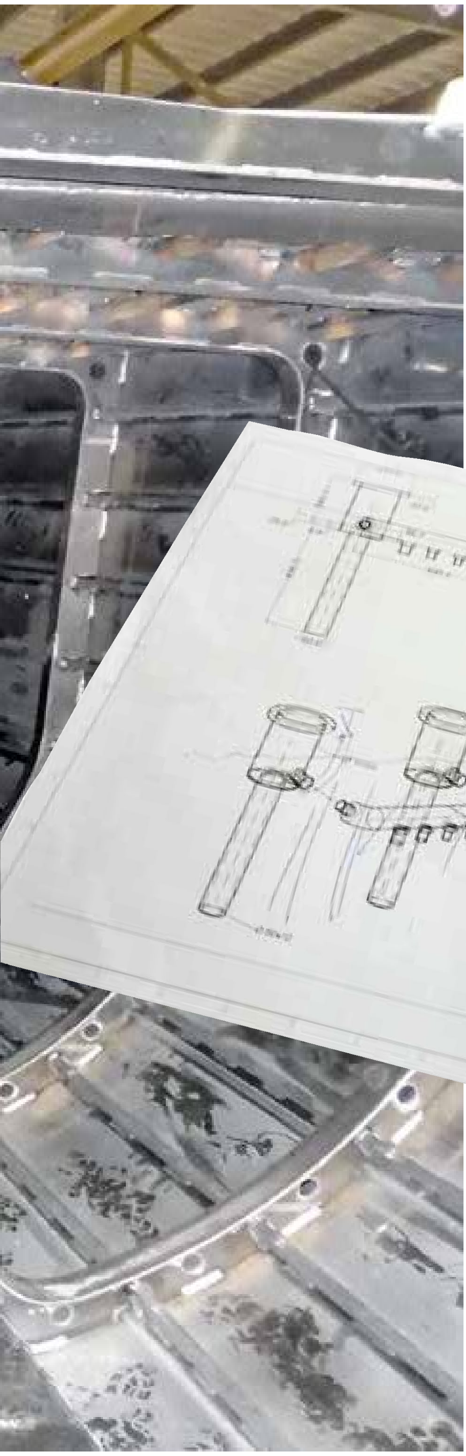
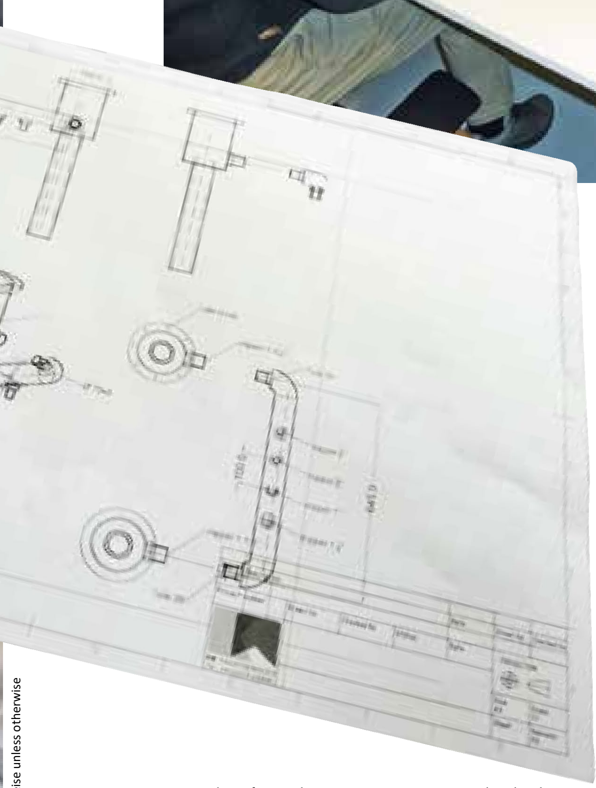
Solid and safe

Typical long-distance vessels are often made of aluminium and are designed for the high seas, the tropics or the Arctic Ocean. Many of these yachts are sailed for tens of thousands of miles and their structure is usually as firm as on the first day, even after hard continuous use. Why are they particularly suitable for these extreme applications? How are they built, and what do old models look like? Ralf Weise gives us some insights.





Large photo: The impressive interior of a 53-foot Berckemeyer Design aluminium hull under construction. The large number of welding seams gives an idea of how complex the production process is.

Above: A KM naval engineer at the computer in the boatyard's construction office.

Right: Detailed drawings for the boat workers in the workshop.

Photos by Ralf Weise unless otherwise

Yachts made of aluminium have gained in popularity in recent years. They have largely replaced steel as a building material. Steel hulls are only occasionally built, for example for flat-bottom vessels. Especially the Dutch, traditionally very fond of metal boat building, have turned towards modern sailing yachts and are building vessels of modern construction which do not have to take second place to FRP cruisers when it comes to speed and manoeuvrability combined with comfort. They also have some further advantages.

Pros and cons

- They are solidly built; in the event of a collision, the elastic material will dent but not tear.
- They are generally well insulated and are suitable both for the tropics and for colder regions.
- The material wears more slowly, partly because it does not absorb moisture.
- The electrical conductivity makes the yacht desensitised to lightning.
- In addition, there are some strength-relevant aspects that already play a role when the boat is being constructed.

Disadvantages

- On the one hand, there is the environmental aspect – see also our box on ecological aspects.
- The problem of galvanic and electrolytic corrosion.
- The poor durability of paint applied to the surface.
- Not least the high price, especially compared to a series-production boat made of FRP.

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The boatyard receives ready-cut panels and components.

Each individual component is unambiguously labelled.

The components are shaped using a hydraulic ram.

Construction

We visited two producers and looked over their shoulders at their work.
The smaller business, the Benjamins boatyard in Emden, is an experienced aluminium constructor which is currently building a boat for itself and which produces about four hulls a year; the other is KM Yachtbuilders in the Netherlands, which produces completely sail-ready yachts. There were striking similarities between the two boatyards. We have generalised this here as a generally valid representation of the state of aluminium boat building. Of course, there are also slight differences in the details, but to discuss them would go beyond the scope of this article. If a yacht is to be produced, its construction must first be designed. A design office is commissioned to deliver a set of blueprints to the boatyard, with the aid of which the yacht yard could build the boat. However, a number of details still have to be agreed beforehand, because the experience and production methods of the boatyard are not included in the data set that comes from the computer.
This data is fed in in order to create drawings or templates, which are then implemented for the boat workers and which help to make production as safe and efficient as possible. Thus, the boatyard's own design office is basically occupied throughout the entire construction process with specifying and accompanying the construction process on the basis of the first drawings.
When the construction of the boat begins, the computer will generate an implementation from the outer shell and provide the dimensions of the outer shell plates, bulkheads and other components, which serves as a basis for controlling cutting devices. The cutting is carried out either with a laser, by water jet, with plasma cutters or with a milling cutter in external industrial plants. The high costs of a modern cutting system would be unprofitable for smaller artisanal boatyard. The finished plates and also thicker components such as chainplates or mounts and individual parts such as whole or partial bulkheads or tank caps are then supplied. The well-labelled parts are allocated on pallets to the ship to be built.
Then bulkhead frames are built. They consist of the side frames, the deck beam, the knees in between and the floor timber. The curved parts of the frame bulkhead are previously pressed into shape by hand with a press.
Relief holes or cut-outs for stringers are already incorporated in the plate blank; the chording of the ribs or stringers is already contained in the profile or, in the case of timbers, may be incorporated at the boatyard using a cantilever bench.
The boat is initially built overhead. In this case, a framework of frames and bulkheads is placed on a kind of slipway and aligned with the aid of lasers. The stringers are then welded onto this frame construction. They can be cut relatively easily with a cross-cut or circular saw and a special saw blade. Based on the uniform stringer course, an experienced boat builder will immediately recognise whether the lines are taut, i.e. show uniform curvature. If this is not the case, a frame may be set incorrectly or not

Aluminium cutting of flat material is done with a circular saw.

Cutting a profile to length with the cross-cut saw.

Right: The strong frames with strapping and relief holes.

precisely aligned. In most cases, it is possible to compensate for relatively small errors by means of readjustment. In the worst case, a weld seam is taken apart again, and the component is correctly pressed and re-welded. Such work occurs when a yacht type is built for the first time; with a series boat, the exact alignment usually works at the first attempt.

Then the hull is plated. The material for this as delivered was perfectly tailored, but in the case of a round shredder the rounding must still be formed, both lengthwise and transversely. This is done with rollers through which the plates are pushed. Forming can also be carried out with a hydraulic ram, and a simple rubber hammer can sometimes help with fine work.

The plates are placed on the framework and initially fixed with short weld seams. For each plate, the exact fit is checked. If it does not fit, then the rounding may have to be pressed again. If all the plates fit, the hull is welded.

Weldability

As simple as aluminium is to process compared to steel, it is difficult to weld. Depending on the alloy constituents, aluminium alloys have a melting temperature of approximately 650 degrees. Steel has a melting temperature of around 1,400 degrees, also depending on the alloy.

The transition from the solid to the liquid state does not take place smoothly with aluminium, unlike with steel, which first glows dark red, then in light red, and then drips off. In the case of aluminium, the transition is abrupt. Welders only recognise the melting point after a lot of practice. For welding, the two adjoining material parts as well as the weld metal must be fused together at as close to the same temperature as possible. If the metal is too hot, it drips away; if it is too cold, no permanent connection is created. Therefore, the welding work is carried out by well-trained personnel with as much experience as possible. The other difficulty is that metals expand during heating, including aluminium, which does so twice as much as steel. This leads to what is known as welding distortion. Two closely juxtaposed plates, which are welded together, expand. Not evenly, because a weld seam is drawn slowly. The material has to go somewhere and, since the sides are blocked by adjoining material, it presses upwards. During the subsequent cooling, it contracts again and wants to escape downwards. Therefore, welding must be carried out in such a way that the introduction of heat takes place in a precisely metered manner. This is done in small “pilger” steps. Beads of approximately ten centimetres are welded, then there is an interruption of ten centimetres, and then the work on the previous weld seam is continued. In some places, studs over the plate joint also help to keep the plates aligned with one another and to keep the metal sheet straight as it becomes hot. Welding is always done between the studs. If these are knocked off, the intermediate space is welded. For finishing, the outer shell with the weld beads on its surface must be sanded, so

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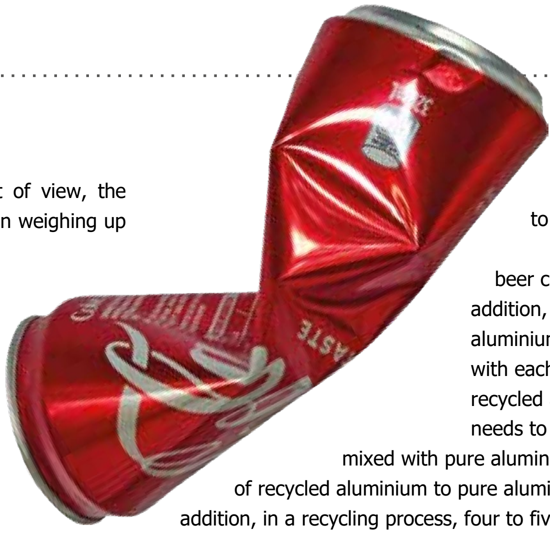
The deck knee with its relief hole is integrated into the bulkhead frame.

The floor timbers also have relief holes and welding holes.

A roller is used to form the outer shell plates in a controlled manner.



Ecological aspects

As attractive as aluminium is from a technical point of view, the ecological aspect must also be taken into account when weighing up the advantages and disadvantages.

CO₂ balance: About 17 tonnes of CO_2 are emitted in Central Europe for the production of one tonne of aluminium. For aluminium produced in China, the figure is 25 tonnes. If the energy is produced mainly from hydropower, as in the case of production in Norway, the emission drops to 7 tonnes. By way of comparison, The much-maligned steel industry emits about 1.5 tonnes of CO_2 per tonne of steel. The bad reputation is solely due to the large quantity of 45 million tonnes of steel produced annually in Germany.

And how does it compare to laminating resin? For one tonne of epoxy resin, around 9.5 tonnes of CO_2 are produced – with the modern green resins, only half as much. If natural fibres are used as reinforcing material, this part of the composite material is almost carbon-neutral. For carbon fibres, the balance rises by 22 to 31 tonnes of CO_2 per tonne. One tonne of polyester resin emits 2.3 tonnes of CO_2. The installed weight must be taken into account in this very rough calculation.

As a rough indication: The production of a boat structure requires twice the aluminium weight in the case of steel and half the aluminium weight in the case of lightweight construction using epoxy resin.

Recycling: Here, too, aluminium is not as advantageous as was initially assumed. This is primarily due to the fact that many different aluminium alloys are used. Seawater-resistant aluminium is particularly high-quality, while the sheet metal of a beer can is inferior. It is therefore impossible to build ships or aircraft from recycled beverage cans, while, in reverse production only works to a limited extent, because the material for beer cans must be food-safe. In addition, the quality of the aluminium decreases considerably with each recycling step, and the recycled aluminium repeatedly needs to be mixed with pure aluminium. Thus, the proportion of recycled aluminium to pure aluminium is only a quarter. In addition, in a recycling process, four to five per cent of the material is lost through oxidation, and in the case of particularly sensitive alloys even up to 25 per cent.

Overall, it is better for steel to be reused (unless it has already rusted away).

Plastic scores the worst in comparison. Here it is customary to use the shredded material as an additive in road surfacing or to add it in the production of cement. Depending on the calculation method used, cement production is responsible for 4 to 8 per cent or 2.8 gigatonnes of global CO_2 emissions and thus consumes more than worldwide air traffic. With the new resins and natural fibres, however, recycling will change for the better in the next few years.

Production: For aluminium, the production is often outsourced. In addition to the high energy consumption, a lot of water and land is consumed. A large part of the bauxite is mined in the tropics, and for this forests are often cleared. In the further recovery process, among other things, highly toxic red mud is produced, which is stored in special tanks. Up to 6.2 tonnes of red mud are produced when one tonne of aluminium is extracted.

At the stapling points it can be seen where the studs were fastened to align the plates and keep them straight.

After sanded, the weld seam and the stapling points are no longer visible.

All seams are sanded in between before welding continues in “pilger” steps.

a few stapling points more or less are irrelevant. Working carefully in this way will ensure that hardly any levelling, i.e. smoothing out of welding distortion, will be needed.
Another difficulty is that oxidized aluminium is less readily weldable than pure aluminium, since the oxide layer has a melting temperature three times higher. Therefore, the quality is improved if the components to be welded are sanded before welding.

Completion

When the shell is in place, the hull is turned over and further components are installed, such as the mirror and the cockpit. These are followed, in the interior, by smaller parts such as the tanks, the rudder tube, the floor supports, partial bulkheads and the engine bed. All these components are prefabricated. A larger assemblage, such as the aluminium components for the floor, is first spread out on the ground before installation in order to check whether all parts are complete and fit together cleanly. On the deck, too, the fine-tuning now begins, with the installation of the hatch frames and the installation of fairleads and the construction of railing feet and bollards. And now again, the advantage of a metal construction is evident: All the load-bearing elements are firmly attached to the hull and deck and cannot later lead to leakage even under very severe conditions. Then the hull is insulated, either by gluing or injecting the insulation material individually between the frame fields.
As with other construction methods, the installation of the technology now begins: The machinery, cable routing, piping, valves, pumps and hydraulics are installed as far as possible before the furnishing is started.
Finally, the hull is made pretty from the outside. A deck covering is laid, cockpit rings are used, and the yacht is painted or partially painted. As already mentioned, the painting is not so simple, since the oxide layer prevents good adhesion to the substrate and the paint is pressed upwards again. Earlier, etch primer was used for the preparation, but this did not prove successful, as the acid it contained further attacked the metal and thus also prevented the permanent bonding of the coating.

Many boatyards resort to sandblasting, but this is not unproblematic either, among other things because, at the end of the blasting of the entire ship, the area that was first treated is oxidising again. For this reason, some boatyards sand the surfaces shortly before applying the paint in order to keep the distance between oxide removal and coating as small as possible.
For technical reasons, it is not necessary to protect the aluminium above the water level; aesthetic reasons dominate here. In the water line and in the underwater area, however, the material must be protected against corrosion. Here, primers and coatings based on epoxy resin are used, which combine well with the metal and have also proven themselves over the long term.

Two boatyards as examples

Dutch yacht construction has long been characterised by its diversity. Although there are no large-scale boatyards such as Jeanneau or Bavaria, a large number of small family businesses and medium-sized enterprises with up to 20 employees offer a wide range of different types of

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The welding takes place in "pilger" steps to keep the delay within limits.

The "pilger" step procedure can be seen as the welder pauses
in his work.

The re-sanded seam is prepared to weld the next step.

shipbuilding. In particular, the long tradition of metal yacht construction still enjoys great popularity here, so the change from steel to aluminium seems logical.

KM Yachtbuilders

Many of the photos shown here were taken at the Dutch boatyard KM Yachtbuilders in Makkum. This business produces individual builds, but also series ships, also called Semi Custom Designs.

The boatyard is mainly known by the brand name Bestevaer, construction by Dykstra Naval Architects. The Bestevaer 45 is the most frequently produced boat; we reported on it in our boat test in PALSTEK 4-17.

In addition to hull construction, KM is also dedicated to furnishing and completion. We were impressed by the very large, tidy carpentry workshop, where the wooden parts are manufactured using computer-controlled milling machines.

In addition to new builds of 14 to 30 metres in length, the boatyard also deals with the repair, maintenance and restoration of aluminium yachts, including other brands, and sells used Bestevaer yachts.

Benjamins yachtbuilders

In Germany, the small yachtbuilder Benjamins is the leader. The owner, Heiner Uffen, has a lot of experience in yacht building, which can also be seen from his

Completed Bestevaer 45.

It is tried and tested practice not to build the mirror directly together with the hull, but only to assemble it as an entire component and to weld it in a precisely aligned manner.

All individual parts of the floor are spread out on the ground before installation.

boats. He also contributes his expertise to the design, so that the yacht construction can be carried out very efficiently without much reworking. He enjoys working with the design firm Berckemeyer Yachtdesign. Some of these designs are traditional-looking above the water line but modern in the underwater areas, often with variable draught. In addition to a large deck salon, other designs offer plenty of storage space so that you can carry all the things that are common today on long journeys.

However, Benjamins only builds the hulls. The fitting-out is handled by companies in the immediate vicinity in close consultation with the boatyard management and the owner.

Corrosion

Many people are critical of aluminium yachts because galvanic and electrolytic corrosion can be a problem.

Briefly: Galvanic corrosion occurs when two metals with different electrochemical voltages are connected by an electrolyte, in this case seawater. The metal with the lower voltage releases atoms into the electrolyte – it becomes the anode. If

a higher-quality metal is electricity-conductively connected there, then it absorbs atoms and becomes the cathode. Since aluminium has a low voltage, it thus strives to flow to the higher-quality metal such as the propeller or shaft; it releases material which is visible in the form of corrosion and craters. But this only works with the help of an electrolyte. The much-feared copper coin in the bilge does no harm as long as the bilge remains dry and no seawater is added.

If the part of the vessel under water is covered with an unbroken epoxy resin coating, it provides sufficient protection as long as it is undamaged.

In order to direct an electron flow into ordered and controllable paths, sacrificial anodes made of zinc or magnesium are also attached. These metals have even lower valency than aluminium, so that this material instead of the aluminium emits electrons and the aluminium falls out of the voltage series.

If everything is properly set up and maintained, corrosion should not cause a problem. Another point is electrolytic corrosion. This means that a current is applied to the metal from the outside and subsequently aluminium ions can flow in an

electrolyte.

The problem is reduced by careful two-pole routing of the DC network. It should be borne in mind that it will sometimes be difficult to insulate the components. Thus, the shaft system and, in its extension, also the motor must be insulated. Here, the gear cables should not be forgotten: they lead from the metal in the gearbox to the gear and perhaps via a sail drive into the water. Another source of faults is the shore power connection, the protective conductor of which must be connected to the ship for safety reasons; faulty currents can easily be conducted into the hull via the protective conductor. An isolating transformer, which creates galvanic isolation from the land, provides a remedy. My colleague Martin Reincke has provided detailed background knowledge on this subject in PALSTEK. Even the on-board passages are sources of danger, but not if they are made of plastic.

Starting to become outdated

Of course, aluminium ships are also offered on the secondhand boat market, but mostly at selling prices which are significantly higher than those of comparable FRP ships from the same vintages.

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A piece of outer shell and the deck.

A view of how thick the insulation is inside.

The big carpentry workshop at KM Yachtbuilders.

The stern still open before fixing the mirror.

Some facts about materials

Bauxite as a raw material for the extraction of aluminium is predominantly found in the tropics and in the southern hemisphere. The largest producers are Brazil and Australia. Their sedimentary rock contains up to 60 per cent aluminium oxide, which is considered a basic material for aluminium production. In order to obtain pure aluminium, the conversion into sodium aluminium and further into aluminium hydroxide is carried out before it is smelted. While the first steps usually take place in the mining areas, the very energy-intensive smelting takes place in the industrialised countries, including Russia and China.

Pure aluminium is unsuitable for boatbuilding. Therefore, other metals such as manganese (Mn) magnesium (Mg) or silicon (Si) are added in the smelting process in order to achieve an alloy which can be easily formed and welded, which is solid and elastic and has good durability in seawater. The alloy AlMg4.5 Mn, designated EN AW-5083 according to DIN EN 573, is customary for boat hulls.

This alloy is supplied in many different states – for example: annealed, cold-annealed or slightly cold-hardened. These states are denoted by identification numbers such as H11 or H111. The state H111 is a material which is soft and readily formable, as it is used for the plating of rounded hulls. The material is elastic. For example, the elongation at break is 16 per cent, which is less than for shipbuilding steel (20 to 22%), but significantly higher than for plastic

Aluminium must have the right alloys as a sheet material, but also as a profile workpiece, in order to be suitable for boatbuilding.

(2 to 4%). At 2.7, the specific gravity is about one-third that of steel (7.8) and is slightly higher than that of FRP (1.5 to 1.8). A particularly high-quality alloy is the material Alustar (5059), which has tin and zirconium added. It has a higher strength but is particularly expensive, so that it is hardly used in yacht construction.

The high corrosion resistance in the air arises because aluminium forms a thin oxide layer on the surface as soon as it comes into contact with oxygen. This layer protects the material permanently. In masts, this layer is produced artificially by anodisation. It is thicker and therefore more resistant than in the case of pure oxygen oxidation. The advantage of aluminium is that, in contrast to steel, there is no need to apply additional paint to the area above water in order to protect it. However, it also has the disadvantage that paints adhere only very poorly to this oxide layer.

This Judel-Vrolijk design was also built by Benjamins.

Sailors wonder whether an older aluminium ship is worth the money or even represents a risk. The average age of used yachts is usually between 20 and 30 years, an age at which many competing FRP yachts are already struggling with structural fatigue phenomena or osmosis. On an aluminium ship, of course, everything on board ages just as quickly as on ships made of other materials: machinery, rig, sail, technology, furniture and equipment.

The hull, however, has its own peculiarities. First of all, there is the external appearance. While a twenty-year-old plastic yacht usually still has the original gel coat, which, when well polished still has an attractive shine, a paint job on an aluminium yacht will already look heavily worn. Even those who can still make friends with the silvery natural outer shell will certainly find the deck covering or the cockpit paint unattractive. There is not much left of the gloss of the paint here; in some places the paint may dissolve, and the paint is pressed upwards via oxide points. While

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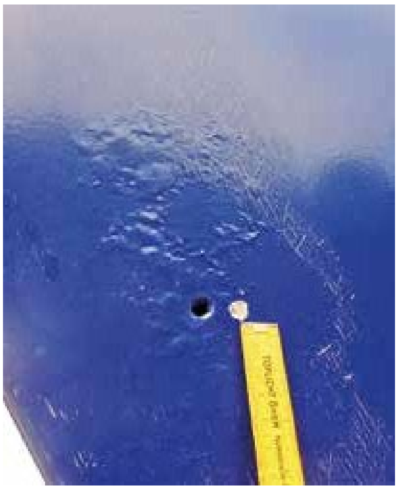
Here, the paint blooms under a railing support made of stainless steel; slight corrosion under the paint would be possible here.



Typical blooming on a painted aluminium yacht, here near the chain case bilge hole. Further checks are essential.

This coating in the water tank must be removed so that any corrosion that may be present underneath it can be detected.

This bubble is evidence of coating detachment. The cause must be checked.

Aluminium oxide blooms beneath the paint, a sign of more serious corrosion damage.

Lead bars were stored in this ballast room. After leakage, considerable pitting corrosion occurred.

gel coat damage on FRP yachts is a serious problem, these impairments are purely visual. The strength is not impaired as a result. However, in the case of paint damage in the vicinity of other metals, usually stainless steel, it can be assumed that the metal under the blooming paint is easily attacked. In most cases, however, the corrosion underneath shows a depth of less than 1 millimetre and is not relevant to strength. However, the part of the vessel under water must be looked at carefully. If the epoxy coating is good everywhere and there are no dents or signs of paint dissolving, then the hull is very likely to be healthy, i.e. there is no corrosion.

If the paint dissolves, a further check is advisable in order to check whether galvanic corrosion is present in the form of pitting. This can only be seen after the dissolved paint has been removed with a sharp tool.

A more detailed test method would be to have an expert examine the hull using ultrasound. This method checks areas the size of the measuring head, i.e. only one area the size of a 10-cent coin per measuring point. Even with 100 measuring points, there is therefore a high chance that a damaged area will be overlooked. Even if an experienced expert already has a good indication of where to measure based on the surface condition, uncertainties remain. The risk of overlooking a spot with pitting is about as high as overlooking a regressed osmosis bubble under a thick layer of paint and antifouling.

The ballast range can also be problematic. In fin keels, the lead is stowed in the aluminium keel and covered from above. A safe method as long as no

water penetrates into this area. If it does, the whole thing can be transformed into a lead-aluminium battery, which can quickly destroy the aluminium. Checking for damage is only possible using ultrasound.
Many aluminium yachts have a variable draught. Here, the ballast is stored in its own containers in the ship's floor. This is also not a problem as long as no water penetrates. If it does, then the galvanic corrosion occurring here is significantly more serious than in the fin keel, since pitting corrosion occurs directly in the ship's floor.
Another critical area is the water tank. In many aluminium boats, it is directly integrated into the structure and not coated. In particular, chlorine-containing water or, worse still, a drinking water additive of silver ions, can attack the metal and can lead to massive pitting. Therefore, if possible, the water tank must be opened and inspected before buying a boat.
The undoubtedly present white powder, aluminium oxide, does indeed indicate oxidation, but it does not yet mean that there must be more serious damage. If the white coating has been scraped off and the corrosion underneath is less than 1 mm deep, the damage is safe. If the tank is coated with a paint suitable for drinking water, it must be checked whether it still adheres well. If it dissolves, there is the same problem as with natural aluminium. Basically, the decision of the owners as to whether it makes sense at all to store drinking water in aluminium tanks is not least for hygienic reasons.
In summary, it can be said that, in spite of the critical areas mentioned, experience has shown that massive corrosion damage rarely occurs and a well-built aluminium boat still has high overall strength even with some minor corrosion damage. With professional electrical installation, high-quality and permanently undamaged underwater coating and sufficient anode protection against future corrosion, a well-built boat would have to outlive a human being.