→ Seawater resistance of wrought aluminium alloys

1 General

The term 'seawater resistance' comes from the ship-building and marine technology field. Although it is not defined further in any way, it can nevertheless be regarded as a material property. It says that the respective alloy is suitable for use as a constructional material because of its strength, its weldability and the good corrosion behaviour it exhibits in seawater. Seawater resistance does not therefore rule out the occurrence of different types of corrosion. Germanischer Lloyd and DIN 81249-1 use the expression 'suitable for use in seawater', which is nearer to the point and does not imply complete resistance. According to DIN 81249-1, a material is suitable for use in seawater if a component, that is appropriate for the material concerned, is produced from it and is not expected to suffer corrosion damage within the planned life of the component when used in seawater. The wrought alloys suitable for use in seawater, which exhibit good corrosion behaviour, are listed in Table 1.

When choosing the material and the design, the relevant standard, such as EN 1999, EN 13195 and the relevant provisions of the shipbuilding classification societies should be taken into account.

Table 1: Wrought aluminium alloys that according to DIN 81249-1 are suitable for use in marine environments.

EN AW-1080A	[Al 99,8 (A)]
EN AW-1070A	[Al 99,7]
EN AW-1050A	[Al 99,5]* **
EN AW-1200A	[Al 99,0] **
EN AW-3103	[Al Mn1] **
EN AW-3003	[Al Mn1Cu]
EN AW-3105	[Al Mn0,5Mg0,5]
EN AW-3005	[Al Mn1Mg0,5]*
EN AW-3004	[Al Mn1Mg1]
EN AW-5005	[Al Mg1(B)] **
EN AW-5005A	[Al Mg1(C)]
EN AW-5051A	[Al Mg2 (B)]
EN AW-5052	[Al Mg2,5] **
EN AW-5754	[Al Mg3]* **
EN AW-5154	[Al Mg 3,5] **
EN AW-5082	[Al Mg4,5]*
EN AW-5019	[Al Mg5]
EN AW-5251	[Al Mg2] **
EN AW-5049	[Al Mg2Mn0,8]*
EN AW-5059	[Al Mg5,5MnZnZr]
EN AW-5454	[Al Mg3Mn]* **
EN AW 5456	[Al Mg5Mn1] **
EN AW-5086	[Al Mg4] **
EN AW-5083	[Al Mg4,5Mn0,7]*
EN AW-5383	Al Mg4,5Mn0,7] **
EN AW-5182	[Al Mg4,5Mn0,4]
EN AW 6005	[Al SiMg] **
EN AW-6060	[Al MgSi]* **
EN AW-6063	[Al Mg0,7Si] **
EN AW-6106	[Al MgSiMn] **
EN AW-6005A	[Al SiMg(A)]* **
EN AW-6082	[Al Si1MgMn]* **
EN AW-6061	[Al Mg1SiCu]*
EN AW-6012	[Al MgSi1Pb]
EN AW-7020	[Al Zn4,5Mg1]* ***

* Alloys that are used preferentially in marine environments
** Wrought alloys for shipbuilding, marine and off-shore applications according to EN 13195
*** Only in 'quenched and artificially aged' temper

2 Corrosion behaviour of aluminium alloys in seawater and marine atmospheres

Corrosion behaviour, corrosion rate and the occurrence of the different types of corrosion depend on the material and its temper, the design and the operating conditions. With the operating conditions one has to determine whether the component will be used in the immersion zone, the tidal zone, the splash zone or in the marine atmosphere. In addition, movement and temperature are factors that have an important influence.

The following types of corrosion mainly occur:

- uniform corrosion
- formation of shallow craters
- pitting
- crevice corrosion
- intergranular corrosion

No further consideration will be given here to uniform corrosion because it is only of minor importance as a result of passivation of the surface due to formation of an oxide film.

2.1 Formation of pits and craters

2.1.1 Marine atmosphere

Corrosion with the formation of pits and shallow craters occurs in the alloys listed in Table 1. The depth of attack grows relatively quickly in the first two years but undergoes little further growth in the subsequent years, and is limited to a few tenths of a millimetre. If there are no decorative demands placed on a component, corrosion protection is not usually necessary. The appearance of the metal surface can become pockmarked as a result of adherent corrosion products.

2.1.2 Seawater

The Al, AlMg and AlMgMn type alloys listed in Table 1 are regarded as being particularly corrosion resistant alloys. The corrosion behaviour of the age-hardenable AlMgSi alloys listed is good in marine environments. These alloys exhibit better corrosion behaviour in the naturally aged temper. In the artificially aged temper, the Al Zn4,5Mn1 alloy exhibits satisfactory corrosion behaviour. It should therefore only be used in this temper.

Under conditions of permanent immersion, extensive fouling occurs. Below this there is uniform corrosion, but this can differ very markedly depending on the conditions (e.g. high oxygen content in the North Sea, lower oxygen content in the Persian Gulf).

There is considerable scatter in the growth rates for the depths of pits and shallow craters in the immersion zone for the alloys listed in Table 1. Reference values are given in Table 2.

Table 2: Growth rates for depths of pits and shallow craters [2]

Alloy type / alloy	Depth growth rate mm/a
Al	0.0025 to 0.75
AlMg, AlMn, AlMgMn	0.03 to 1.0
AlMgSi	0.05 to 0.1
Al Zn4,5Mg1	0.02 to 1.2

The extent and depth of the corrosive attack in the form of pits and craters depend on the duration of the exposure and the actual value of the corrosion potential with respect to the pitting potential. Other influencing factors are aeration and other oxidising agents, such as heavy-metal salts, and the flow rate.

Components used in the immersion zone can also be protected effectively against pitting or shallow-crater formation by use of cathodic protection, which means use of galvanic anodes or impressed currents.

In the tidal zone, it is recommended to use an organic coating for corrosion protection. In addition, cathodic corrosion protection can be used.

If components are only used in the spray zone, it is possible under certain conditions to forego additional corrosion protection if there are no decorative requirements (see also 2.1.1).

2.2 Crevice corrosion

Design-related crevices and screw holes are a critical aspect and, if possible, should be sealed. Crevices smaller than 0.5 mm are particularly effective as corrosion sites because they draw in aqueous media by means of a capillary action, and this leads to crevice corrosion because of the formation of a differential aeration cell. Crevice corrosion occurs between two metal surfaces or between metal and non-metal surfaces. Crevice corrosion can also lead to corrosion under gaskets. With proper processing it is possible to avoid crevices that give rise to crevice corrosion.

2.3 Intergranular corrosion

In wrought alloys of the EN AW-5XXX series with a magnesium content greater than 3 %, intergranular corrosion can occur if the microstructure is sensitised.

3 Further reading and standards

[1] Germanischer Lloyd, Rules & Guidelines, II Materials and Welding, Part 1 Metallic Materials, Hamburg, 2009

[2] DIN 81249 Corrosion of metals in sea water and sea atmosphere
Part 1: Definitions, basic information
Part 2: Free corrosion in sea water
Part 3: Galvanic corrosion in sea water
Part 4: Corrosion in sea atmosphere
November 1997

[3] EN 13195 Aluminium and aluminium alloys - Wrought and cast products for marine applications (shipbuilding, marine and offshore) - Part 1: Specifications (German version: 2013-12)

[4] EN 1999 Eurocode 9: Design of aluminium structures
Part 1-1 General structural rules, 2014-03
Part 1-2 Structural fire design, 2010-12
Part 1-3 Structures susceptible to fatigue, 2011-11
Part 1-4 Cold-formed structural sheeting, 2010-05
Part 1-5 Shell structures, 2017-03

[5] EN 1090 Execution of steel structures and aluminium structures
Part 1: Requirements for conformity assessment of structural components, 2008-09
Part 3: Technical requirements for aluminium structures, 2008-09

[6] H. Meißner. Sea-water in situ experiments using aluminium materials in the Arabian Gulf. *Aluminium Supplement in English* 61 (1985) (2) E114-E116.

[7] W. Huppatz, D. Wieser: Electrochemical behaviour of aluminium and possibilities of practical corrosion protection. *Werkstoffe und Korrosion* 40 (1989) 57-62 (in German).

[8] W. Huppatz:. Cathodic protection and corrosion protection by anodic oxide coatings for aluminium materials in seawater. *Werkstoffe und Korrosion* 38 (1987) 627-629 (in German).

[9] V. Brücken, H. Dahmen, W. Huppatz, L. Knutsson, H. Meißner and F.J. Reker: Aluminium in seawater. *Aluminium* 63 (1987) 1139-1150 (in German).

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