

Results from Field Testing of Aluminium Extrusions on a Truck for Six Years. Comparisons with Accelerated Corrosion Testing.

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In order to study various functional properties of Aluminium extrusions a handful alloys have been produced and extruded for subsequent testing, including corrosion testing. Specimens were exposed to accelerated laboratory corrosion tests, such as SWAAT (Sea Water Artificial Acidified Test), VDA cyclic test (VDA = Verband Der Automobilindustrie) and IGC (Inter Granular Corrosion test). In order to compare the results from these accelerated corrosion tests with corrosion behavior in a real life exposure, similar specimens were mounted on a trailer travelling a distance of more than 612 830 km for up to 6 years. For the 6xxx-alloys it is a very clear resemblance of the corrosion mode for field tested- and IGC tested materials, being strongly dependent on the grain structure towards the surface. The field test also seems to give a fairly good ranking of the corrosion resistance of the 6xxx-alloys compared with both SWAAT and VDA-testing of the same alloys with respect to weight loss measurements.

Keywords: *Corrosion, Field test, Accelerated test, Microstructure.*

1. Introduction

Several accelerated corrosion tests for Aluminium alloys exist, designed to simulate the effects of various environmental conditions. They may vary from relative short time exposure in tough, cycling environments to longer exposure times under more gentle conditions. The corrosion behavior in a specific atmosphere and environment will also be a function of the alloy chemistry, microstructure, surface treatment etc. and the tests may tell something about the relative corrosion resistance of different alloys. There may however be of great interest to compare the results from accelerated tests with long time field tests. In a previous work [1], powder coated AA6xxx Aluminium extrusions were exposed outdoors in an industrial/marine atmosphere for ten years and it was found that these specimens showed some deviating behavior compared with results from corresponding accelerated corrosion tests.

2. Materials and Experimental Procedure

A number of 19 different extruded profiles of several 6xxx- and 7xxx alloys were collected for field test on a truck. The profiles were all in (or close to) a peak aged temper. In Table 1, the chemical composition of the alloys is summarized. The numbers are mostly average values of 4 sparks by optical emission spectrograph on the profile surfaces. Some of the alloys were previously tested in different accelerated corrosion tests, although not always at the same time or in the same tests.

Two racks were made in order to have two equal sets of specimens mounted on different places on the vehicle. Specimens with dimensions of approximately 10 cm along the extrusion direction and 7 cm in width were cut off from the profiles. Two holes, each Ø12 mm, were drilled in all specimens in order to fasten them along continuous screws isolated in rubber tubing with the same diameter as the holes. All specimens were degreased with acetone, weighed and their dimensions measured. The specimens were firmly mounted with the extrusion direction vertical and all specimens were separated approximately 15 mm by distance pieces of plastic with outer diameter Ø22,5 mm, around the rubber tubing. Each rack was filled with 24 specimens, where alloy 6xxx-A acted as a reference material on both sides- and on 4 places in between the other specimens.

Table 1. Alloy chemistry. Average values of 4 sparks on profile surfaces on alloy 6xxx-A to L.

Alloy	Fe	Si	Mg	Mn	Cr	Zn	Cu	Ti	V	Ni	Zr	Ga
6xxx-A	0,20	0,43	0,51	0,02	0,00	0,01	0,01	0,01	0,01	0,00	0,00	0,01
6xxx-B	0,19	0,51	0,64	0,01	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,01
6xxx-C	0,22	0,97	0,80	0,55	0,15	0,01	0,10	0,01	0,00	0,00	0,00	0,01
6xxx-D	0,19	0,42	0,48	0,02	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,01
6xxx-E	0,19	0,62	0,46	0,19	0,00	0,03	0,16	0,02	0,01	0,00	0,00	0,01
6xxx-F	0,19	0,59	0,85	0,05	0,02	0,01	0,22	0,01	0,01	0,00	0,00	0,01
6xxx-G	0,19	0,51	0,42	0,02	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,01
6xxx-H	0,19	0,50	0,41	0,02	0,00	0,01	0,00	0,01	0,12	0,00	0,00	0,01
6xxx-I	0,20	0,87	0,82	0,22	0,00	0,01	0,03	0,01	0,01	0,00	0,00	0,01
6xxx-J	0,19	0,67	0,79	0,01	0,08	0,01	0,10	0,03	0,00	0,00	0,00	0,01
6xxx-K	0,20	0,63	0,56	0,17	0,00	0,01	0,14	0,01	0,01	0,00	0,00	0,01
6xxx-L	0,18	0,99	0,64	0,51	0,00	0,02	0,00	0,01	0,01	0,00	0,00	0,01
6xxx-M	0,23	0,78	0,52	0,16	0,00	0,31	0,79	0,02	0,01	0,01	0,00	0,01
6xxx-N	0,23	0,77	0,51	0,16	0,00	0,00	0,77	0,02	0,01	0,01	0,00	0,01
7xxx-A	0,17	0,08	1,21			6,53	0,02				0,17	
7xxx-B	0,17	0,09	0,65			5,53	0,04				0,16	
7xxx-C	0,13	0,04	0,87			5,69	0,03				0,16	
7xxx-D	0,12	0,04	2,26			6,05	2,45				0,15	
7xxx-E	0,16	0,08	1,18			5,41	0,01				0,16	

One rack was mounted on the top of the girder between the vehicles and the other into an empty rack for a spare wheel underneath the truck. The 7xxx-alloys in aged temper were mounted in the racks about 5 months later. After a total exposure time of the racks for about 2,5 years the rack mounted on the top of the girder between the vehicles was dismantled and the specimens inspected. The second rack was dismantled after a total exposure time of about 6 years. During this time the truck had been travelling 612 830 km between western part of mid-Norway to the south and east of Norway as well as to Sweden. This involves much road-salting in the wintertime. Several car washes were also included.

The specimens were thoroughly cleaned and dried before measuring the weight in as-corroded condition. The corrosion products were chemically removed by immersing in 1000 ml solutions consisting of 50 ml phosphoric acid (H_3PO_4), 20 g chromium trioxide (CrO_3) and de-ionized water at 80°C for 15 minutes following by immersing in Nitric acid (HNO_3) at room temperature for 2-5 minutes, according to ASTM-G1 [2]. There is a risk that some of the Aluminium surface also will be removed during this treatment.

3. Experimental results

In the present work it was observed an almost proportional relation between weight gain and weight loss before and after removing the corrosion products.

3.1 Weight loss

The total weight loss of each specimen, after removing the corrosion products are shown in Figure 1. The calculations are based on total weight loss of the specimens divided by the area of only one side of the specimens, which is sometimes used when there is different degree of corrosion on the two sides. The weight loss measurements have been accompanied with surface examinations and metallographic examinations of cross sections of the specimens in the rack exposed for the longest time.

3.2 Surface Appearance

After removing the corrosion products, the specimen surfaces were examined in stereo microscope as well as in optical light microscope.

It was observed some crevice corrosion around the drilled holes where the distance pieces of plastic around the rubber tubing were placed. Most crevice corrosion was found on alloy 6xxx-C, E,

F, I, J, K, M, N (high Cu, except I) and all the 7xxx alloys. This localized corrosion will contribute to the total weight loss of the specimens.

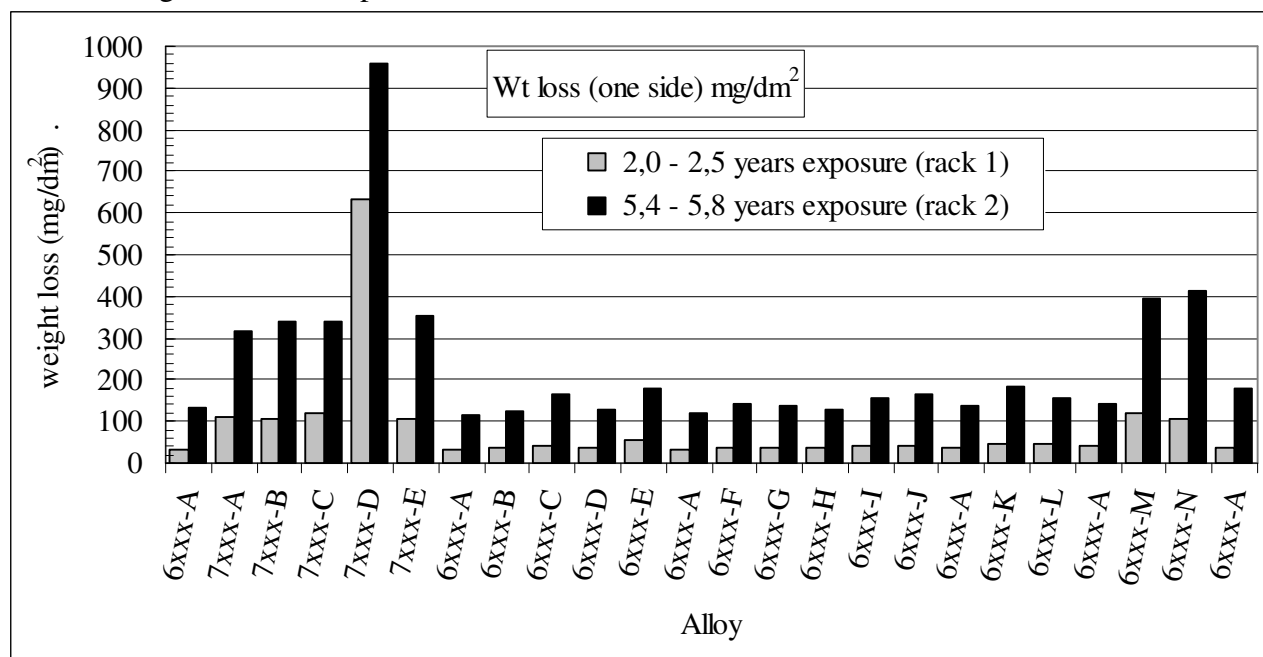


Fig.1. Total weight loss after removing the corrosion products on Aluminium specimens. The 7xxx-alloys were exposed about 5 months less than the 6xxx alloys. The figure also shows the relative positions of the specimens in the racks. Alloy 6xxx-A is used in 6 different positions. For the rack with the longest exposure time (i.e. underneath the trailer) the driving direction is towards left in the figure.

In general only minor corrosion was observed on the edges of the specimens.

The corrosion appearance in the central area some millimeters away from the edges was in principle the same on the two sides of each specimen and is summarized in Table 2 together with results from the metallographic examinations. Full descriptions of the corroded surfaces are difficult to define in all details.

3.3 Examination of microstructure and corrosion modes

Cross sections, 45° to the extrusion direction were made on all specimens in order to reveal both the microstructure and corrosion attack mode. Some examples are shown in Figures 2-7.

Several forms of corrosion are observed. A recrystallised top surface layer with grain boundaries almost perpendicular towards the surface seems to be subjected to intercrystalline corrosion down to the underlying structure with stronger texture, as seen in Figures 2, 4 and 7. With no surface grains the corrosion takes form of pitting as shown in Figures 3 and 6. In some cases (Figure 5) a special mode of corrosion takes place underneath the top surface grain. This is sometimes observed together with blisters and may possibly be defined as exfoliation corrosion. When intercrystalline corrosion takes place, it is sometimes observed that whole grains have fallen out.

Table 2. Corrosion appearance in the central area of the corroded surfaces, some millimeter away from the edges.

General description of "central" area of corroded specimen surfaces.	Alloy
Some small- and some larger localized attacks along grain boundaries.	6xxx-A, B, D, E, F, G, H, I, J, K, L
Many small- and some larger localized pits.	6xxx-C
Grain boundary attacks. Some minor exfoliation. Discoloured surface.	6xxx-M, N
Areas with interconnected corrosion. Grain boundary attacks of top layer.	7xxx-A, E
Attacks on- and underneath surface grains. Some blistering on C.	7xxx-B, C
Discoloured surface. Whole surface corroded. General/superficial corrosion. Pits.	7xxx-D

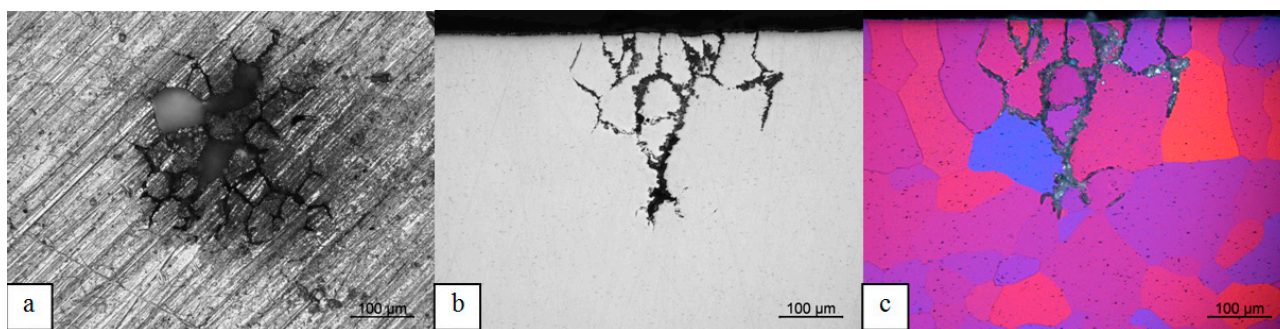


Fig.2. Alloy 6xxx-A. a) Surface view, b) and c) cross section of same area. Intergranular corrosion. All micrographs with same magnification.

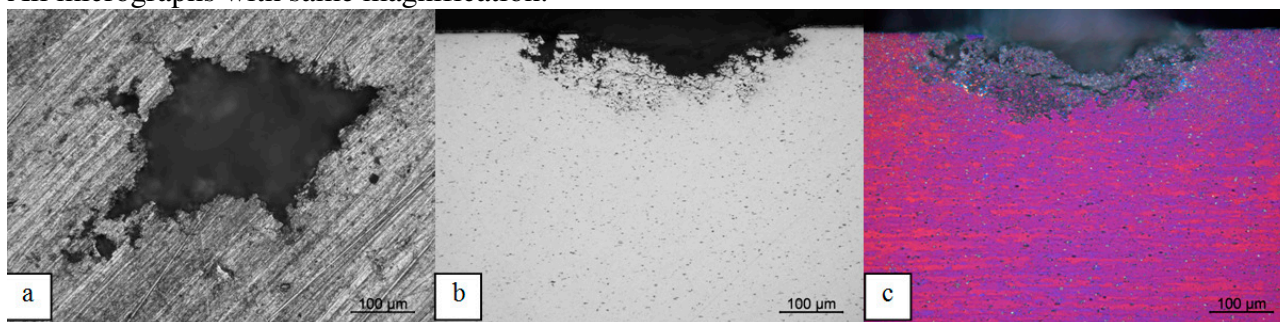


Fig.3. Alloy 6xxx-C. a) Surface view, b) and c) cross section of same area. Pitting corrosion. All micrographs with same magnification.

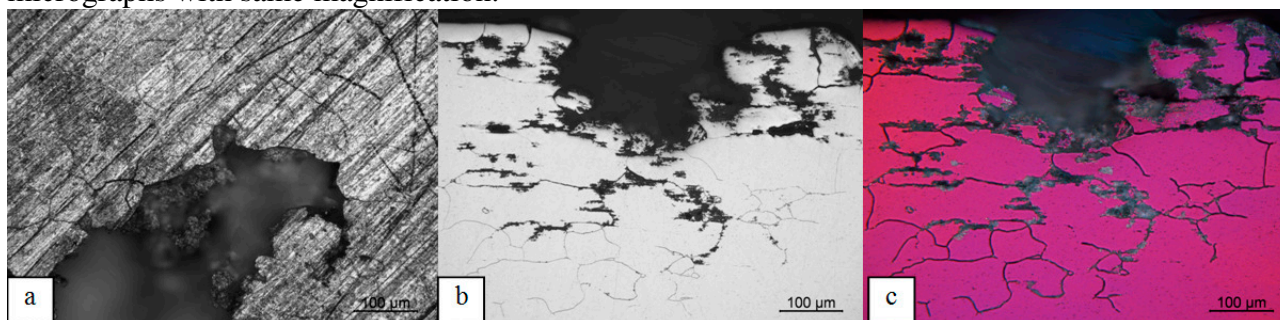


Fig.4. Alloy 6xxx-M. a) Surface view, b) and c) cross section of same area. Strong intergranular corrosion (grain structure not well shown here). All micrographs with same magnification.

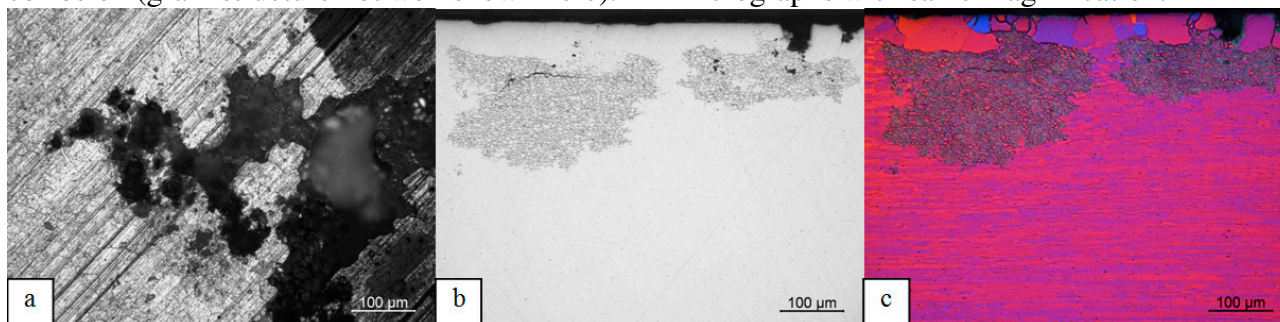


Fig.5. Alloy 7xxx-C. a) Surface view, b) and c) cross section of same area. Intergranular corrosion of top surface layer and exfoliation corrosion. Same as 7xxx-B without any observed exfoliation. All micrographs have equal magnification.

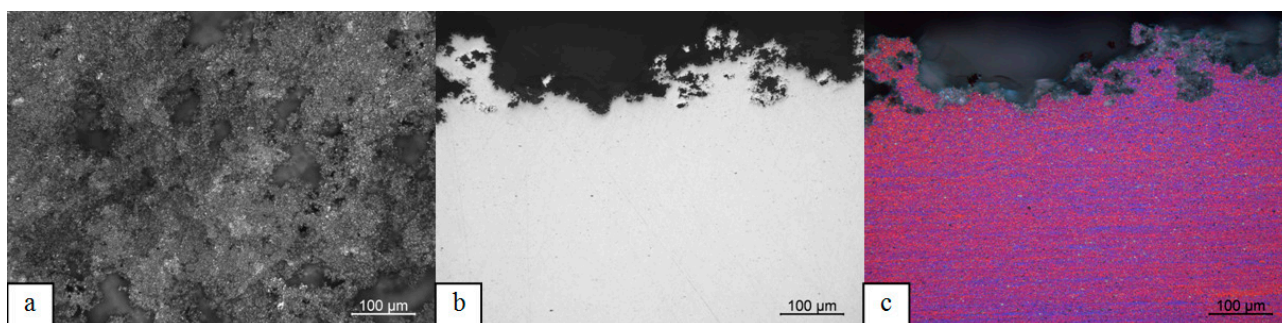


Fig.6. Alloy 7xxx-D. a) Surface view, b) and c) cross section of same area. General/superficial corrosion. All micrographs with same magnification.

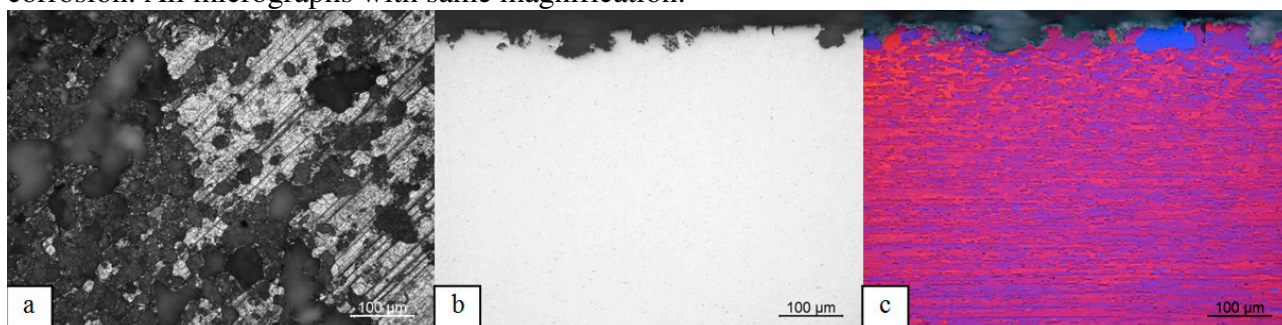


Fig.7. Alloy 7xxx-E. a) Surface view, b) and c) cross section of same area. Intergranular corrosion of top layer. All micrographs with same magnification.

3.4 Results from Previous Accelerated Tests

The same 7xxx-alloys (identical chemistry) have been tested in SWAAT (Sea Water Artificial Acidified Test), according to ASTM G 85 - 94 Annex A3. The electrolyte is synthetic sea water, acidified with acetic acid to pH 2.8-3.0. The test cycle is 30 min. spray followed by 90 min. soak at above 98 % relative humidity and the exposure temperature is 49°C. The samples were exposed inclined 15° from the vertical, with the extrusion lines vertically. The weight loss after 1000 hours of exposure was calculated to be between 4000 to 6500 mg/dm² with alloy 7xxx-B having the highest weight loss and 7xxx-E the lowest. SWAAT test clearly is a very tough test for 7xxx alloys and gives severe pitting. It is also large- and varying differences of the degree of corrosion on the two sides of the specimens.

In previously intercrystalline corrosion tests (IGC) performed according to ASTM G110, which includes an etching step and immersion in an electrolyte for 48 hours, it was observed very similar corrosion modes as observed in this investigation for all the different 6xxx alloys, although no weight loss measurements were performed.

Some of the 6xxx-alloys have previously also been tested in both SWAAT and VDA (a cyclic test) and the weight loss from these tests are compared with the results from the field test in Figure 8. The order of the alloys is set with increasing Cu-content. From the figure it is clear that the SWAAT test give a much larger variation in corrosion response for the different alloys than both the VDA- and field tests show. The SWAAT test mainly generates heavy pitting corrosion and may be useful for ranking the corrosion performance in such environments. However, there seems to be some correlation between the weight losses of the specimens in these three tests. The corrosion of the field tested specimens is almost equal on both sides of each specimen and the weight loss could therefore as well be divided by the total area.

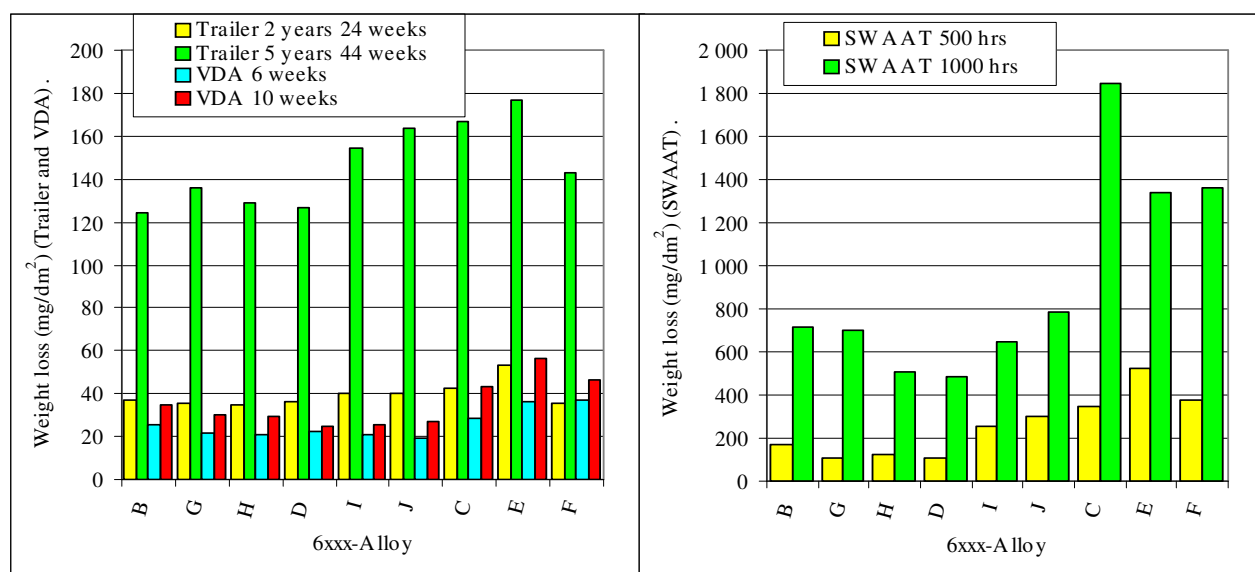


Fig.8. Weight loss of specimens exposed in field test, VDA (fig to the right) and SWAAT (fig to the left), for different periods. All numbers are based on the area of one side of the specimens.

4. Discussion

It is clear that the position of the specimens in the racks is not influencing the corrosion behavior, as the reference material is almost equally corroded on all positions.

Weight loss measurements alone only give some indications of the relative corrosion resistance of alloys. A high weight loss may be due to a general surface corrosion that might be much less severe than deep locally attacks in a specimen with lower weight loss. Heavy intercrystalline corrosion may cause removal of surface grains and will also lead to a higher weight loss. A tendency to increasing weight loss with increasing Cu in the alloys is observed and may be due to increased tendency to IGC due to noble grain boundary precipitates [3].

5. Conclusion

For the 6xxx-alloys it is a very clear resemblance of the corrosion mode for field tested- and IGC tested materials, being strongly dependent on the grain structure towards the surface. The field test also seems to give a fairly good ranking of the corrosion resistance of the 6xxx-alloys compared with both SWAAT and VDA-testing of the same alloys.

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