TALAT Lecture 2102.02

An Upper Casing for an Automobile Steering Column

15 pages, 16 figures

Basic Level

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Objectives:
This chapter offers an example of product development. The goals are:

to impart knowledge about:
- cold forging of aluminium
- 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.

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2102.02 An Upper Casing for an Automobile Steering Column

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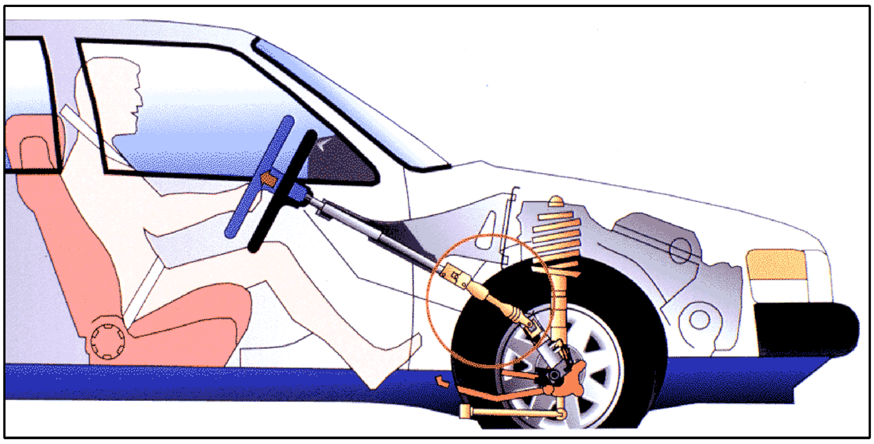
Introduction

New products are developed almost every day in the automotive industry. More rigorous standards for safety, comfort and environmental protection present tremendous challenges for product developers.

In this example, we will be developing a small part, the upper casing for the steering column of a car. **Figure 2102.02.01** indicates where the component fits into the car's steering system. Between 200,000 and 300,000 units are to be manufactured each year.



TALAT Training in Aluminium Application Technologies | Steering Column upper Shaft | 2102.02.01

Basic Specifications

Since the component we are going to develop comprises an integral part of the steering system, it might be expedient to look at the functions for the steering column first (see **Figure 2102.02.02**).

Functions

- Transfer Torque
- Facilitate Length Adjustment
- Collapsible
- Transfer Torque "at an Angle"

TALAT Training in Aluminium Application Technologies | Functions | 2102.02.02

Transfer torque. The main function is to transfer torque from the steering wheel to the steering worm.
Facilitate length adjustment. The steering wheel is to be adjustable and the adjustment device is to be located in the upper part of the column.
Collapse upon impact. For safety's sake, the steering column has to collapse if the car is exposed to extreme stress such as the impact of a head-on collision.
Transfer torque "at an angle", i.e. transfer torque and movement between two parts.

Figures 2102.02.03 and 2102.02.04 show requirements and properties for the upper casing:

Less vehicle weight means less energy consumption and a reduction in CO_2 emissions. This criterion is becoming more important as environmental awareness increases. The same is true of profitable recirculation. All parts of the car's steering system are considered safety components. The requirement concerning absolute reliability throughout the car's lifetime is therefore of the utmost importance.

Requirements

- Transfer torque of at least 160 Nm
- Fatigue: ± 40 Nm at 5 x 10^5 cycles
- Max. ext. diameter of the tube: 30 mm
- Max. ext. diameter of the yoke: 42 mm
- 100% reproducible

TALAT	Main Requirements	2102.02.03

Properties

- High reliability throughout the car`s lifetime
- Minimum play in the transfer of torque
- Easy to assemble
- Dimensional accuracy
- Corrosion-resistant
- Favourable price
- Light weight
- Profitable to recycle

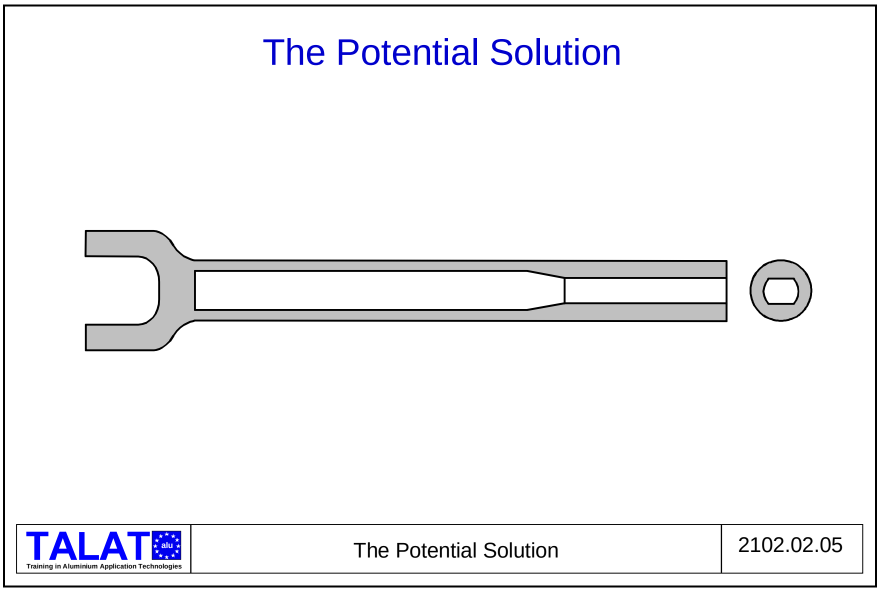
TALAT	Properties	2102.02.04

Possible Solution Concepts

Our task is to develop a part that will transfer torque at varying angles, facilitate length adjustment, be corrosion-resistant, light weight and lend itself to fabrication by a safe, reproducible process with minimal variations in quality.

The fact that we are looking for a light component for the transfer of torque brings a tubular solution to mind right away (see **Figure 2102.02.05**). Since we also have to facilitate axial movement without forfeiting torsion, the inside of our tube can't be circular. A multi-sided solution would be possible, however. The requirement that the product receive torque at an angle might conceivably be fulfilled by a yoke that could be assembled into a "cross bearing".

Figure 2102.02.05 illustrates one potential solution, a component featuring a multi-sided opening with a yoke at the end.



Material, Process and Form
(Figure 2102.02.06)

When designing a product, it is important to take into consideration the interaction between form, material and process. With the potential solution in **Figure 2102.02.05** as our starting point, we already have a form for the product. It might therefore be useful to consider which materials and production processes can be used and to determine which of them fulfil the functional requirements.

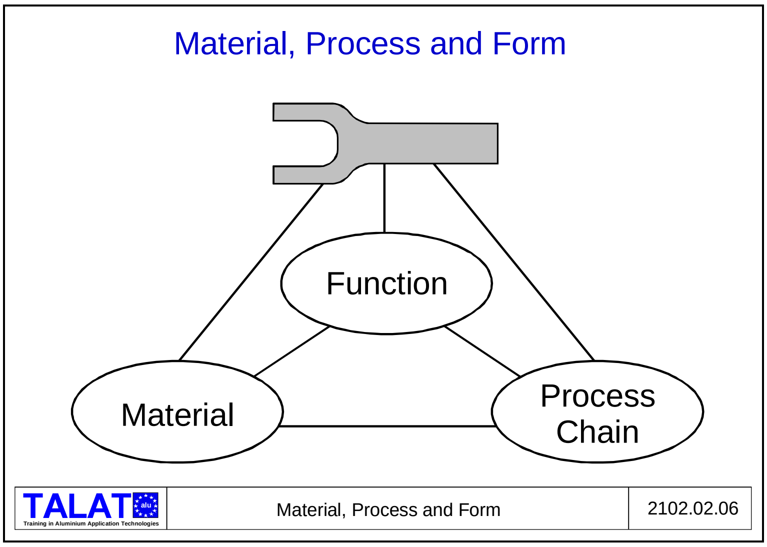
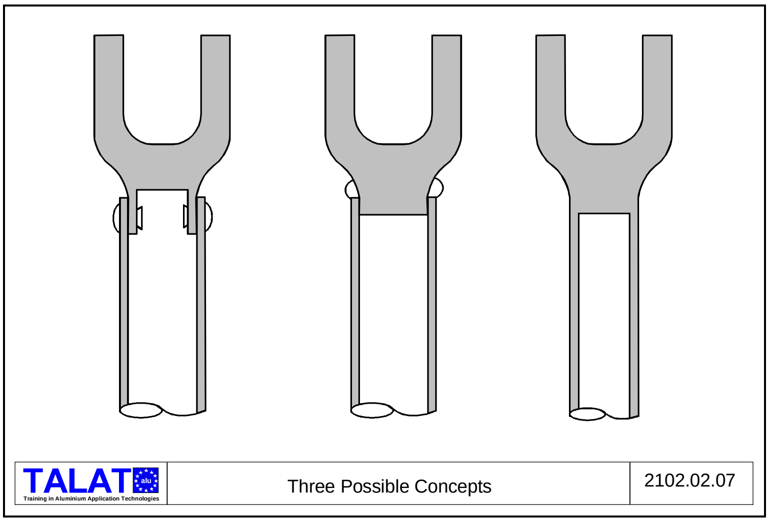


Figure 2102.02.07 shows three possible solution concepts. The two first ones show the yoke and tube joined by riveting and welding. he last solution is fabricated in one piece. Steel and aluminium are the most obvious materials, although it is also quite possible that fibre-reinforced plastic could be used as well.



Steel (**Figure 2102.02.08**)

Various steel solutions might include a tube joined to a hot-forged yoke, a cast yoke, a yoke pressed from sheet or a cold-forged yoke. Joining could be accomplished by welding, but quality assurance would be expensive. Riveting is another possibility, but the shear strength in and wear on the rivets and holes represent a quality and safety problem. On the other hand, a combination of welding and riveting might be possible. Serration and riveting offer another possibility, but serration is expensive.

There is no satisfactory way of using steel to fabricate the part in one piece.

Selection of Process and Material

Material \ Method	Riveting (A)	Welding (B)	One Piece (C)
Steel	Possible	Possible	Not Possible
Aluminium	Not Suitable	Possible, But Not Good	Suitable

Conclusion:
Want to Look Closer on "One Piece Aluminium" by Cold Forging

TALAT	Selection of Process and Material	2102.02.08

Aluminium

If we choose aluminium, we could use an extruded tube joined to either a hot-forged yoke, a cast yoke, an extruded yoke or a cold-forged yoke. Welding is another possible joining method, but quality assurance would be even more difficult than it would be for steel. Riveting is not advisable because of the wear on the rivet holes and the chance of galvanic corrosion between the steel rivets and the aluminium.

Aluminium is a very ductile material. Cold forging is a manufacturing process which should make it possible to fabricate the shaft all in one piece, provided we can find an appropriate aluminium alloy.

Plastic

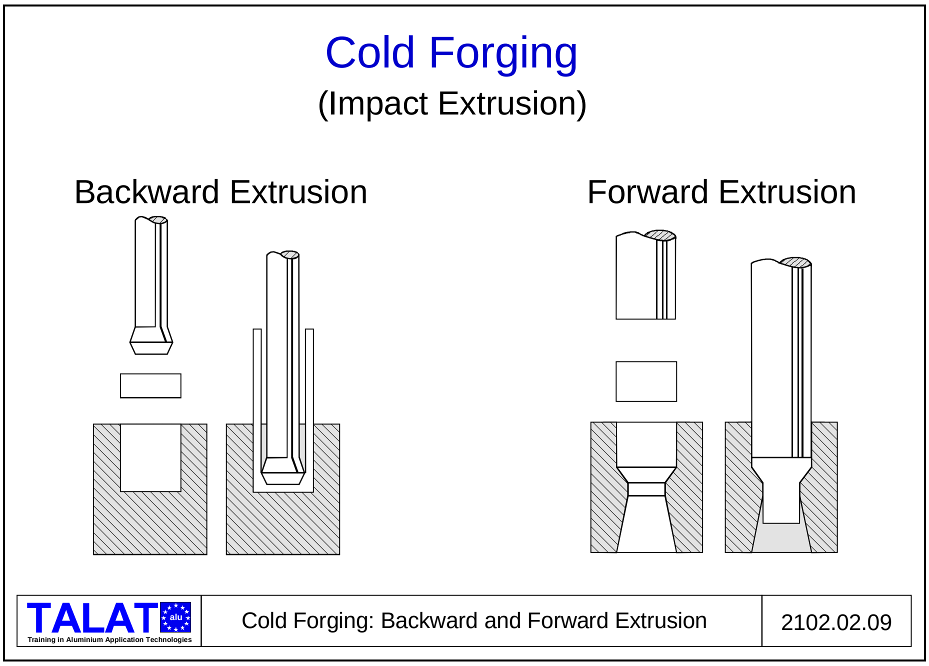
It is conceivable that extruded plastic composites could be used in combination with pre-formed aluminium yokes. The tube and yoke could be attached to each other by using a partially cured composite and completing curing after joining. The fact that the process requires several operations makes it a resource-intensive alternative. The quality assurance standards are stringent and execution would present some difficulty.
Conclusion: Safety and reliability requirements prompt us to look more closely at a solution based on a one-piece device. Cold forging of aluminium is thus the only method available to us.

Since we know that this process also affords the product light weight and good mechanical properties, and that it is appropriate for mass production, the cold forging process would certainly be worth investigating more closely.

SPECIAL STUDY: Cold Forging (or Impact Extrusion)

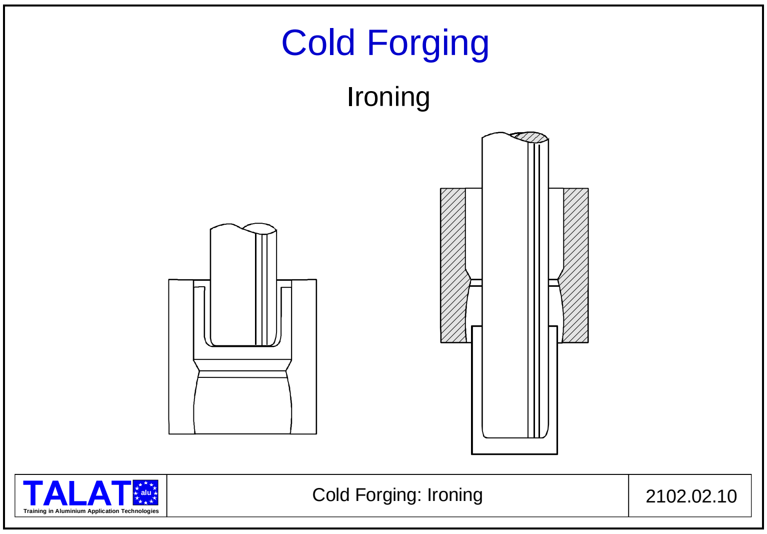
Cold forging is a process in which the material, in cold condition, is subjected to such powerful pressure that it flows into a shape determined by the forming die and punch. It is possible to form both hollow and solid objects using this method, which has mainly been used to fabricate products with simple geometries that are manufactured in extremely large runs. In recent years, cold forging has also been used for more complex geometries and smaller runs.

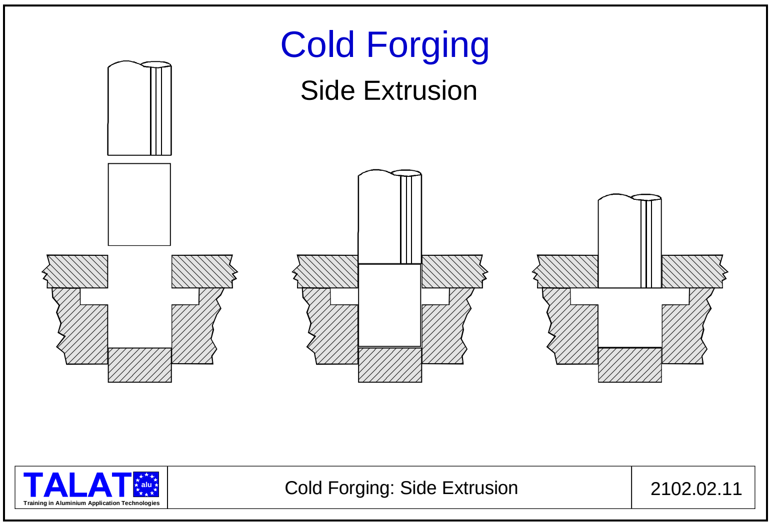
A cold slug is placed in a die, then a punch exerts so much pressure that the metal is forced to flow upward into the cavity between the punch and the die, i.e. it fills the mould. One important prerequisite for the process is that the slug must be properly prepared in advance, e.g. by a softening anneal and surface lubrication. Briefly, the lubrication involves cleaning the material in several chemical baths. The cleaning is followed by the application of a coat of phosphate porous enough to absorb a sufficient amount of lubricant. The lubricants are usually made of detergents.



Cold Forging: Backward and Forward Extrusion 2102.02.09

The four most important types of cold forging are shown in **Figure 2102.02.09, Figure 2102.02.10** and **Figure 2102.02.11**.





Combination cold forging consists of different combinations of the methods mentioned above.

Cold forging is extremely demanding as regards the design and fabrication of tools and tool surfaces, the choice of alloy, proper annealing and lubrication of the slug prior to forging.

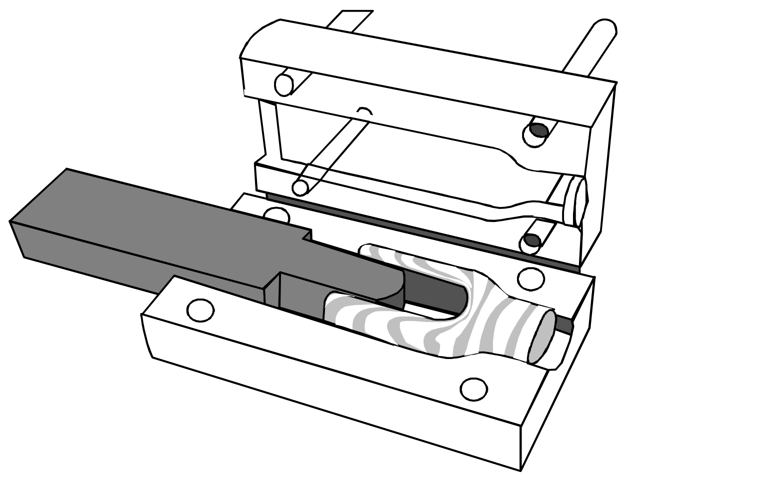
Mathematical Models

Today there are commercial software programmes on the market that can simulate cold forging. These programmes provide information about material flow, pressure, stretching, heat development, etc. in the slug being shaped. For the time being, these programmes are only available for slugs that are symmetrical around their axis of *rotation and for simple products. The lack of good empirical data about friction conditions, etc., means we still don't know enough about the cold forging mechanism.*

To a large extent, the development of new products must therefore be based on experience. It is vital to achieve sufficient material flow to prevent metal discontinuities, etc. and the standards for making the punches and dies are very stringent, meaning there is likely to be some trial and error before we obtain a satisfactory result.

Model Tests

*Models are often very useful during the development phase. Using easily deformable modelling materials and designing the tools and dies in wood or plastic allows us to simulate the process. That way mock-ups can be used to test the actual forming process (**Figure 2102.02.12**). The models demonstrate the flow of the material through the tool and provide important initial data for correct machine tool design.*



TALAT Training in Aluminium Application Technologies | Model Tests | 2102.02.12

The General Processing Chain for Cold Forging

The initial material often comprises extruded rods and bars cut to the desired length and subsequently subjected to a softening anneal to make them as ductile as possible. Prior to extrusion, a lubricant must be applied to the slug to keep it from sticking to the die). Many products must undergo softening anneals, lubrication and cold forging repeatedly before they reach their final shape. To restore the strength of the material, the product must be heat-treated before it can move on to machining. Heat-treatment consists of solution heat-treatment and aging (seeTALAT lecture 2101.01).

*Cold forging is a process which offers many advantages (see **Figure 2102.02.13**):*

Cold forgings

- Good material properties
- Economic in mass production
- Reliable process

TALAT Training in Aluminium Application Technologies | Cold Forgings | 2102.02.13

Tensile strength and hardness are improved by cold forging. Even the most high-strength age hardenable alloys (7000 series with Zn, Mg and Cu) can be cold forged and thus achieve exceptionally good strength properties.

One characteristic of cold forging is that the grain flow lines follow the surface contours of the component. The material has a smooth surface, reducing the notch effect and improving fatigue strength. The dimensional tolerances are minimal, between 0.2 and 0.02 mm, depending on the shape of the part. The small tolerances reduce the life of the tools as they allow less wear before a product falls out of tolerance.

Material utilisation is very good. The greatest loss of material often occurs in connection with cutting slugs. The process itself can easily be automated and it is very productive, making it especially appropriate for large runs. The economical size of the minimum run will depend on weight/dimensions and alternative processes, but in general it should not be less than a few thousand units for large parts and preferably a few tens of thousands for smaller parts.

Owing to the narrow dimensional tolerances and the smooth surface achieved, machining can often be avoided or reduced to a minimum.

Cold forging is a highly stable process which reduces the need for quality inspection. These days, the options for shaping products are excellent, making it possible to produce many components that once had to be fabricated from several pieces. This makes the method even more appropriate for the fabrication of components that are subject to the most rigorous safety standards.

Now we return to the development of the steering column and address the choice of aluminium alloy

Choice of Alloy

(**Figure 2102.02.14**)

Our choice of alloy must take account of the functional requirements as well as the requirements posed by the cold forging process. Our primary goal is to find an alloy which is *strong* and *highly ductile*. Good formability is important to improving the efficiency of the production process. It would be best to find an alloy which is highly ductile and which can attain sufficient strength through the cold forging process alone. Unfortunately, there is no such alloy that could be used for this product. e must therefore find a heat-treatable alloy, i.e. an alloy that derives its strength from heat-treatment after forming (see TALAT lecture 2101.01). As regards strength, the alloys in the 7000 series achieve the highest scores. However, they are more difficult to shape and more prone to corrosion than the alloys in the 6000 series that might be possibilities here, for example 6005, 6063, 6082 and 6351. But 6063 is not strong enough and 6005 is too brittle. Either of the two remaining alloys could be used, but 6351 is the more ductile of the two.

Choice Among Heat-Treatable Alloys

Alloy	Formability	Strength	Ductility	Corrosion-resistance
7000 Series	Poor	Excellent	Varies	Poor
6005	Good	Ok	Too Brittle	Ok
6351	Good, better than 6082	Ok	Ok	Good
6082	Good	Ok	Ok	Good
6063	Good	Insufficient	Ok	Ok

Conclusion: Choose AA 6351

TALAT Training in Aluminium Application Technologies | Choice Among Heat-Treatable Alloys | 2102.02.14

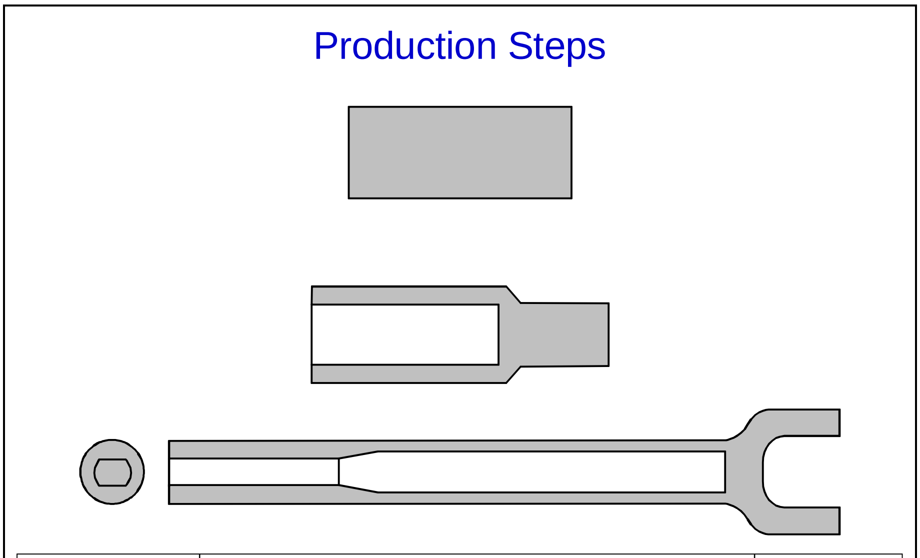
We also have standards for corrosion-resistance. The 6000 series is generally best in this respect. 6351 and 6082 have both been approved as structural materials for offshore applications and they offer good corrosion-resistance.

Conclusion: We choose alloy AA 6351 because it best satisfies our functional requirements and is easiest to form.

Preparations for Production

The functional and other requirements will dictate the main parameters of the design. As the sketch (**Figure 2102.02.05**) shows, the wall is thicker at the end of the tube where the inside isn't round. This special shape will ensure that the component is strong enough to receive the torsional forces that have to be transferred to the solid rod that will be fitted into the extruded hole. The rest of the tube has a thinner wall and a circular shape inside. We have chosen this design so the steering column can slide smoothly in the hole, facilitating length adjustment and allowing it to collapse upon impact.

Figure 2102.02.15 shows the initial slug, the extruded rod and the first step in the production process.



Production Steps

2102.02.15

Once the sketches are approved, model tools are made, any adjustments are undertaken and tests are conducted. Then the real tools can be engineered and produced. The next step is a test run. The metallurgical characteristics of the product are examined to discover any propensity to crack, and to observe the product's flow lines and texture. The product's hardness is measured after heat treatment. Finally, the shaft is machined, and torsion and fatigue tests are conducted.

This is a special product which requires very thorough preparations before it can be put into production. The development of this type of product is often a slow process which calls for close cooperation between the customer and the manufacturer.

Summary

We have arrived at a solution that fully satisfies our requirements concerning functions, specifications and properties. Safety properties have been decisive for our choice of solution, but aluminium is also an excellent choice in the light of requirements related to environment-friendliness, low weight and recyclability.

A number of other solutions are used in cars today, but all of them are more complex designs made of steel or aluminium. None of them fulfil the functional requirements and specifications as "elegantly" as the cold forged solution.

There is reason to expect that the automotive industry will steadily increase its use of aluminium, chiefly due to environmental standards that tend to amplify the importance of aluminium's light weight and excellent recyclability (**Figure 2102.02.16**).

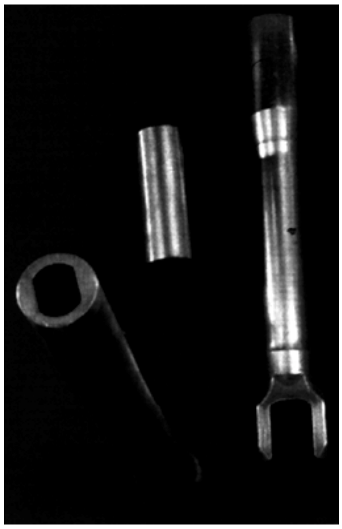
This product has been in production since 1987 and it functions well both in production and in actual use in automotive steering columns. The market prospects are considered to be quite good. Comparable products produced by the same process have been in use since the late-1970s. Thus far, between 1.5 and 2 million units have been produced and are being used *inter alia* by Volvo, Saab and Corvette.

Environmental Standards for car production

- Low weight
- Recyclable Materials
- Design for disassembly for recycling

↓

Aluminium



TALAT alu Training in Aluminium Application Technologies	Environmental Standards for Car Production	2102.02.16

Literature

Metals Handbook, 9th ed.,vol 14, American Society for Metals, Metals Park, Ohio 44073.

Aluminium Impacts Design Manual and Application Guide, Aluminum Association, 818 Connecticut Ave., Washington D.C. 20006.

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

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