

Long Carbon Europe
Sheet Piling



ArcelorMittal

AMLoCor Steel Grade | 2011

AMLoCOR
SIGNIFICANTLY INCREASES
THE DESIGN LIFE OF
SEAPORT STRUCTURES



Introduction

ArcelorMittal's new 'low corrosion' steel grade will undoubtedly revolutionize the design of port structures. As a matter of fact, steel sheet piles have been used for over 100 years to build reliable and cost-effective temporary and permanent structures worldwide. Countless quay walls of major European ports have been constructed with steel sheet piles. One concern for the designers and port authorities was the durability of these marine structures. Corrosion of steel is a natural phenomenon that occurs whenever steel is in contact with humidity or water. However, it has not prevented investors and engineers from using steel in marine applications.

Several methods can be selected to achieve the predefined service life of a steel structure. One way to deal with the corrosion is to consider a certain loss of steel thickness over the service life, sometimes referred to as 'sacrificial thickness' or 'static reserve', and to take it into account in the design by considering reduced section properties of the sheet piles. Quite efficient but generally more expensive solutions are coatings and cathodic protection.



Fig. 2 Continuous casting of AMLoCor

But the foremost action was to start investigating into new steel grades that would be less prone to corrosion.

The key challenge was to develop a micro-alloyed steel that would perform better in the different zones to which a typical maritime quay wall is exposed. Several steel grades were tested in various ports over long periods. Many laboratory tests were conducted to determine the influence of a range of parameters. Furthermore, trials at the steel plant and rolling mill were done to optimize the production of such special steels.

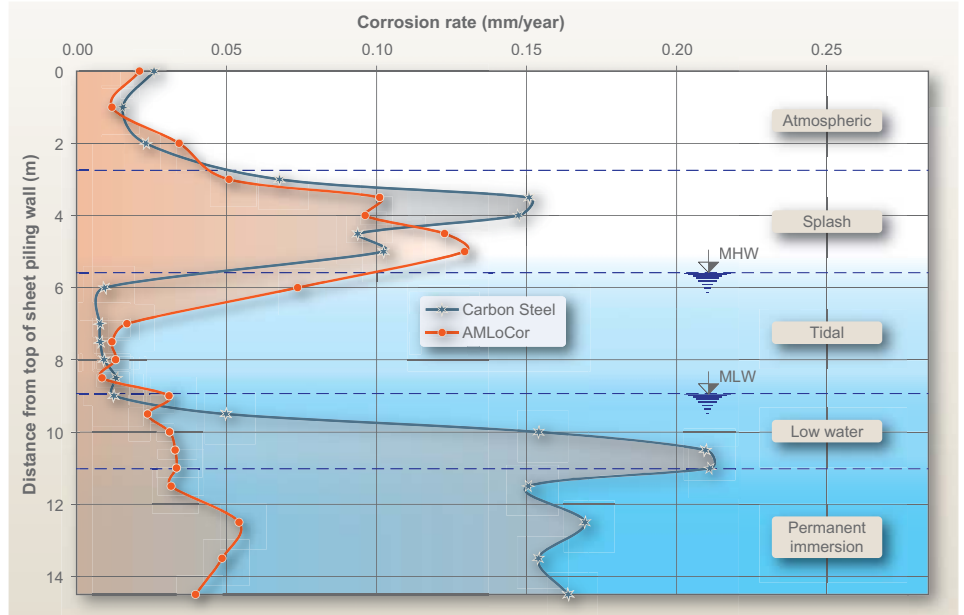


Fig. 1 Corrosion rates measured in a Northern European port

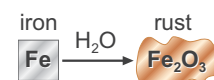
In-situ test specimens have proven that the **loss of steel thickness of AMLoCor is reduced by a factor 3 to 5**, depending on the exposed zones.

Furthermore, a Life Cycle Assessment (LCA) made by ArcelorMittal analysed the environmental impact of steel structures and shows it is an excellent 'green solution' compared to alternative construction methods.

ArcelorMittal is working on offering its whole product range in AMLoCor steel grade, which will encompass the combined wall systems in the future. Only Z sheet piles are offered currently.

Advantages of the new steel grade

Corrosion is a natural electrochemical phenomenon affecting metals and metallic alloys like steel. It consists in transforming the iron atom in the steel into its original state, natural iron oxide (formation of a rust layer).



Coating layers prevent this chemical reaction simply by separating the steel surface from the electrolyte. The coating forms a barrier that reduces the transfer of reactants between the steel and the water. A rust layer on the surface can have a similar protective effect.

Durability is of course the issue that European manufacturers tackled over 20 years ago. First of all, by surveying many ports and official administrations, and publishing the results of corrosion rates. For instance, in Eurocode 3 Part 5, tables with typical corrosion rates can be found, valid for standard carbon steel, in northern European countries.

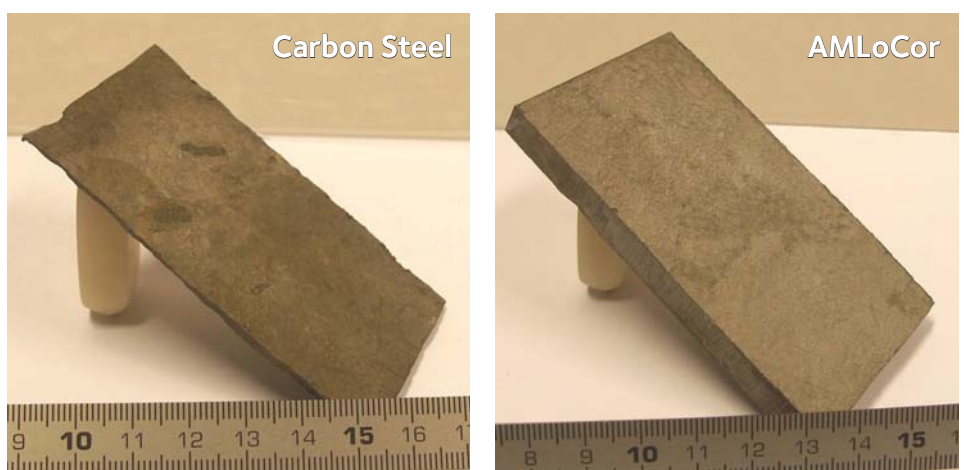


Fig. 3 15 year old samples, Northern European port

Cathodic protection works in a different way: the chemical reaction still occurs, but a less noble metallic element is introduced into the system and corrodes instead of the steel (galvanic anodes of aluminium for instance), or an electrical system provides the required electrons to protect the steel. Corrosion is a very complex topic that will not be dealt with in more detail in this brochure.

Full scale and laboratory tests have been performed during the last twenty years.

The chemical composition has been slightly improved all along those research projects in order to fulfil the requirements of the product, from durability to fabrication and welding. The excellent performance in the low water zone and in the immersion zone has been confirmed. Although it is not a 'standard' carbon steel used in the construction industry, this micro-alloyed steel can be designed and installed based on standard design procedures and guidelines valid for steel sheet piles, for instance according to EN 1997, EN 1993 Part 5, EN 10248, EN 12063, EAU 2004, etc. However, the design approach has to be adapted to take into account the loss of steel thickness. The design may consider a combination of additional protection methods for zones where the steel is less effective, including coatings, concrete capping beams, etc.

AMLoCor steel grade is slightly more expensive per tonne than carbon steel due to the cost of the additional alloys, just like other such special steels as ASTM A690. However the cost-efficiency of any solution needs to consider the overall

investment during the whole service life. **AMLoCor** will in many cases **yield the cheapest solution in the long-term.**

In addition AMLoCor protects steel from ALWC (Accelerated Low Water Corrosion) which is related to biological activity enhancing degradation of steel in the low water zone. The exact mechanism has not yet been scientifically identified, but some seaports in the UK and France have reported this issue. Samples of the new steel grade are being tested over a period of a few years in a lake in Northern USA affected by accelerated corrosion.

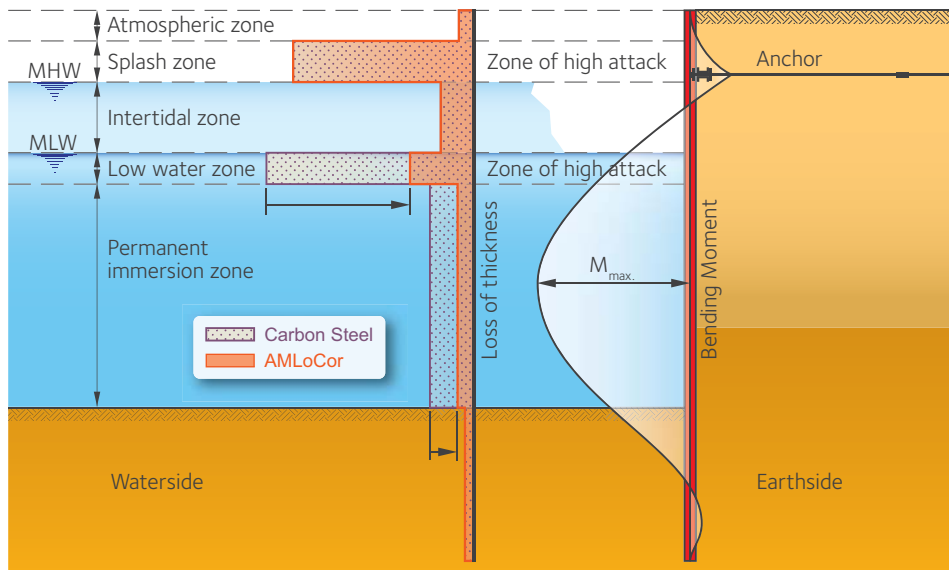


Fig. 4 Typical loss of steel thickness in a marine environment

This brochure is limited to **marine structures**, even though the new steel grade might be quite efficient in inland waterways and lakes.

The main advantage of AMLoCor is a significant reduction of the corrosion rates in the Low Water Zone (LWZ) and in the Permanent Immersion Zone (PIZ).

For the verification of the structure, the designers take into account the 'general' corrosion, assuming that the loss of thickness is uniform all over the surface, as opposed to 'pitting' corrosion, which might have more local influence on the serviceability state.

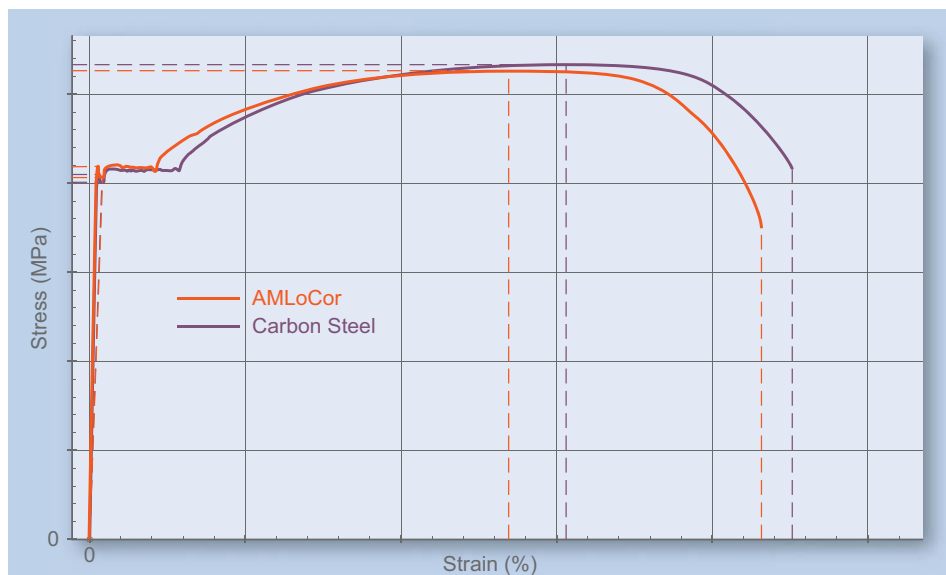


Fig. 5 Stress - Strain diagram

In general, the maximum bending moments, and consequently the steel stresses, are in an area where corrosion rates are relatively low: permanent immersion zone or embedded zone (soil). Yet the Low Water Zone sometimes governs the design because in the permanent immersion zone the reduction of the section properties is offset by the lower thickness loss.

It is common practice to analyse the driveability of new steel grades during the development stage. Having a good toughness, it was never really an issue, but nevertheless, a driving test in very hard soil conditions was performed in Denmark in order to compare the behaviour of one section rolled in a 'standard' S 355 GP vs. AMLoCor steel grades. The whole test programme was done under the supervision of an independent body to certify the results of the test. Piles were driven with an impact hammer and a vibratory hammer, and then pulled out for visual inspection and measurement of the section geometry. Additionally, a PDA analysis of the piles was done during the driving. The test confirmed that AMLoCor performed as well as equivalent carbon steel in hard driving conditions.

At this stage **steel grades with yield strength of 320 MPa and above** can be achieved, depending on the sheet pile section. A table showing the combinations of available steel grades and sheet pile sections will be updated regularly. Please check our website for the latest edition.

Welding, splicing, fabrication has also been addressed in detail.



Fig. 6 Samples in a major port, Northern Europe

Steel properties

By deduction from its behaviour and mechanical properties, AMLoCor can be considered as equivalent to a 'standard' carbon steel used in the construction industry. Hence it can be used in the design of a retaining structure similarly to any standard steel grade applicable to hot rolled steel sheet piles, like EN 10248. Fig. 5 shows two stress-strain diagrams of a S 355 GP and an AMLoCor Blue 355 sample. Both show the typical elastic behaviour of the steel until reaching the yield strength R_{eH} , followed by a long elasto-plastic deformation, and the increase of the resistance until reaching the tensile strength R_m . The ratio R_m/R_{eH} is quite similar to a standard S 355 GP. The toughness of the steel exceeds the requirement (27J at 0°C) of the future EN 10248.

Design considerations

The use of cathodic protection (CP) can avoid any corrosion in the submerged zones: LWZ and PIZ, see figure 1. By contrast, if AMLoCor is used, **loss of thickness (LoT)** due to corrosion has to be taken into account at design verification of the structure. But LoT will be drastically reduced thanks to the use of AMLoCor. For design purpose LoT data for classical steel grades in accordance with EN 10248: 1995 are available either based on local experience or on recommendations and standards (EAU 2004, EN 1993-5: 2007).

From these, design LoT data for AMLoCor are obtained using the

Corrosion Impediment Ratio (CIR)

$$CIR = \frac{LoT_{Steel}}{LoT_{AMLoCor}} \Rightarrow LoT_{AMLoCor} = \frac{LoT_{Steel}}{CIR}$$

CIR should be taken from the following table:

Zone	Low Water	Permanent Immersion	Splash
CIR	5	3	1

If limit state design is used, the following design verification approach is recommended:

- at ultimate limit state (ULS), design verification takes into account reduced design resistances $R_{d,cor}$ due to corrosion loss of thickness over the whole structure: $E_d \leq R_{d,cor}$
- at serviceability limit state, the structure is checked against perforation in every zone: $LoT < \text{minimum thickness}$.

As mechanical properties of AMLoCor grades are fully equivalent to normal piling grades, design structural resistances can be determined according to all relevant design codes used for steel sheet piling structures, like EN 1993-5:2007.

Provided the right filler material is used for welding, design verifications for welds also can be done according to these codes. For partial factor verification, it is worth noting, that due to the extreme care required during manufacturing of piling products in AMLoCor, scattering of properties is limited and partial factors for the material properties used for piling steel grades fully apply.

Comparative costing

Compared to the unprotected steel piling solution the use of AMLoCor leads to considerable savings in steel weight, as soon as corrosion LoT in the immersion zone is significant.

On the other hand, CP always leads to the minimum weight of the structure. But it generates significant additional cost for both investment and maintenance. Also galvanic CP has an important environmental impact on the sheet pile solution¹⁾.

The cost for CP is proportional to the projected wet surface of the sheet pile wall, whereas the additional cost for the AMLoCor is proportional to the weight. From this it transpires that the lighter the piling structure, the higher the cost advantage for the AMLoCor solution.



Fig. 7 Prototype of the US measuring device

Fabrication, installation, connections, maintenance

The intrinsic properties of AMLoCor make it a 'special' steel grade with respect to welding. Specific welding procedures have been worked out to ensure state-of-the-art welding. Welders also have to be certified accordingly. The choice of the electrodes is important. Please contact us for more information on the different welding procedures.

Splicing and special piles can be based on EN 12063, except for the welding procedures.

Some of our special connectors are available in AMLoCor grade.

Connections have to be designed carefully. To avoid damage to connecting devices, like bolts and wailings, it has to be ensured that different steel grades which are not compatible are protected. One essential parameter is the contact surface of both elements. In very unfavourable conditions, an insulated material at the interface between different elements may be recommended.



Fig. 8 AMLoCor beam blank used for rolling sheet pile

AMLoCor is compatible with coating systems that can be applied on standard sheet piling steel grades. Galvanization is not recommended in combination with AMLoCor as efficiency of this protective method will be quite poor. Coatings shall be compatible with cathodic protection if CP is foreseen. From an economical point of view, combining AMLoCor with a CP may be a cost-effective solution in certain instances.

Sheet pile walls in AMLoCor do not need any specific maintenance. Depending on the design method used, a regular survey of the coatings and residual thickness of sheet piles may be recommended.

AMLoCor sheet piles can be installed with all the typical driving equipment: impact hammer, vibratory hammer and hydraulic presses.

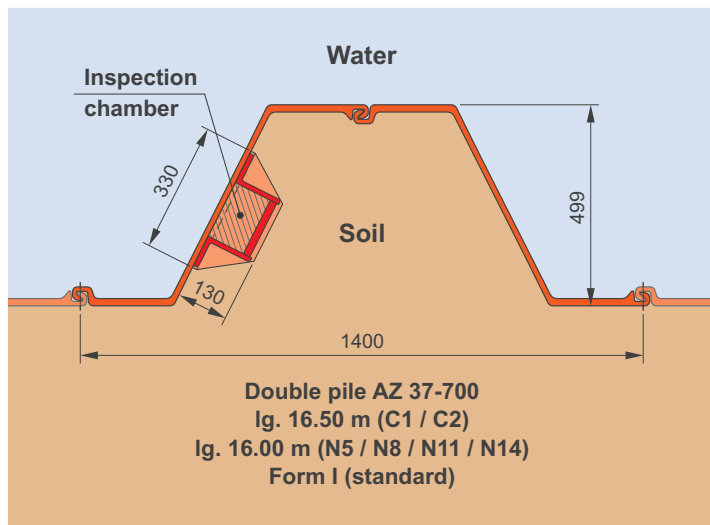


Fig. 9 Detail of a special sheet pile for monitoring the residual thickness

Services

The expertise of the engineers of our Technical Department allowed us to become a reference for many design engineers, project owners and contractors seeking professional advice. Our skilled engineers will assist you with any technical issue, free of charge. If you need a welding procedure, or guidance on fabricating special sheet piles, on sealants, on design, layout drawings, etc, do not hesitate to contact us.

The longevity of AMLoCor is being tested in different ports. Our Research Department has developed a special measuring device to allow the measurement of the residual thickness at different levels on a structure. This requires special sheet piles being fabricated beforehand and installed as part of the quay wall. A manhole on the quay wall surface allows the introduction of the device behind the sheet pile wall. Traditional inspection methods (ultra sonic sensor), performed from the waterside, require cleansing of the rust layer. Corrosion products are removed, thus activating the steel surface. As a result, corrosion is reinitialized and measurement campaigns are distorted. The new developed method will yield more accurate results and will not damage the corrosion products. Measurements can be done every year, over a period of minimum five years. The R&D department can also assist project owners with this type of additional survey of the structure.

ArcelorMittal can also assist with the elaboration of a tender specification for AMLoCor steel grades.

AMLoCor

THE NEW STEEL SOLUTION FOR MARINE STRUCTURES

LOSS OF STEEL THICKNESS IN SEAWATER
REDUCED BY A FACTOR 3 TO 5



Fig. 10 Fabricated special sheet pile with inspection chamber

¹⁾ Hettinger, A.L.; Bourdouxhe, M.P.; Schmitt, A.

"Comparative Environmental evaluation of retaining structures made of steel sheet piling or reinforced concrete". ArcelorMittal, 2010.



Reference case: Port of Shoreham, UK

Port of Shoreham in the UK installed a pilot wall in 2010. The anchored quay wall is ~30 m long, with one anchor level, and a retained height of 8.7 m. It utilizes sheet piles from one trial rolling, 16.0 m long AZ 37-700 sheet piles in AMLoCor Blue 355, with a yield strength of 355 MPa. The vibratory hammer used to drive the first meters into the ground was a PVE model '2315' with a maximum amplitude of 16 mm and a centrifugal force of 870 kN. If required, the sheets were driven to final elevation with a double acting hydraulic impact hammer, a BSP model 'SL 30' with a 2.5 t ram mass, a drop height of 1.25 m. It can provide 30 kNm of energy per blow at full stroke. The sheets were driven through an alluvial gravel layer (with SPT blow counts up to 25) down into a stiff alluvial clay layer. Some sheets penetrated the chalk layer.

Four sheet piles were installed with the additional channel elements required for the future inspection of the residual thickness, as well as two standard S 355 GP sheet piles. These will serve as reference samples to

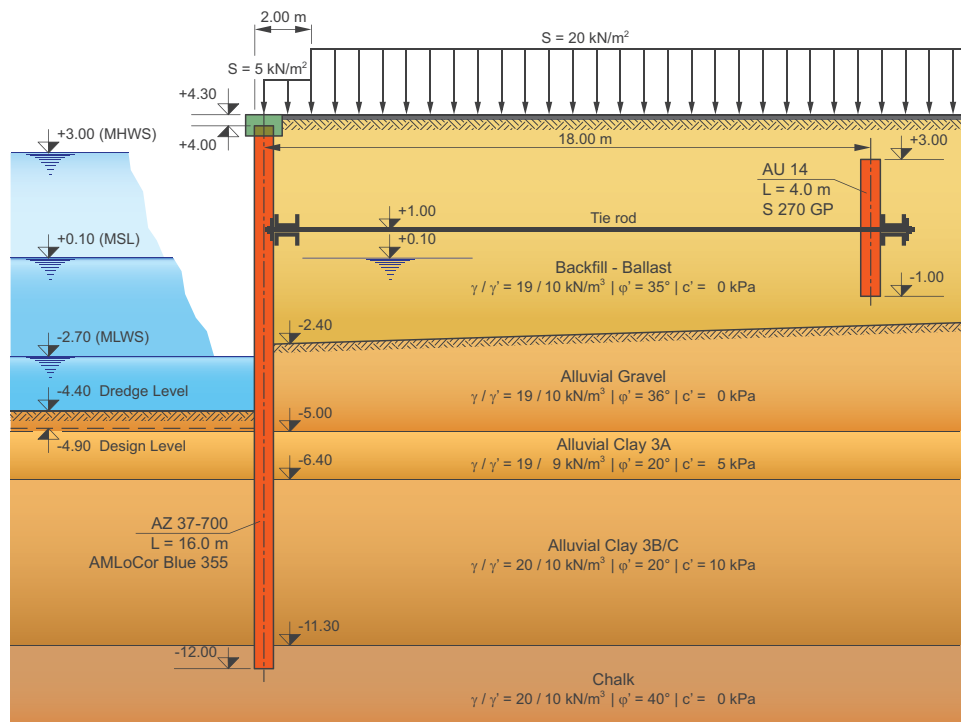


Fig. 12 Port of Shoreham. Cross Section

compare the effective corrosion rates of both steel grades under the exact same conditions.

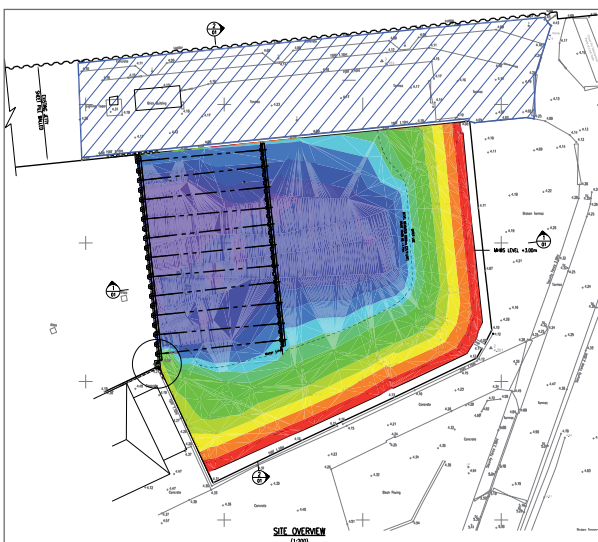


Fig. 11 Port of Shoreham. Layout of the wall



Fig. 13 Port of Shoreham. AMLoCor steel sheet pile wall



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