidade





# Defeitos Básicos

## Deterioração

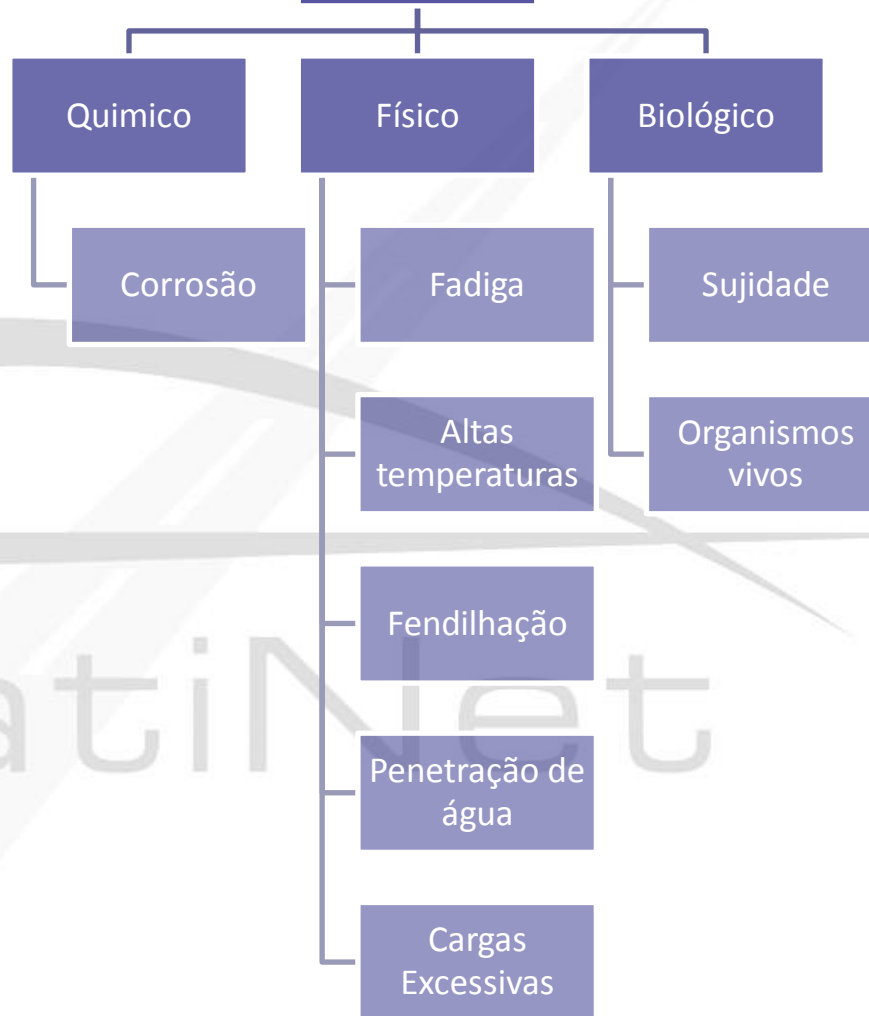


## Perda de Material



# Mecanismos de degradação

## Mecanismos de Degradação



REPORT TITLE

- The mass transport of the oxidant or of the reaction products;
- The anodic or cathodic charge transfer;
- The properties of the passive film.

When this limiting step is accelerated, the term "depolarization" is sometimes used, we then speak of cathodic or anodic depolarization according to the partial reaction considered (Crole, 1938).

The products of reactions (4.4.1) and (4.4.3) are ions dissolved in water and can respond by giving a precipitate given by the reaction:

$$M^{n+} + nOH^{-} \rightarrow M(OH)_n \quad (4.1.4)$$

The corrosion process is of the electrochemical type, because it is both a chemical reaction (precipitation, etc.), but also an electron transfer. The precipitate is a hydroxide which covers the metal surface. In the case of products containing iron, it is rust. This reaction is called "recovery" or the old terminology "passivation". If this layer is completely sealed from the time of the smallest thickness, less than 10-9 m, passivation is called perfect (Rahmanov, 1938).

Croissance du film solide    
  Film précipité

*Fig. 4.1.2 Widespread corrosion process involving phenomena of charge transfer, film formation and transport processes, from ASM Handbook (1987).*

Figure 4.1.2 illustrates the different sites (numbered 1 to 7) on the surface of a metal M immersed in an aerated electrolyte solution in which the reactions occur, influenced by the formation of a precipitate on the one hand, and solid corrosion products on the other.

When corrosion products are soluble enough not to precipitate at the metal surface, allowing free access of the liquid at any point on the metal surface, then the reaction of anodic dissolution of metal (site 1) or the cathodic reduction of oxygen (site 2) generally controls the overall reaction. If these reactions are rapid and the oxygen concentration is low, then its rate of diffusion to the cathodic site (site 3) will be the limiting factor of corrosion.

In a liquid, convection represents an infinite capacity of transport in relation to flows involved in corrosion reactions. However, between the convective fluid and metal, there is a laminar boundary layer which can only be penetrated by diffusion. But the spread, even in the liquid phase, is a relatively slow transport process. The laminar boundary layer will have two effects:



- For the removal of corrosion products, this may lead to local enrichment leading to precipitation;



# 4.2 INSPECÇÃO

## > NDT “IN SITU”



INSPECTION TECHNIQUES			
<b>MAGNETIC PARTICLES TECHNIQUE</b>			
Objective / Application field	Detection of surface and subsurface discontinuities, defects in metallic elements		
Principles	<p>The technique consists in applying to a ferromagnetic material a magnetic field with simultaneous pulverization of revealing made up of very fine iron oxide particles. The surface defects cause at their place a magnetic flux leakage on which the particles of the revealing accumulate. Detection of the indications of defects is done in visible light with coloured particles or in U.V. light with fluorescent particles.</p> <p>Before the test, metal parts are cleaned (oil, corrosion product, paint...)</p> <p>Applicable mainly to welds with internal defects at the surface or subsurface (2 to 3 mm)</p>		
Equipment and availability	Several commercial systems available.		
Destructive features	NDT I/II/III	DT I/II	SO I/II
Cost of inspection	Low I/II	Medium I/II	High I/II
Access to elements	1 Face I/II/III	2 Faces I/II	
Qualifications / interpretation	Inspector I/II/III	Inspector-Specialist I/II/III	Specialised I/II/III
Condition of application in situ	<p>Traffic restriction: NO</p> <p>Preliminary works: Surface cleaning</p> <p>Environmental restriction: electromagnetic perturbations</p> <p>Time consumption: medium</p>		
Advantages	<p>Detection of surface or subsurface defects</p> <p>Several magnetisation methods</p> <p>Estimation of the length of cracks</p>		
Limits	<p>Applicable only to ferromagnetic materials</p> <p>Surface must be cleaned (oil, metal) before inspection (time consuming in presence of corrosion)</p>		
Maturity	> 10 years I/II/III	< 5 years I/II	Under development I/II
Accuracy	-		
Standards	<p>ISO 2284, Non-destructive testing - Penetrant testing and magnetic particle testing - Viewing conditions</p> <p>ISO 2284-1, Non-destructive testing - Magnetic particle testing - Part 1: General principles</p> <p>ISO 2284-2, Non-destructive testing - Magnetic particle testing - Part 2: Detection media</p> <p>ISO 2284-3, Non-destructive testing - Magnetic particle testing - Part 3: Equipment</p> <p>ISO 17038, Non-destructive testing of welds - Magnetic particle testing</p> <p>ISO 23278, Non-destructive testing of welds - Magnetic particle testing of welds - Acceptance levels</p>		
Examples	 <p>Detection of cracking in welded element Typical application</p>	 <p>Magnetisation of the element Typical result</p>	
Application under development	-		
REFERENCES	<p>EN 1330-7, Non-destructive testing - Terminology - Part 7: Terms used in magnetic particle testing</p> <p>EN 444-05 Standard Practice for Magnetic Particle Testing</p> <p>EN 229-01 Standard Guide for Magnetic Particle Examination</p> <p>EN 2207-04 Standard Guide for Use of UV-A and Visible Light Sources and Meters used in the Liquid Penetrant and Magnetic Particle Methods</p>		
Contribution / authors	Version and date: 15-01-10		





# 4.3 REPARAÇÃO E PROTECÇÃO DE ESTRUTURA METÁLICA





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duratiNet		STEEL STRUCTURES				
REPAIR METHODS						
<b>STOP HOLE</b>						
<b>Description</b>	Stop hole consists in drilling a hole at or close to the crack tip to reduce the local stress concentration and prevent crack propagation.					
<b>Applicability</b>	<b>Defect(s)</b>	Small through-thickness cracks subjected to low stress ranges in plates or plate components of structural elements, and to arrest the crack tip of large cracks provided that the remaining length of the crack is repaired by either welding or bolted splice plates.				
	<b>Generic</b>	Fatigue life extension technique of cracked structural elements, in both welded and bolted/riveted structures.				
	<b>Advantages  Disadvantages</b>	Simple, economic and used as a temporary or emergency repair method.				
	<b>Effectiveness</b>	In welded structures, stop hole is good for fatigue cracking due to lack of fusion, cold cracks, restraint and web breathing and may also be applied for causes such as: vibration, web gaps and geometrical changes. In bolted and riveted structures, this method is excellent for out-of-plane bending, good for problems such as secondary stresses, and fair for local stress concentration.				
	<b>Limits</b>	Should be used together with other repair methods but it can be considered permanent if specific conditions are fulfilled. It very dependent on the operator skill and experience. Special care is also required when crack fronts are not uniform through the thickness.*				
	<b>Control</b>	Visual inspection and NDT such as liquid penetrant testing, according to EN 571-1 [49] and EN ISO 23277 [50]. If the crack tip was not intercepted, the hole should be slightly enlarged.				
<b>Specific equipment</b>		Drilling machines, such as a portable magnetic drill machine. Protective clothing and equipment.				
<b>Sustainability</b>	<b>Social</b>	<b>Service disruption</b>	Yes <input type="checkbox"/>	No <input checked="" type="checkbox"/>		
		<b>Environmental and health</b>	<b>Health</b>	Yes <input type="checkbox"/>	No <input checked="" type="checkbox"/>	
			<b>Ecology</b>	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	The waste caused by drilling should be collected.
	<b>Economical</b>	<b>Preliminary works</b>	Yes <input type="checkbox"/>	No <input checked="" type="checkbox"/>		
		<b>Specialized labour</b>	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>		
		<b>Time consumption</b>	Low <input checked="" type="checkbox"/>		Medium <input checked="" type="checkbox"/>	High <input type="checkbox"/>
		<b>Posterior works</b>	Yes <input checked="" type="checkbox"/>	No <input type="checkbox"/>	Restoration of protective system depending on the material.	
<b>Cost</b>	Low <input checked="" type="checkbox"/>		Medium <input type="checkbox"/>	High <input type="checkbox"/>		
<b>Standards</b>		No available European standards. Literature referred in the manual text.				



### REPAIR TECHNIQUES | SYSTEMS FOR PROTECTION OF STRUCTURAL STEEL

many types of paints.	detect, but it may be prevented by adopting suitable quality control procedures.
Good resistance to acidic conditions, unlike metal coatings, and different materials available for different requirements.	
No limits on size and type of structure.	The expected life is difficult to predict, even with standards and specifications, unlike metal coatings.
Generally, application is straightforward.	

#### 4.3 Protective coating systems

##### 4.3.1 Paint coatings

###### General

The most applied protective system to metallic structures is paint coating. This type of protective system provides several advantages such as <sup>122</sup>; easy applicability; no limitation on the size of protected steelwork and decorative finishing.

Paint and paint coating are 2 different terms where paint is the liquid material and paint coating is the protective film formed after drying. Paint is normally constituted by binder, pigment and solvent. The protective film is formed by solvent evaporation and binder conversion into a solid paint film. The paint may also have other constituents, e.g. diluents, depending on the required properties which are best preserved when selecting an appropriate application technique. Both liquid paint and paint coating require different properties <sup>122</sup>.

The properties of paint should include <sup>122</sup>; capability of application and drying under specified conditions; capacity to provide good adhesion and required decoration; and ability to provide a dry film with suitable properties, e.g. hardness, gloss, etc.

Standard EN ISO 12944-5 <sup>127</sup> describes several types of paint used in the protection of steel structures against corrosion. Annex A from the same standard contains numerous tables where some of the most common paint systems are characterized and divided according to their compositivity category.

Paint properties are determined mainly by the type of binder used. Table 16 from Annex C, in Standard EN ISO 12944-5 <sup>127</sup>, provides the main physical and mechanical properties of different generic types of paint.

Table 16. General properties of different generic types of paint <sup>127</sup>

Suitability	Poly(vinyl chloride) (PVC)	Chlorinated rubber (CR)	Acrylic (AY)	Akyd (AK)	Polyurethane, aromatic (PUR, aromatic)	Polyurethane, aliphatic (PUR, aliphatic)	zinc silicate (ZS)	Epoxy (EP)	Epoxy combination (EPC)
■ Good	▲	▲	▲	▲	●	■	■	●	●
▲ Limited									
● Poor									
□ Not relevant									
Gloss retention	▲	▲	▲	▲	●	■	■	●	●



### REPAIR TECHNIQUES | SYSTEMS FOR PROTECTION OF STRUCTURAL STEEL

Colour retention	▲	▲	■	▲	●	■	□	●	●
Resistance to chemicals:									
Water immersion	▲	■	▲	●	▲	●	▲	■	■
Rain/condensation	■	■	■	▲	■	▲	■	■	■
Solvents	●	●	●	▲	■	▲	■	■	▲
Solvents (splash)	●	●	●	■	■	■	■	■	■
Acids	▲	▲	▲	▲	■	▲	■	■	■
Acids (splash)	▲	▲	▲	▲	■	▲	■	■	■
Alkalis	▲	▲	▲	▲	■	▲	■	■	■
Alkalis (splash)	■	■	▲	▲	■	■	■	■	■
Resistance to dry heat:									
up to 70°C	●	●	▲	■	■	■	■	■	■
70°C to 120°C	□	□	▲	■	■	■	■	■	▲
120°C to 150°C	□	□	▲	●	▲	●	■	▲	▲
150°C to 400°C	□	□	□	□	□	□	■	□	□
Physical properties:									
Abrasion resistance	●	●	●	▲	■	▲	■	■	▲
Impact resistance	▲	▲	▲	▲	■	▲	■	■	▲
Flexibility	■	■	■	▲	▲	■	■	■	▲
Hardness	▲	▲	▲	■	■	▲	■	■	■

Note: This information has been drawn from a wide cross-section of sources and is intended to provide a general indication of the properties of the different generic types of paint available. Variations will occur within resin groups, and some products are specifically formulated to provide exceptional resistance to certain chemicals or conditions. Always consult the paint manufacturer when any given paint is chosen for a particular application.

The main requirement for protective paint coatings is to provide protection against the type of environment to which it will be exposed. Other general requirements for paint coatings are <sup>122</sup>; possibility to be repainted; easy application; reasonable storage life and price; durability in the specified environment; formation of a coherent film with good adhesion; resistance to impact and mechanical damage; etc. In order to meet these requirements, suitable binders, pigments, and other additional constituents should be provided.

Protection of steelwork by painting is usually assured by several coatings, forming a protective paint system. The different types of coating are <sup>122</sup>; the priming coat or primer; the undercoat and the finishing coat.

The primer is applied to the substrate and there is no significant difference compared to other coatings. The main function of the primer is to "wet" the steel surface and to provide good adhesion with the steel substrate. Standard EN ISO 12944-5 <sup>127</sup> defines 2 main categories of primer:





**OBRIGADO**