TALAT Training in Aluminium Application Technologies

TALAT Lecture 2102.03

The Transmission Housing of an Inboard-Outboard Engine

25 pages, 26 figures

Basic Level

prepared by Anders Wickberg, Hydro Magnesium, Charlottenburg
and by Skanaluminium, Oslo

Objectives:
This chapter is an example of product development. The goals are:
To impart knowledge about:

- different ways of casting aluminium and criteria for selecting casting methods
- the heat treatment of aluminium
- corrosion-proofing and surface treatment of cast alloys used in a saline environment
- choice of alloy

To provide insight into:

- how to develop a product using the general specificiations and the interaction between form, material and processing chain
- the importance of being thoroughly familiar with the different design materials, their processing possibilities and properties.

Prerequisites:
The lecture is recommended for those situations, where a brief, general background information about aluminium is needed as an introduction of other subject areas of aluminium application technologies.

This lecture is part of the self-contained course „Aluminium in Product Development“ which is treated under TALAT lectures 2101 and 2102. It was originally developed by Skanaluminium, Oslo, and is reproduced for TALAT with kind permission of Skanaluminium. The translation from Norwegian into English was funded within the TALAT project.

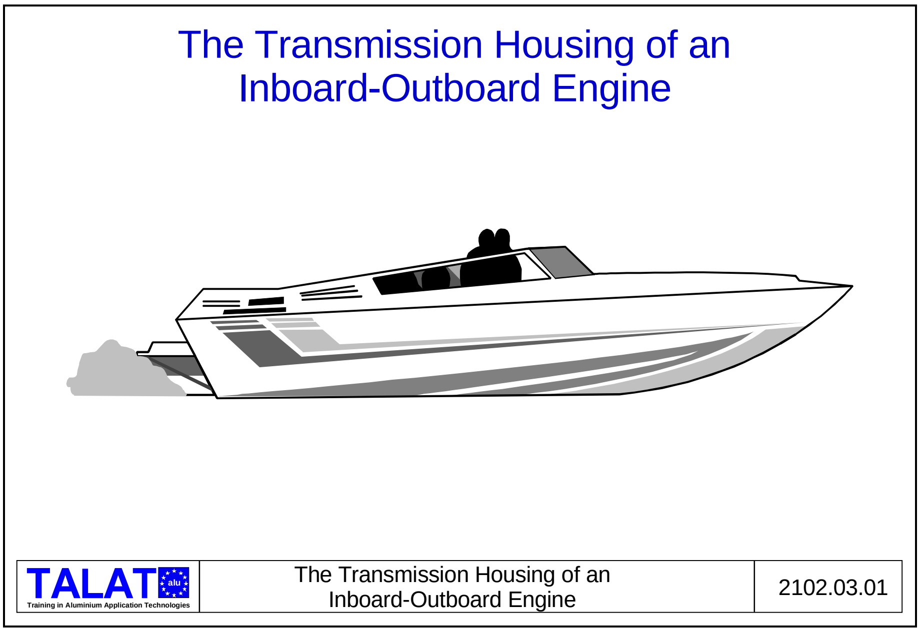
Date of Issue: 1994
© EAA - European Aluminium Association

2102.03 The Transmission Housing of an Inboard-Outboard Engine

Table of contents

Introduction

Inboard-outboard engines (**Figure 2102.03.01)** are designed to incorporate the advantages of outboard and inboard marine engines and to eliminate the disadvantages of both. This variety of engine is mainly used in fairly large, high-speed pleasure craft. The vessels are typically 5 to 10 m long and have a maximum speed of 30 to 40 knots.



About 150,000 units are sold on the world market each year. Most of the production output is exported to the USA.

This example illustrates the development of the transmission housing that forms the lower section of the engine. Our plan is to produce approx. 30,000 units a year.

Basic Specifications

Let us first take a closer look at the functions the product is expected to perform. It is important to formulate the functions quite separately from any solutions we may already have in mind.

The main functional requirement for the inboard-outboard engine is "to provide propulsion". The following functions apply to the transmission (see **Figure 2102.03.02**):

FUNCTIONS

- Transmit Power
- Withstand Stress
- Protect the Gears
- Circulate Oil
- Handle Cooling Water and Exhaust
- Protect the Propeller

TALAT — Training in Aluminium Application Technologies | Functions | 2102.03.02

Transmit power. The primary function is that the transmission be able to transmit power from the propeller to the vessel.

Withstand stress. An inboard-outboard unit must be capable of withstanding the dynamic stress and strain caused by the sea and engine vibrations. It must also be designed to withstand as much extraordinary stress as possible, including shocks resulting from grounding, hitting rocks, etc.

Protect the gears. The transmission housing is also a gearbox. It keeps components in place and protects the shafts, gears and bearings needed to transmit power from the engine to the propeller.

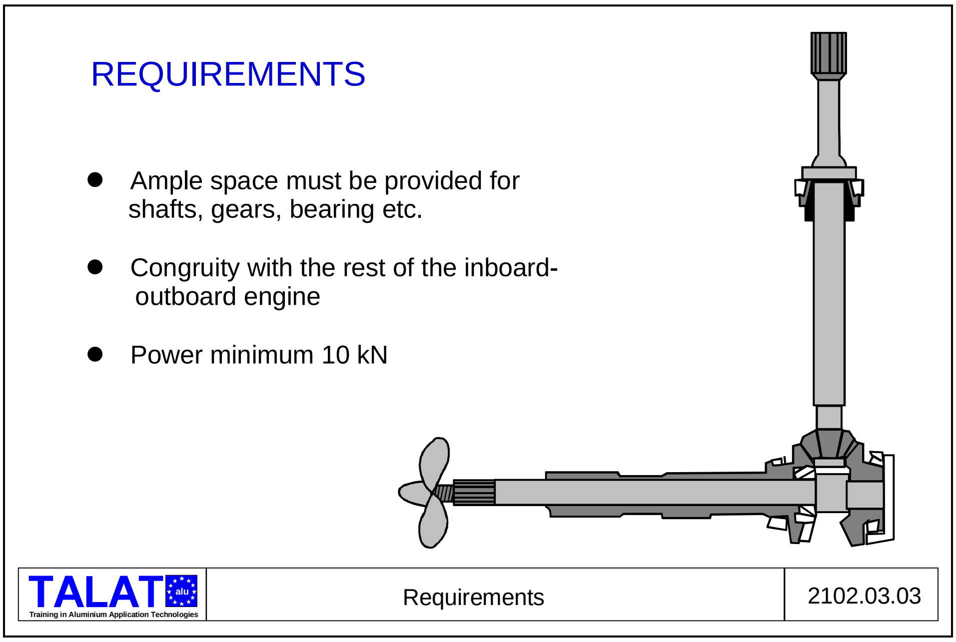
Circulate oil. Gears and bearings have to be correctly lubricated. The gears must run through the crankcase sump, and oil has to circulate throughout the transmission. The transmission must therefore include built-in channels to ensure the flow of oil.

Handle cooling water and exhaust. Boat-builders balk at making more than one hole in a vessel's hull when they mount an engine. This means the intake of cooling water and the discharge of engine exhaust both have to be handled through the transmission housing. The transmission housing must therefore have built-in channels for the intake of cooling water and the discharge of exhaust.

Protect the propeller. The transmission housing must be designed to protect the propeller when the vessel is in motion.

Requirements

Certain requirements apply to the construction of this product because it is part of a larger structure (see **Figure 2102.03.03**):



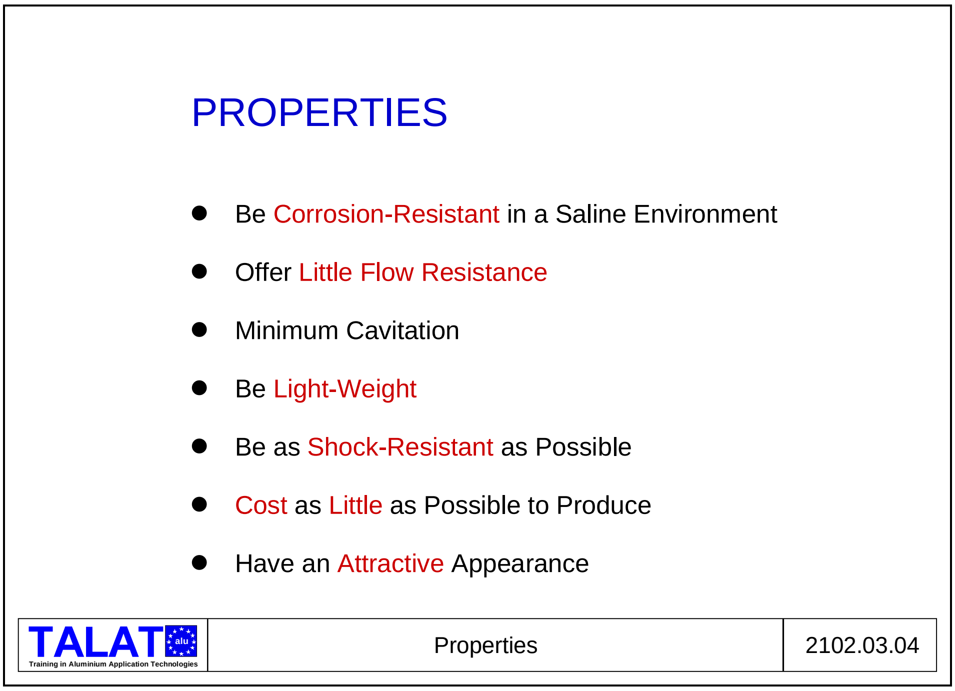
Ample space must be provided for shafts, gears, bearings, etc. The product has to be adapted to the dimensions and tolerances that apply.

Congruity with the rest of the inboard-outboard engine. We must be sure to satisfy the demands placed on us as a supplier of component parts.

Transmit enough power from the propeller for the vessel to reach at least 10 knots. The product must be scaled on the basis of the largest engines and must therefore be able to withstand corresponding levels of stress.

Properties

When we are ready to choose a solution, there will be a number of conditions, sometimes even conflicting conditions, that must be taken into consideration. We've set up some criteria for this particular example (**Figure 2102.03.04**). The product should:



⇒ **be corrosion-resistant in a saline environment**. This factor is essential. It will weigh heavily when we make our decision because it affects upkeep, safety and aesthetics.

⇒ **offer little flow resistance**. The size and shape of the product are highly significant for its flow resistance. This means we must try to find a design that ensures very little cavitation in the flow.

⇒ **reduce cavitation**. It is important that the product be designed to minimise cavitation and loss of efficiency.

⇒ **be lightweight**. This results is less energy consumption and better fuel economy. Moreover, a vessel's stability can be adversely affected by a heavy stern.

⇒ **be as shock-resistant as possible**. The transmission housing is extremely exposed to in the event of grounding, hitting rocks, etc. The housing is also intended to protect the vital parts of the engine. Safety demands that the motor and engine be as reliable as possible.

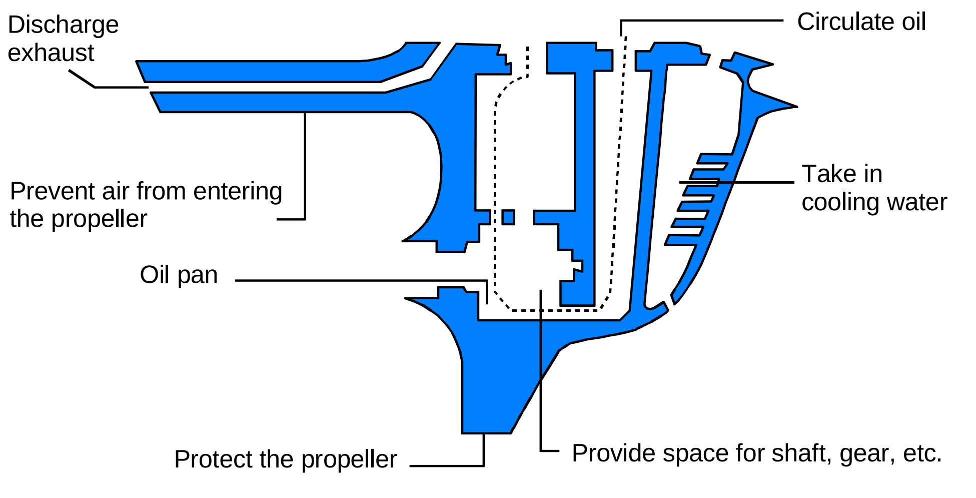
⇒ **cost as little as possible to manufacture**. Although low production costs do have an impact on the competitive situation, in this case production costs are secondary to requirements such as high reliability and low maintenance costs.

⇒ **have an attractive appearance**. The transmission housing must have a design and finish which make the product attractive to even the most discerning customers.

Possible Solution Concepts

The specifications mainly involve the product's design. It is therefore logical to begin by making a rough sketch of the product.

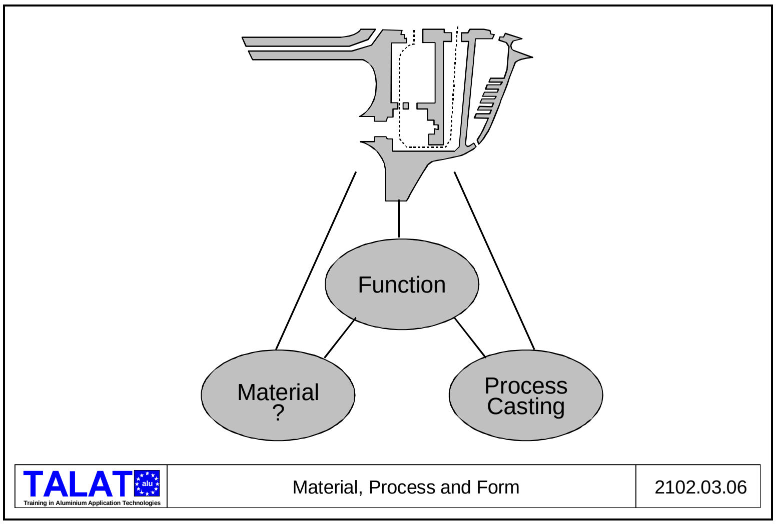
As **Figure 2102.03.05** shows, we have incorporated a streamlined surface, and space has been made for the components to be placed in and protected by the transmission housing. We've tried to accommodate the boat-builder's request that there be just one hole in the hull by installing a system for the intake of cooling water and the discharge of exhaust through the transmission housing. We've also incorporated channels to circulate a flow of oil to the bearings and gears. We've attempted to minimise cavitation by placing a cavitation plate over the propeller so it doesn't suck air. Finally, we've protected the propeller so it won't be damaged by running in shallow water.



TALAT	Possible Solution Concept	2102.03.05

Materials, Process and Form

Still other requirements and desirable features remain to be taken into account. Nevertheless, it is already obvious that the product will have a highly complex geometry. This is significant for our choice of production process and materials. Casting is our only option if we opt for a design such as the one illustrated in the figure. Even at this early stage, it is clear that the solution has to be a cast product (**Figure 2102.03.06**).



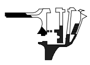
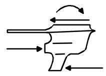
Now we must determine which material is best suited for the product before we can move on to the next step in the development process.

Choice of Materials

The following materials lend themselves well to casting:

Stainless steel
Aluminium
Magnesium
Plastic

Choosing materials is a complex task because we have to examine so many factors that pull in different directions. The table below (cf. **Figure 2102.03.07**) lists the different requirements and attempts to evaluate the various materials options against them.

Complex Geometry 	Weight 	Corrosive Element 	Mechanical Stress 	Attractive Surface	Financially Acceptable
Stainless Steel	-	++	++	-	-
Aluminium	+	+	+	+	+
Magnesium	++	--	-	+	-
Plastic	++	++	-	-	-

TALAT Training in Aluminium Application Technologies | Choice of Material | 2102.03.07

Stainless steel

Requires sand-casting, which leads to high casting and machining costs.
Relatively heavy.
Excellent corrosion resistance.
High strength.
Sand-casting requires a great deal of finishing work to achieve a satisfactory surface.
Expensive material.

Aluminium

Gravity die-casting and pressure die-casting are possible; either option would be preferable to sand-casting.
Light weight.
Good corrosion resistance (provided the alloy and sacrificial anode are appropriate
Reasonably high strength.
Pressure die-casting or gravity die-casting both result in an acceptable finish.
Average production costs.

Magnesium

Especially appropriate for pressure die-casting.
Very light weight.
Extremely poor corrosion resistance in saltwater.
Low moduli of elasticity
Nice finish.
Relatively high production costs

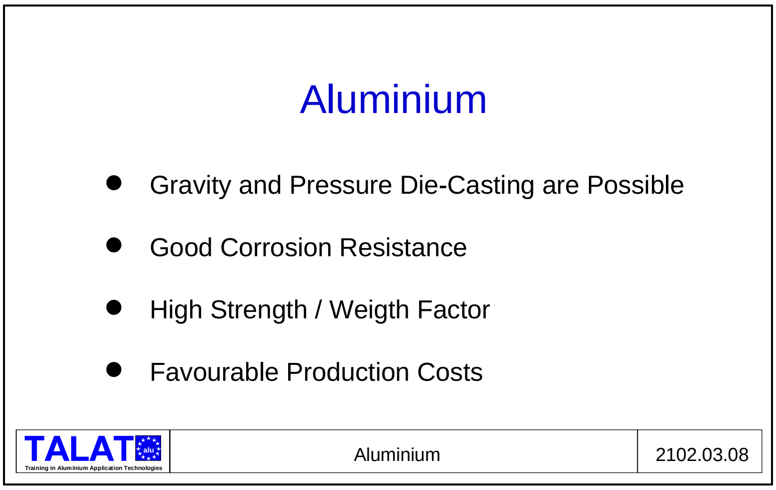
Plastic

Well-suited for injection moulding.
Light weight.
Excellent corrosion resistance.
High strength if the plastic is reinforced, but little rigidity, i.e. a low modulus of elasticity.
Requires no surface treatment.
High production costs.

As you can see, none of the above options stands out as an obvious favorite. Magnesium doesn't score well because it corrodes in saltwater and is expensive to manufacture. Stainless steel loses points for its heavy weight and high production costs. Plastic is disqualified mainly due to its lack of rigidity. But aluminium has no distinct weaknesses or disadvantages as regards the requirements we've listed. It is well-suited for gravity die-casting or pressure die-casting, has good corrosion resistance, a high strength-to-weight ratio and a favorable production price.

Conclusion

Aluminium looks like a good choice in this case (**Figure 2102.03.08**).



At this point of the case study it is worthwile to consider some characteristics of casting aluminium in more detail.

SPECIAL STUDY: Casting Aluminium

It is a good idea to call in expert advice as early as possible in the design phase in order to exploit the possibilities inherent in the casting process and take its limitations into account. Foundries can usually help you select a casting method and offer advice on casting technology as it affects specific designs.

Three main casting methods are commonly used for aluminium: Pressure die-casting, gravity die-casting and sand-casting.

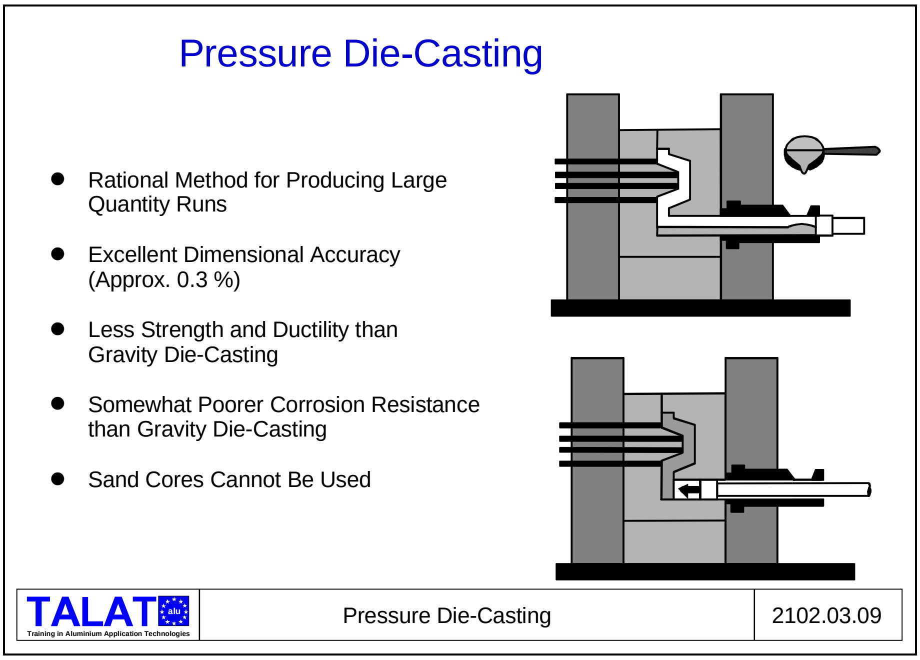
Pressure Die-Casting (Figure 2102.03.09)

This is the most efficient method for producing large quantity runs. Rapid cooling translates into large production capacity. The method is also well-suited to automation. However, the expense of making the tooling means the method is most economical for long production runs.

Pressure die-casting provides a smooth surface and excellent dimensional accuracy. Deviations are usually within 0.3 per cent of the nominal dimensions. The strength and ductility are not as good as with gravity die-casting due to the high velocity of the flow when the mould is filled with metal. As a result gas can be trapped resulting in pores in the metal (see section ***Casting method and the properties of the materials****)*

These trapped gases preclude heat treatment, and thereby rule out that means of altering the metallurgical qualities of the product (see TALAT lecture 2101.01). Pressure die-cast aluminium has a slightly lower resistance to corrosion than gravity die-cast metal, mainly because of the higher content of iron in pressure die-casting alloys.

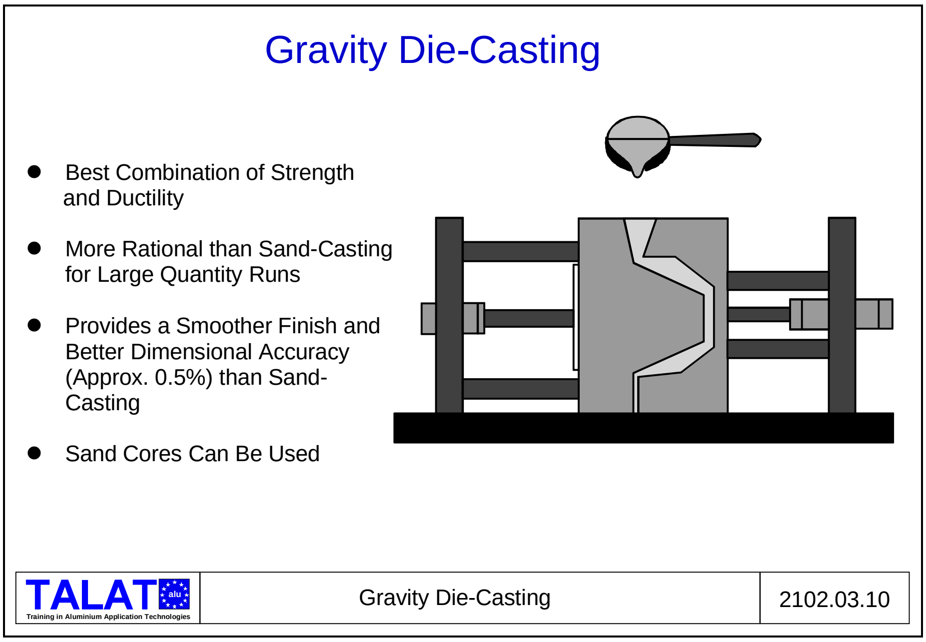
Sand cores cannot be used under high pressures (40 - 100 MPa), so metal cores must be used, but they don't offer the same range of possibilities as regards geometric design.



Gravity Die-Casting

*This method (see **Figure 2102.03.10**) offers the best combination of strength and ductility. It is more economical than sand-casting for large quantity runs, though not as rational as pressure die-casting. Gravity die-casting provides a smoother finish and better dimensional accuracy than sand-casting, though it doesn't quite measure up to pressure die-casting (approx. 0.5 per cent of the nominal dimensions).*

Sand cores can be used, which opens up a wide range of possibilities for products with complex designs.



Sand-Casting
*(**Figure 2102.03.11**)*

This method lends itself well to the production of prototypes and small quantity runs. Sand-casting offers extreme freedom of product design. The finish is relatively coarse and dimensional accuracy is to within plus/minus roughly 1 per cent of the nominal dimensions. The slow cooling rate means that the mechanical properties of the products are not as good as those of products produced by gravity die-casting (see below). The weight of the object to be cast will also play a part in the choice of casting method.

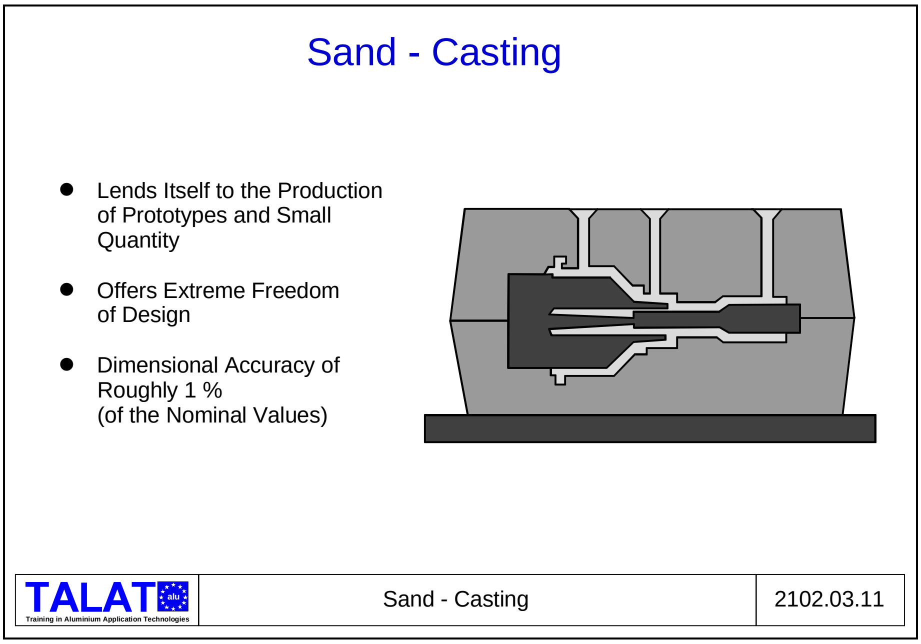
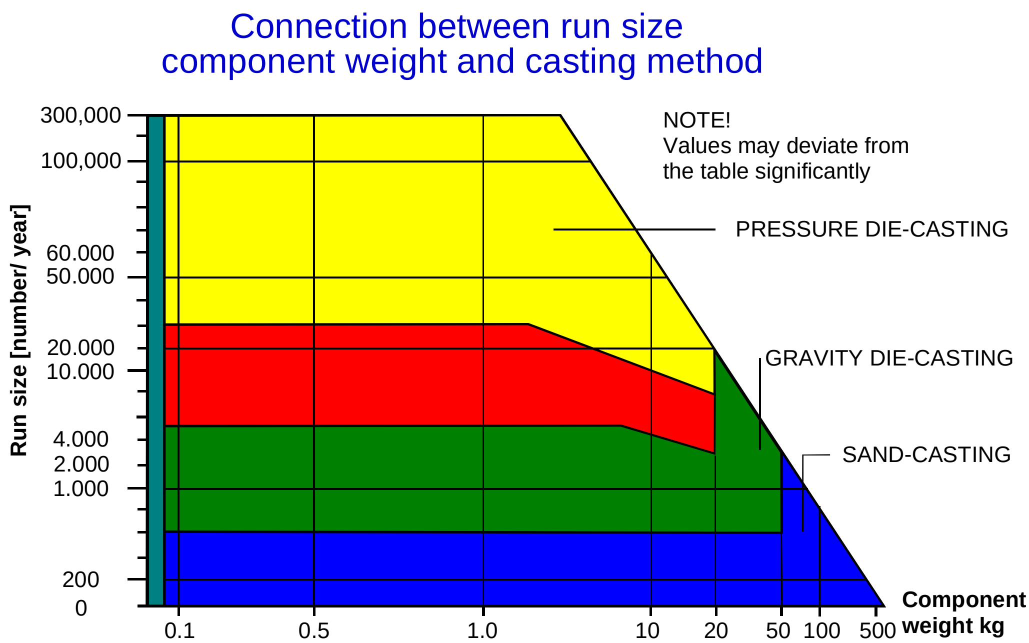


***Figure 2102.03.12** shows the relationship between the production run quantity (units per year), the weight of the object to be cast and the casting method. In actual practice, there will be substantial deviations from this table. For example, there are times when a sand core is preferable for geometric reasons. Such a decision precludes pressure die-casting even for a long production run. In other situations that call for strength and toughness, e.g. for the manufacture of wheels, gravity die-casting would be chosen, even for large quantity runs.*

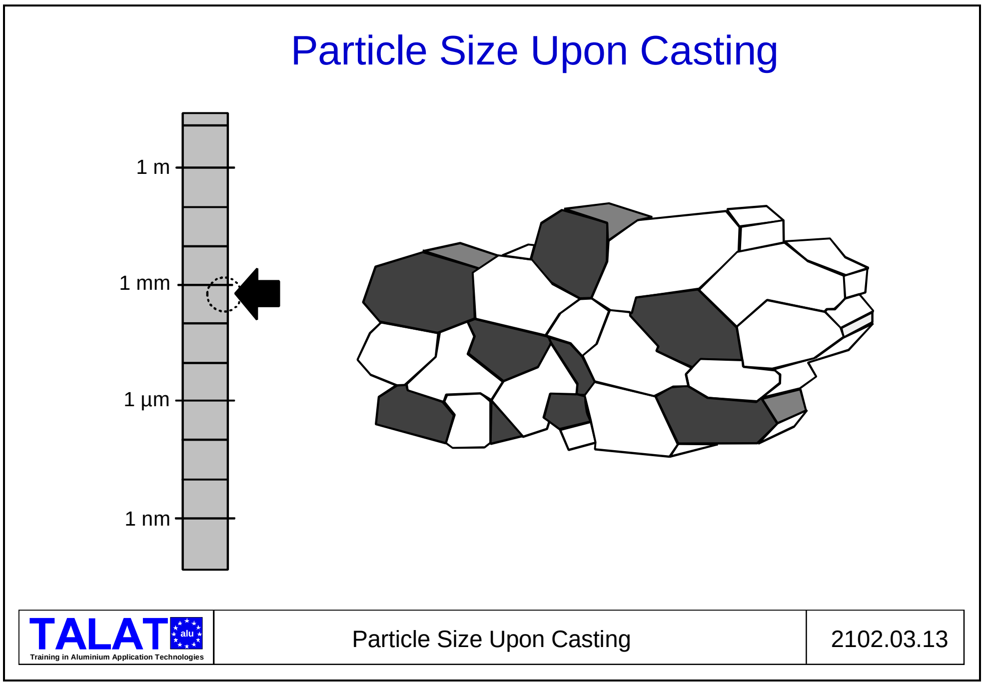


TALAT | Connection between Run Size Component Weight and Casting Method | 2102.03.12

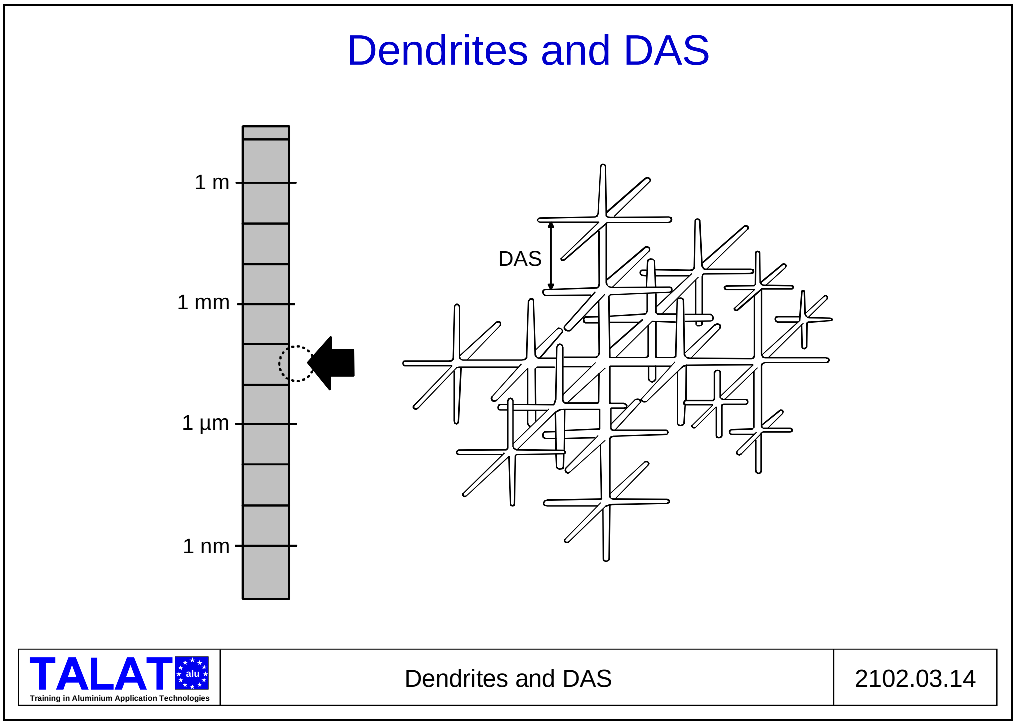
Casting Method and the Properties of the Materials

We have already pointed out that various casting methods result in different metallurgical properties. To understand this, it is necessary to examine what actually happens to the material at the micro-level (see ***Figure 2102.03.13****).*

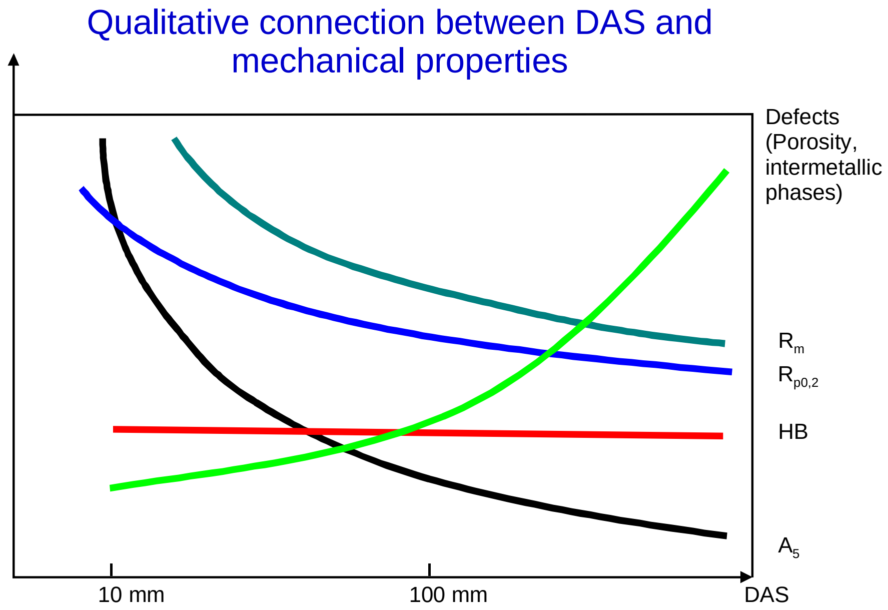
Aluminium consists of grains varying in diameter from 10 to 100 µm, and each individual grain exhibits a different crystallization pattern. The smaller the grains, the stronger the metal (see TALAT lecture 2101.01). Very large grains (0.5 - 5 mm) are formed in cast products that cool fairly slowly.



By examining the grains more closely, we can see that they are composed of crystals with leaf-like branched patterns called dendrites. The dendrite arm spacing, DAS, (cf. ***Figure 2102.03.14****) varies from 10 - 100 µm. The greater the distance, the greater the chance of porosity and intergranular spaces in the structure. This reduces yield strength and tensile strength, while ductility drops dramatically, as indicated in the figure.*



*It is therefore essential to perform the casting operation in such a way as to minimise the distance between the dendrites. The speed of cooling (quenching) after casting is the primary factor affecting the dendrite arm spacing. Rapid quenching results in small distances, a fact which favours thin sections and the use of metal moulds. It would therefore appear that pressure die-casting would have a positive effect on the mechanical properties of a cast product (**Figure 2102.03.15**).*



TALAT	Qualitative connection between DAS and mechanical properties	2102.03.15

However, the mechanical properties still don't turn out as well as expected. During pressure die-casting, the mould is filled at such high velocity that the turbulent flow causes the metal to trap gas. With gravity die-casting, on the other hand, the mould is filled with a laminar flow, preventing that particular problem. In other words, gravity die-casting actually results in the best mechanical properties.

The gas trapped during the pressure die-casting process means the pressure die-cast products cannot be heat treated. Heating would cause the trapped gases near the surface to explode, destroying the finish of the product.

If your goal is to improve the strength of a cast product, it is important to choose an alloy that can be heat treated (see TALAT lecture 2101.01).

We now return to the case study considering the choice of casting method for the engine transmission housing

Choice of Casting Method

Based on what we know about casting aluminium, it should now be possible to select the best casting method for producing the transmission housing (cf. **Figure 2102.03.16**).

Based on a production run of about 30,000 units a year, sand-casting can be ruled out. Our requirements for finish and strength also preclude sand-casting.

Casting Methods

Relative Properties

Method	Rational Production	Strength	Corrosion	Surface
Sand-Casting	Not Suited	Poor	Poor	Poor
Gravity Die-Cast.	Suited	Good	Good	Good
Pressure Die-Cast.	Very Well Suited	Not Good Enough	Not Good Enough	Very Good

Conclusion: Gravity Die-Casting

TALAT Training in Aluminium Application Technologies | Casting Methods | 2102.03.16

Mechanical Properties of Alloys for Gravity Die-Casting

Alloy	Temper (AA)	$R_{p0,2}$ MPa	R_m MPa	A_5 %	HB
AlSi12	F	90	180	5	55 - 75
AlSi10Mg	T6	220	260	1	80 -110
AlSi7Mg*	T6	200	250	4	80 -110
AlSi9Cu3	F	110	180	1	65 - 90
AlMg3	F	100	170	2	50 - 60
AlCu4Ti	T6	250	330	9	90 -105

* Primary alloy (0.2% Fe)

Important Characteristics:
- Good Machinability
- Good Casting Properties
- High Strength
- High Corrosion Resistance

TALAT Training in Aluminium Application Technologies | Mechanical Properties of Alloys for Gravity Die-Casting | 2102.03.17

Our requirements for strength and corrosion-resistance favour gravity die-casting over pressure die-casting. With a production run of 30,000 units a year, however, pressure die-casting might be advantageous. Some manufacturers of inboard-outboard engines use pressure die-cast transmission housings. This means they have compromised their strength and corrosion-resistance requirements to achieve more economical production. Based on the properties we listed at the outset, it would appear that gravity die-casting would be our best choice as it would guarantee the best strength and corrosion-resistance properties.

Conclusion*:* We choose gravity die-casting.

Choice of Alloy

The table lists the alloys most commonly used for gravity die-casting. The strength values listed here are typical values, and must be viewed merely as suggested values. The exact value will to some extent depend on the shape of the product. Foundries can usually provide guaranteed minimum values that can be used for dimensioning. We will attach importance to the following properties when selecting an alloy (**Figure 2102.03.18**):

⇒ Good machinability.
⇒ Good casting properties.
⇒ High strength.
⇒ High corrosion resistance in seawater.

Choice of Alloy

Alloy	Strength	Castability	Machinability	Corrosion-Resistance	Conclusion
AlSi12	Not Good Enough (Non-Heat Treatable)				Eliminated
AlSi9Cu3	Not Good Enough (Non-Heat Treatable)			Not Good Enough (High Cu-Content)	Eliminated
AlCu4Ti				Not Good Enough (High Cu-Content)	Eliminated
AlMg3	Not Good Enough (Non-Heat Treatable)				Eliminated
AlSi7Mg	Good	Good	Good	Good	**Best**, but Most Expensive
AlSi10Mg	Good, a Little Better than AlSi7Mg	Good	Good	Good	**Selected** Due to Properties and Price

TALAT Training in Aluminium Application Technologies | Choice of Alloy | 2102.03.18

The requirements related to strength and good machinability preclude non-heat-treatable AlSi alloys.

The requirement related to corrosion resistance precludes the use of alloys with a high content of Cu.

The requirement related to good castability calls for an alloy with a high Si content (7-12 per cent).

Of all the alloys in the table, we are thus left with AlSi7Mg and AlSi10Mg.

AlSi7Mg is based on primary metal (not re-melted, recycled metal). It contains little iron, which gives the alloy greater ductility than AlSi10Mg. The other mechanical properties are very similar.

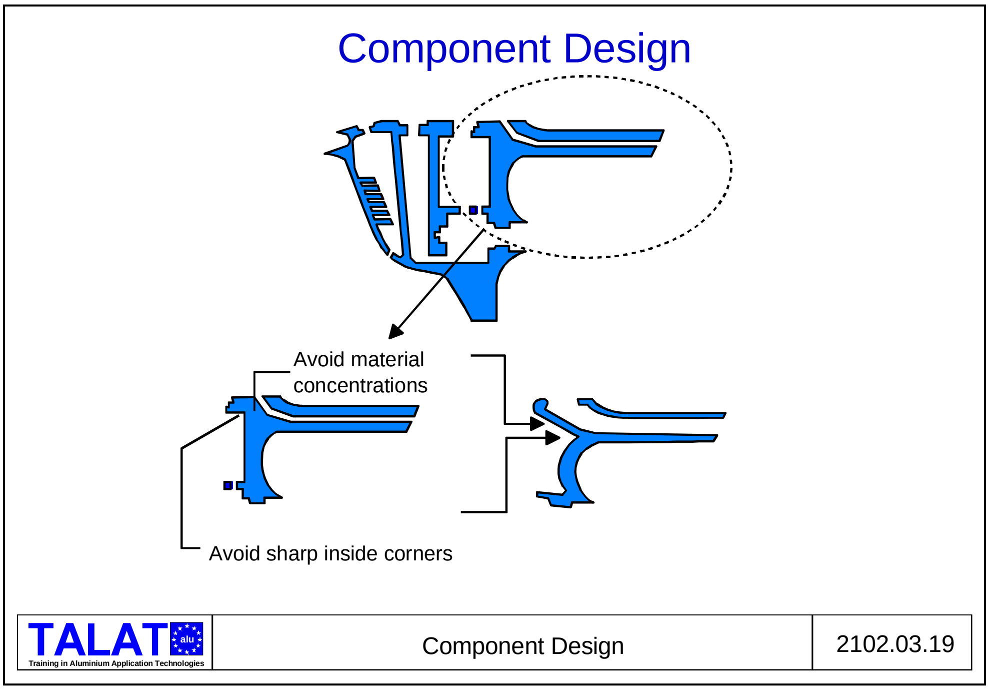
AlSi10Mg is a standard alloy, which makes it considerably less expensive than AlSi7Mg. It also satisfies our requirement for good machinability and has adequate ductility.

Conclusion: We choose to use the AlSi10Mg alloy.

Form and Design

When casting, it is best to operate with even section thicknesses. The metal will shrink about 6 per cent by volume during solidification. If section thicknesses vary, the thinnest sections will solidify first, causing the formation of small vacuums which can lead to cavities within the material (shrinkage).

Sharp corners, especially sharp inside corners, cause internal stress in the material. In addition to adversely affecting the strength of the component, this can result in the formation of cracks as the metal shrinks during solidification. Sharp corners should therefore be avoided (**Figure 2102.03.19**).



Feeders (see **Figure 2102.03.20**) are used to avoid shrinkage cavities. The feeders are a sort of auxiliary casting mould with high heat retention capacity. Thus the metal in the component being cast solidifies before the metal in the feeders. If they are to have any effect, the feeders must be correctly placed in relation to the component. The component must also be designed correctly to ensure a good result. hroughout the entire solidification process, there must be a consecutive area of molten metal between the parts of the component that have already solidified and a feeder. Shrinkage is thereby compensated by refills of molten metal from the feeders. This is what the experts mean when they say: "Be sure the solidification is directed towards any feeders you might be using!"

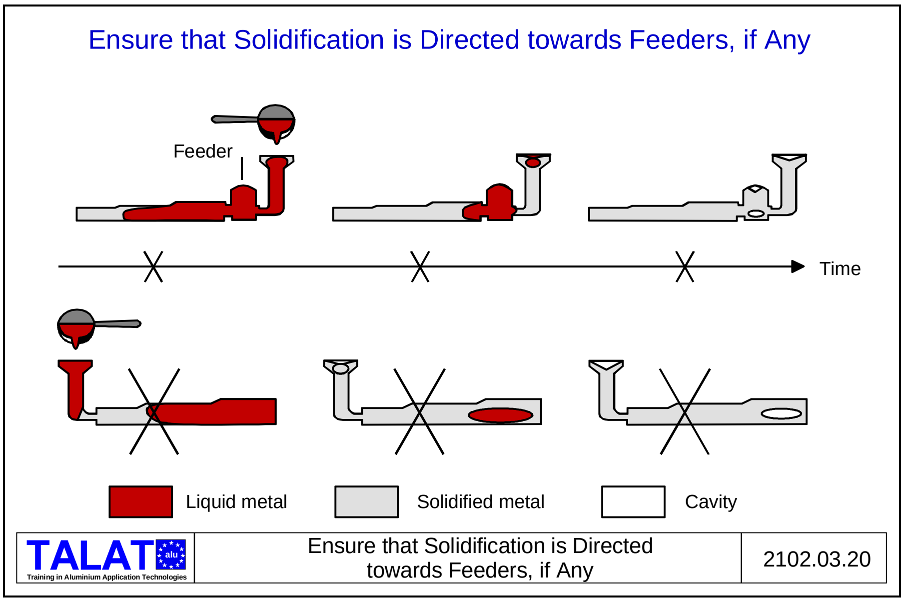
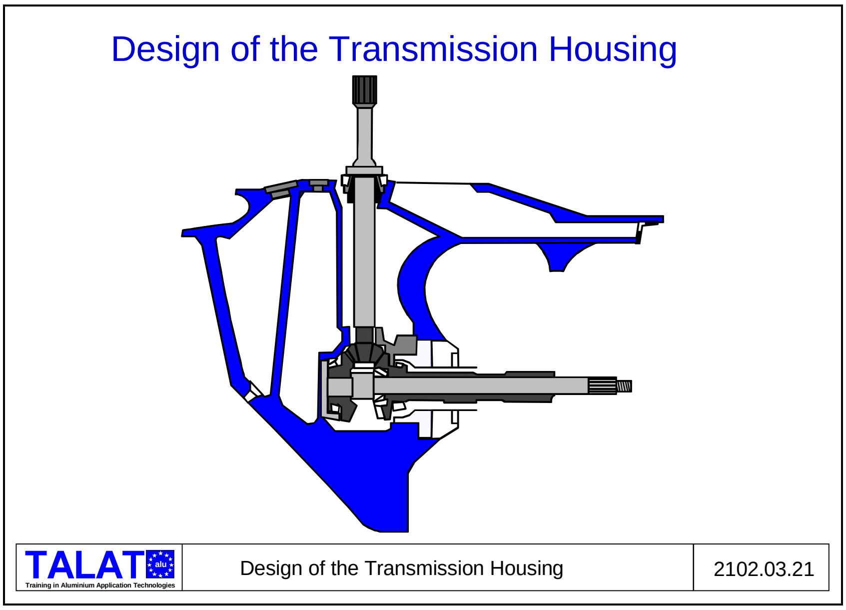


Figure 2102.03.21 shows the design of the transmission housing.



Heat Treatment

Our strength requirement means we want to heat treat the transmission housing. We've chosen the heat-treatable alloy AlSi10Mg (see **Figure 2102.03.22**), which becomes considerably stronger when heat treated due to the precipitation of a semicoherent phase of Mg_2Si. The precipitation results in large distortions in the aluminium lattice, effectively preventing any dislocation movements (see **TALAT Lecture 2101.01**).

Heat Treatment and Mechanical Properties

AlSi10Mg

AlSi10Mg	Untreated (F)	Solution Heat-Treated and Aged (T6)
$R_{p0.2}$	90 MPa	220 MPa
R_m	180 MPa	260 MPa
HB	60	100

TALAT — Training in Aluminium Application Technologies | Heat Treatment and Mechanical Properties | 2102.03.22

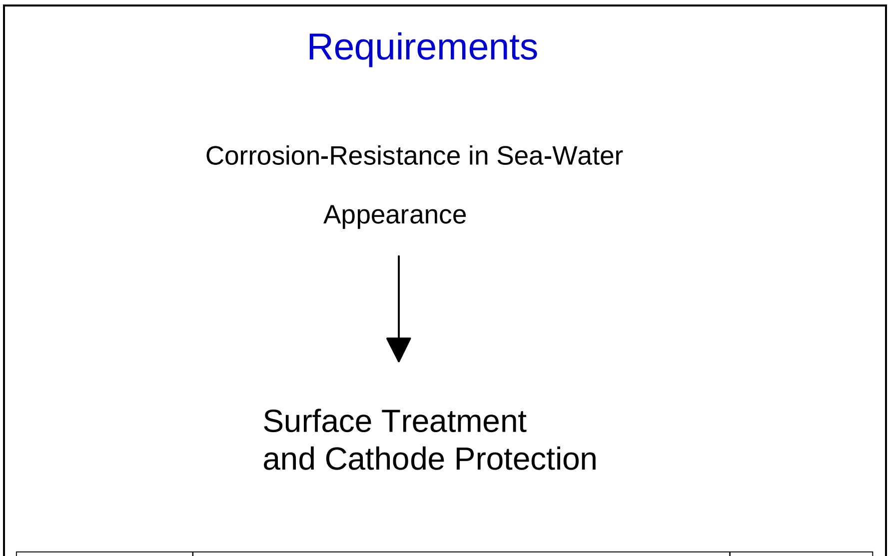
The illustration lists some figures concerning the effect of the aging process. As we can see, it is considerable. It is important to note that the strength characteristics of aluminium are heavily dependent on the thermal treatment applied to the material.

Surface Treatment and Corrosion-Proofing

One important criterion is the material's corrosion resistance in saltwater. In order to fulfil the requirements for an inboard-outboard engine, we must finish the surface and apply cathodic protection (**Figure 2102.03.23**).

Since the product must also be attractive, it is necessary to use a three-coat finish: chromate treatment, a primer and finally a coat of paint (**Figure 2102.03.24**).

Chromate treatment involves a chemical oxidation process which forms a thin protective layer made of a chromium-aluminium compound. The purpose of this treatment is to provide better adhesion for the next coat. Special "conversion" treatments are necessary for almost all aluminium finishing treatments. Chromate treatment also enhances corrosion resistance. The chromate treatment is followed by a zinc chromate primer intended to enhance corrosion resistance. The last step is spraying on a top coat of paint to provide an attractive appearance and protect the primer.



TALAT | Requirements | 2102.03.23

Surface Treatment

Method	Goal
Chromate Treatment	Provide Adhesion and Improve Corrosion-Resistance
Primer (Zinc Chromate)	Improve Corrosion-Resistance
Top Coat (Spray Painting)	Attractive Appearance and Protect Primer

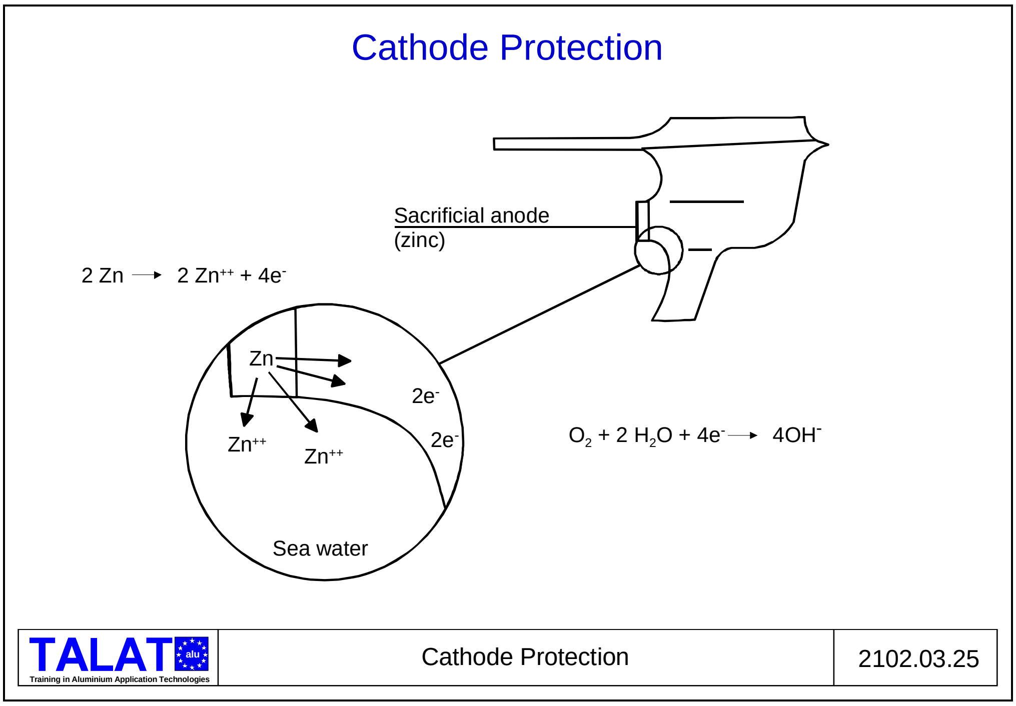
TALAT Training in Aluminium Application Technologies | Surface Treatment | 2102.03.24

Cathodic Protection

The corrosion potential can be reduced with the aid of a sacrificial anode of pure zinc. The mechanism is shown in **Figure 2102.03.25**.

Zinc reduces the corrosion potential down into the passive zone for aluminium. The zinc then dissolves and provides electrons for any cathode reactions on the surface of the aluminium. It is important that the corrosion potential not be reduced too far. That would accelerate the cathode reaction and cause the pH value in the conversion layer on the aluminium to increase. The reaction formula shows that OH ions are formed on the cathode. Once the pH value exceeds a certain limit, the passive zone for aluminium will also be exceeded and the metal will once again corrode.

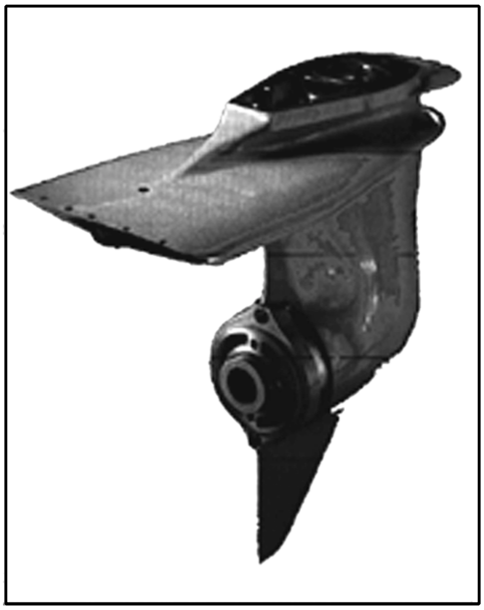
With normal use, the sacrificial anode should be replaced once a year. However, good surface treatment will cause the cathode reaction to proceed slowly and extend the life of the sacrificial anode.



Final Evaluation

We have now arrived at the final solution for our product. In the process, we have made a number of choices and assigned different priorities that resulted in this solution. Before we begin to manufacture the product, we must double check to be sure that the solution really is the one that best satisfies all our original requirements (**Figure 2102.03.26**).

All in all, we have arrived at a concept that makes the product commercially acceptable as far as price is concerned as well, even though we have not opted for the most economical production method. In fact, the product has been manufactured as described above for roughly 30 years and it is still competitive. It offers a prime example of successful product development where functional adaptation and market adaptation go hand in hand.



- Corrosion-resistant in a saline environment
- Power > 10 kN
- Light weight
- Little flow resistance
- Shock resistant
- Attractive appearance
- Somewhat high production costs

TALAT Training in Aluminium Application Technologies	Photo of the Transmission Housing	2102.03.26

Literature

Metals Handbook, 9th ed.,vol. 15, American Society for Metals, Metals Park, Ohio 44073.

Arthur C. Street, *"The Diecasting Book"*, 2.ed, Portcullis Press Ltd, 1986, ISBN 0-86108-235-4.

"Aluminium-Taschenbuch", Aluminium-Verlag, Düsseldorf, 1983. ISBN 3-87017-169-3.

Aluminium Gusslegierungen, 5. Auflage, Bundesverband Deutcher Aluminium-Schmeltzhütten, Düsseldorf, 1988, ISBN 3-87260-093-3.

P. Johne, *"Handbuch der Aluminiumzerspanung"*, Aluminium-Verlag, Düsseldorf, 1984, ISBN 3-87017-172-3.

"Håndbok for støpte materialer, del 3 Aluminiumlegeringer", Verkstedsindustriens Teknologiråd, Postboks 7072 Homansbyen, N-0306 OSLO 3

Svensson, Ingemar, *"Gjuteriteknik"*, Karlebo-serien 10, 3. utg., Karlebo Förlag 1990, ISBN 91-85026-35-2.

List of Figures