A light, durable and economical material for the offshore industry

ALUMINIUM Long experience with numerous aluminium alloys in marine climates and seawater has shown aluminium, especially when suitably designed, to be highly corrosion-resistant. In recent years it has also been increasingly used in the offshore wind energy sector: as a structural material in the construction of supply and maintenance boats, as a lightweight material for helicopter hoist platforms as well as platforms in the towers of wind energy installations, and for cables, transformers and housings for switch cabinets. As Dr Thomas Hentschel from Hydro Aluminium Rolled Products GmbH in Bonn, Germany, points out in the following article, even more marine applications are possible for durable, economical aluminium.

There are a number of reasons to use aluminium as a construction material for offshore installations:

- **Light weight:** The density of aluminium is only a third that of steel, resulting in considerable cost savings and easier transport of construction parts to – and assembly at – the offshore site. Expensive, complex crane work is not required since many parts can be moved and fitted manually. What is more, supporting structures can be slimmer when lighter components are used.
- **Strength:** In spite of their lower densities, aluminium materials suitable for seawater use have a specific strength (strength-to-weight ratio) three times higher than that of steel. Consequently, it is possible to make aluminium components up to 60% lighter than equivalent steel ones.
- **Formability and versatility:** Aluminium sheets can be easily formed and joined. Aluminium profiles with complex geometries and integrated functionalities can be manufactured – so joints can be optimised, making assembly simpler and assuring the structure a long service life.
- **Recycling:** At the end of their service lives, aluminium materials can be 100% recycled, making aluminium a sustainable resource. The high value of aluminium scrap also makes it a valuable capital asset.
- **Corrosion resistance:** This is a crucial property in unmanned offshore wind energy converters. Since such installations are never brought back to shore during their lifetime, maintenance is very expensive and complex. Aluminium assemblies, if constructed and fitted properly, will not corrode. Periodic applications of corrosion-inhibiting coatings are therefore unnecessary.

**Corrosion resistance** To be more specific, aluminium displays excellent corrosion resistance under various environmental conditions. Its natural protective oxide layer prevents general surface corrosion, which, if it occurs at all, is of a localised nature, especially in the form of pitting. After a few years of outdoor exposure, the depth of corrosion normally does not increase substantially, thereby ensuring a lifetime of decades. A large number of aluminium alloys are recommended for use in a marine environment [1; 2].

<table>
<thead>
<tr>
<th>CORROSIVITY CATEGORY</th>
<th>DEFINITION</th>
<th>CORROSION RATES $r_{corr}$ in g/(m$^2$·a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon steel</td>
<td>Zinc</td>
</tr>
<tr>
<td>C1 very low</td>
<td>$r_{corr} &lt; 10$</td>
<td>$r_{corr} &lt; 0.7$</td>
</tr>
<tr>
<td>C2 low</td>
<td>$10 &lt; r_{corr} &lt; 200$</td>
<td>$0.7 &lt; r_{corr} &lt; 5$</td>
</tr>
<tr>
<td>C3 medium</td>
<td>$200 &lt; r_{corr} &lt; 400$</td>
<td>$5 &lt; r_{corr} &lt; 15$</td>
</tr>
<tr>
<td>C4 high</td>
<td>$400 &lt; r_{corr} &lt; 650$</td>
<td>$15 &lt; r_{corr} &lt; 30$</td>
</tr>
<tr>
<td>C5 very high</td>
<td>$650 &lt; r_{corr} &lt; 1500$</td>
<td>$30 &lt; r_{corr} &lt; 60$</td>
</tr>
<tr>
<td>CX extreme</td>
<td>$1500 &lt; r_{corr} &lt; 5500$</td>
<td>$60 &lt; r_{corr} &lt; 180$</td>
</tr>
</tbody>
</table>

Table 1: Corrosion rates $r_{corr}$ for the first year of exposure for different corrosivity categories, according to [3]

![Figure 1: The Oseberg platform with helipad](image-url)
The 5000 series (AlMg) alloys are preferred for aluminium sheets and plates. Aluminium alloys most commonly used for profiles are from the 6000 series (AlMgSi).

The excellent corrosion resistance of aluminium is documented in ISO 9223 (2012), which lists the corrosion rates for various metals during the first year of exposure (Table 1). Corrosion rates for aluminium are about 100 times less in all categories than those for steel, and almost ten times less than those for zinc and copper. Marine climates are categorised as C5 (coastal) and CX (offshore).

Because of its high corrosion resistance in marine environments – even without protective coatings – aluminium has been successfully employed in offshore applications and structures for decades. One example is the Oseberg platform in the Norwegian North Sea, whose crew quarters and helicopter landing pad are made of uncoated aluminium sheets and profiles (Figure 1). Aluminium is also being used now in offshore wind energy installations as a construction material for stairs and railings, platforms for maintenance crews as well as for various other internal components of the tower.

North Sea Buoy II

Owing to the very long service lives and complete recyclability of aluminium constructions, there is an acute shortage of samples available for material analysis. The North Sea Buoy II (NSB II) of Germany’s Federal Maritime and Hydrographic Agency is an exception. Located 120km west of the island of Sylt, it has been part of a network of meteorological measurement stations for over 30 years. The body of the 15m-high buoy is made of uncoated aluminium sheets and profiles, and the mounted measuring container is painted bright yellow (Figure 2). When the buoy is on site, most of it is under water. While the part of the buoy above water does not require any corrosion protection, the parts below water are protected by sacrificial anodes made of zinc that are typically affixed 2m apart (Figure 3). The body of the buoy is regularly brought to shore and cleaned with high-pressure water jets to remove fouling. Other periodic maintenance has not yet been carried out. According to the latest evaluation, NSB II can continue operating for another ten years. The buoy’s excellent condition includes:

- No appreciable loss in wall thickness;
- No cracks in the base material or weld seams;
- Weldability equal to that of new material;
- All screws without problems (screw material: 1.4571 stainless steel).

A boat striking the buoy in 2010 necessitated unscheduled maintenance. Samples were taken from replaced parts for laboratory analysis: a plate of aluminium alloy 5083 (AlMg4.5 Mn0.7), which was located about 2m above water, and a pipe of aluminium alloy 6082 (AlSi1MgMn), which was located about 2m below water. The plate exhibited a corrosion depth of 0.2 to 0.5mm, and the pipe a corrosion depth of about 0.1mm. The exceedingly low corrosion in the submerged part showed how effective protection with zinc anodes is. This favourable corrosion behaviour has been confirmed and statistically supported by data from the experimental test station at the North Sea island of Helgoland. They show that for AlMg(Mn) sheet alloys located within the spray zone, the maximum corrosion depth is reached within a few years, after which corrosion progresses very slowly. This evidently holds true for more than 30 years, since the corrosion depths measured on the buoy samples from the spray zone were only slightly higher than those measured on the Helgoland test samples. Weathered aluminium materials generally do not corrode uniformly, but experience local pitting corrosion. Therefore the average depth of attack is much less than the maximum depth. Even after ten years in the splash zone, only a few micrometres of material degraded on average, equivalent to several g/m², as shown in Table 1.

Telescopic gangways

Four aluminium telescopic gangways that have been used on North Sea platforms for up to 17 years were also inspected. Samples could not be taken, however, because the gangways were free of damage and meant to be used further.

Figure 4 shows one of them in its working environment on the oil platform Safe Scandinavia in the Scottish North Sea. Like the NSB II, the gangways were built with uncoated aluminium extrusions and plates using the aluminium alloys 5083 and 6082.
Galvanic corrosion

As already stated, aluminium materials are highly corrosion-resistant thanks to the natural oxide layer on their surface. Aluminium is a base metal, however, and defects in the oxide layer lead to pitting corrosion. As described above, these local corrosion attacks are mostly not very deep because the points of attack are deactivated by a new formation of the oxide layer. This is called "repassivation". But when aluminium materials are assembled with noble metals, repassivation can be suppressed in the vicinity of the joint, intensifying the corrosion attack observed on the panels as described above. Of particular interest was the area around the points of contact, similar to the attack observed on the panels in the Helgoland test. The area of contact between the aluminium and washer was free of corrosion.

In the case of stainless steel screws (1.4571), corrosion attacks about 0.5mm deep were measured in the aluminium next to the screw connection. Aluminium in contact with seawater-resistant CrNiMo steels (type 316), may be used without galvanic separation if the steel surface is small compared with that of the aluminium and moderate corrosion can be tolerated [4]. This has been confirmed by field observations. An aluminium ladder was inspected after assembly ten years earlier at a height of about 20m on a wind turbine tower at the Kentish Flats wind farm, off the southern English coast. The aluminium used, 5083 and 6060 (AlMgSi), had the expected superficial corrosion as described above. Of particular interest was the area around the stainless steel screws in direct contact with the aluminium. There was only moderate galvanic corrosion around the point of contact, similar to the attack observed on the panels in the Helgoland test. The area of contact between the aluminium and washer was free of corrosion.

It is noteworthy that aluminium is essentially compatible with stainless steels but incompatible with unalloyed steels. Considering the electrochemical potentials in seawater for the materials in question, different behaviour would be expected. The potential difference between aluminium and stainless steels is in fact much larger than that between aluminium and carbon steels (Table 2).

There are numerous other examples of successful structures mixing aluminium with steel components and fasteners. The stainless steel screws on the NSB II have already been mentioned. The four aluminium telescopic gangways show the effectiveness of targeted anti-corrosion measures. At the galvanised and painted steel joints, the different metals were mostly isolated with neoprene seals, so no galvanic corrosion could occur (Figure 7). Such seals also prevented direct contact with stainless steel screws (Figure 8).

Coated aluminium

In contrast to steel, the organic coating of aluminium materials in the marine sector is less suitable for corrosion protection than for decorative appearance [4] [7].

Table 3: Corrosion protection measures for aluminium in the marine environment

<table>
<thead>
<tr>
<th>ZONE</th>
<th>NO PROTECTION</th>
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<tr>
<td>above sea level</td>
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<td>coating + anodes</td>
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Table 2: Practical potentials of different metals in seawater (values versus saturated calomel electrode), following [5]

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>POTENTIAL [V]</th>
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<tbody>
<tr>
<td>Stainless steel type 316</td>
<td>from +0.00 to -0.15</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>from -0.60 to -0.70</td>
</tr>
<tr>
<td>Aluminium alloys for marine applic</td>
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Figure 7: No galvanic corrosion between aluminium and galvanised steel

Figure 8: Seals prevent direct contact with stainless steel screws

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Sometimes a signalling effect may be the purpose of a coating, as in the NSB II’s bright yellow measuring container (Figure 2). A well-executed protective coating, though rarely necessary, provides effective corrosion protection. It is included with other possible corrosion-protection measures in Table 3. When painting aluminium structures, pre-treating the surface is essential. In addition to degreasing, the oxide layer has to be removed either chemically (pickling) or mechanically (sanding, sweeping or grinding) prior to coating [6, 7]. This is the only way to permanently prevent paint delamination in a marine environment.

Good adhesion to a pre-treated metal face is essential. In addition to other possible corrosion-protection measures in Table 3. Pre-treatment of the aluminium surface is required. The concept involves chemically etching the surface and subsequent passivation by a conversion layer (Cr VI, Cr III or Cr-free) or pre-anodisation.

The two coating concepts are compared in Table 4. Experience has shown the concept recommended by GSB to make better use of aluminium’s potential since the corrosion resistance of coated surfaces is promoted more by the surface pre-treatment than by the coating. However, the necessary chemical conversion requires a bath treatment, which must be integrated into the production process of an aluminium construction. Delamination of coated aluminium is more of a cosmetic problem. The typical filiform corrosion – starting from cut edges or paint defects – is a near-surface phenomenon and does not affect the load-bearing capacity of a part.

To protect coated surfaces in a submerged zone, galvanic anodes must be used just like for uncoated aluminium. This effectively suppresses the progress of corrosion on damaged parts. Another interesting coating method is the application of corrosion protection films. The Halunder Jet is a 52m-long, all-aluminium catamaran that has been shuttling daily between Hamburg and Helgoland during the summer season for almost ten years. The skin of its hull is not painted, but covered with a surface protection film to give the ship a distinctive design and keep it running.

**Outlook**

Aluminium can often be used in the marine sector without surface coating. In a splash zone, corrosion depth increases very little after three years. Even after many years, it does not exceed 0.5mm in most cases. To preserve aluminium’s natural resistance to corrosion, the following guidelines apply:

- Natural cleaning of the surface by rain is advantageous;
- Permanent moisture in crevices is to be avoided;
- Galvanic contact with carbon steel is to be avoided;
- Galvanic isolation from stainless or galvanised steel is advantageous but not always necessary;
- In a submerged zone, galvanic anodes provide effective protection.

Aluminium has enormous potential in the entire range of offshore applications. Ideally, it can be used in auxiliary structures such as railings, ladders, platforms, stairs, etc. But even large-scale structures are a possible field of application. Given the example of the all-aluminium crew quarters of the major oil and gas production platforms, aluminium could also be a sustainable, cost-effective alternative in transformer and work/living platforms in the offshore wind energy sector.

### Table 4: Coating concepts for aluminium in the marine environment

<table>
<thead>
<tr>
<th>Schematic</th>
<th>NORSOK STANDARD M-501</th>
<th>GSB GUIDELINE AL631</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning</td>
<td>Sweep blasting =&gt; anchor profile 25-45μm</td>
<td>Degreasing with ~1g/m² material removal</td>
</tr>
<tr>
<td>Passivation</td>
<td>Conversion layer &lt; 1g/m² (Cr-VI, Cr-III or Cr-free) pre-anodisation 3-8μm</td>
<td></td>
</tr>
<tr>
<td>Coating</td>
<td>epoxy primer 50μm</td>
<td>one coat topcoat 50μm (wet or powder)</td>
</tr>
<tr>
<td>Total thickness</td>
<td>225μm</td>
<td>75μm</td>
</tr>
</tbody>
</table>

**References**

[8] GSB AL 631, International Quality Regula