TALAT Lecture 2201.01

State of the Art

17 pages, 15 figures

Basic Level

prepared by Asmond Broli, Hydro Aluminium Structures, Karmoy

Objectives:

- To aquaint those who are unfamiliar with the use of aluminium in stressed applications, with the past experiences and likely future developments

Prerequisites:

A general engineering background is an advantage but the subject matter is suitable for most audiences concerned with transport and structural applications..

Date of Issue: 1994

2201.01 State of the Art

Table of contents

Historical Development

Aluminium was relatively new when it was first introduced as a structural material. The selection of alloys was limited and the fabrication techniques very primitive compared with the situation today. Despite these facts, structural aluminium applications were successfully introduced into many areas.

In this connection it is most relevant to group the applications into three main fields, and to look at a few examples in

the Marine Industry,
the Transport Industry,
the Civil Engineering Industry.

Marine Industry

While the first steel ship was built in 1859, and only 11 steel ships were built in 1878, aluminium came into use in marine applications interestingly soon after steel. Already during the 1890s aluminium components were added to scores of ships and boats. But the alloys and the fabricating techniques then available were unsatisfactory and aluminium fell into disuse.

The 1922 Washington Disarmament Conference, which limited total naval displacements, again spurred the thinking of naval architects toward aluminium. New aluminium alloys were being developed to meet the strength and corrosion-resisting requirements for marine constructions.

In 1928, the light cruiser U.S.S. *Houston* was built with deckhouses of the then popular structural alloy Duralumin. This ushered in a new era of warship construction. By 1940, aluminium was used structurally for about 100 U.S. warships. More recently, the U.S.S. *Dewey*, a guided missile destroyer leader with aluminium superstructure, joined the fleet.

The earliest applications to merchant ships were achieved in 1934 on three Mystic Steamship Company colliers. One of these, a converted freighter, the S.S. *Glen White*, trimmed badly by the bow. The steel bulkhead between nos. 2 and 3 holds was replaced by an aluminium alloy 6053 bulkhead which corrected the condition and permitted carriage of 65 tons of extra cargo. When inspected 10 years later, there was no indication of corrosion or excessive damage from coal handling. The adjacent steel bulkhead, however, suffered from both.

Further development of alloys continued during the 1930s, a period which saw aluminium used in additional merchant ship structural installations.

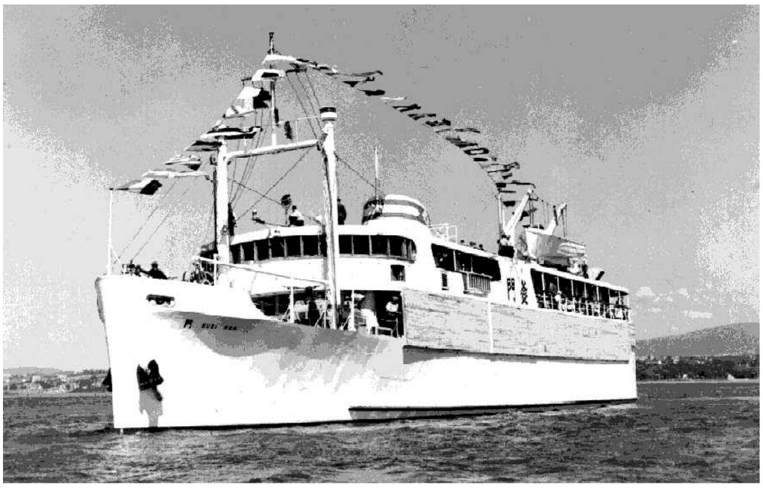
The higher-strength aluminium alloy 6061 containing magnesium and silicon as major alloying elements, was under development prior to World War II. In 1944, as a result of wartime experience, it replaced alloy 6053 for structural use, and was quickly adopted for postwar merchant ships.

Aluminium construction received great impetus with the development of high-speed welding techniques and other weldable alloys, particularly the Al-Mg 5000 series. Since the early 1950s the majority of naval and merchant ship aluminium structures have been welded.

As a consequence a total of more than 1000 merchant ships had been built with aluminium superstructures in the beginning of the 1960s.

One of the best known ships with an aluminium superstructure is the S/S *United States* where the utilization of 2000 tons of aluminium resulted in a total weight saving of 8000 tons for the total vessel.

In addition to commercial ships and warships, aluminium is now used for tankers, fishing vessels, personnel boats, ferries and hydrofoils (**Figure 2201.01.01**).



TALAT Training in Aluminium Application Technologies	Yangtze River Vessel with Aluminium Superstructure Built 1948	2201.01.01

Transport Industry

In this context it is especially worth mentioning

the air transport,
the rail transport, and
the road transport industries.

In air transport the development and use of aluminium alloys is directly linked to the development of that industry. It is clearly documentable that without the availability of aluminium the civil aeroplane industry would still be in its infancy. Although titanium, carbon fibre composites and stainless steel were used for military aircraft 70% of the airframes of civil aircraft is aluminium alloy.

The use of aluminium in rail transport is another success story.

The railway industry took immediate interest in using aluminium when it became available on an industrial scale around the turn of the century. Initially, the interest centered on the light weight and corrosion resistant aluminium as a substitute for brass fittings and wood or steel panelling in a coach structure, which was characterised by a strong, load carrying steel underframe and a largely wooden superstructure.

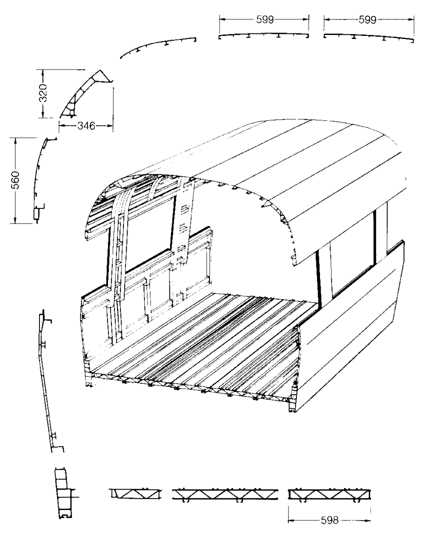
During the twenties and thirties the design philosophy changed to enhance passenger safety and reduce weight. The approach was to consider underframe and superstructure as a load bearing entity. Steel panels riveted to a steel framework were used initially followed shortly by aluminium sheet fastened to aluminium extrusions. This "sheet and stringer" or "stretched -skin" design still persists to date for modern steel coaches with the important difference that welding came in to replace the old-fashioned riveting and that higher strength copper-bearing or stainless steels helped to improve the rust-problem and to reduce weight.

A further recognisable change in the design of aluminium railway cars was dictated by economic aspects. The significant increase in labour cost during the seventies spurred the use of larger amounts of extruded sections with integrated functions. Together with the availability of semi-automatic, multiplehead welding equipment, it became possible to fabricate floor, roof and sidewall subassemblies with only a few longitudinal welding passes on extruded shapes running the entire length of the car.

By using integrally stiffened extruded side and roof panels the rectification of distorsion , which is inherently necessary in the stitch-welded or spot-welded "sheet and stringer" design, was largely avoided. At the same time, labour-intensive finishing work and the need for filler paste application preparatory to painting was reduced significantly.

In summary, the full application of the aluminium extrusion technology for the vehicle body design resulted in cost reductions to such an extent that light-weight aluminium coaches were and are being built at equal or lower costs than conventional steel coaches.

The all-extrusion design has consequently been applied in numerous modern railcar projects all over the world (**Figure 2201.01.02**).



Source: VAW aluminium AG, Bonn

TALAT	All-Extrusion Design of High-Speed Passenger Train Intercity Express, Germany. Built 1992.	2201.01.02

Aluminium alloys always have been used for automotive components including engine parts, wheels, body panels and the structure frame since the beginning of the century. In most cases the technical performance was satisfactory with significant weight savings resulting. Often, however, the increased cost was not seen to be justified but this situation is now changing with the demand for reduced fuel consumption and the need to add safety and antipollution devices.

In trucks, trailers and tankers aluminium has been used for the past 40 years, the weight advantages resulting in payload increase and for fuel savings which are more obvious than in the automobile.

Civil Engineering Industry

During the 1930s a gradual introduction of aluminium applications into the civil engineering industries took place. Special attention was directed towards various kinds of roof structures, building systems, stairs, stairtowers, gangways, masts, silos, cranes, pylons, towers, pedestrian bridges etc. (**Figure 2201.01.03**).

In addition more recently a large number of structural military applications were developed, e.g. transportable bridges, gun mountings, tanks etc.

TALAT Training in Aluminium Application Technologies	Aluminium Transmission Pylon, British Columbia Built 1952	2201.01.03

During the 1940s aluminium was introduced in road bridges, particularly in the USA. Compared with the technology of today oldfashioned alloys and fabrication techniques (riveting) were used. By 1963, approx. 20 road bridges had been built in the USA (the longest being 100 m), and a total of approx. 40 worldwide.

Costwise these bridges were more expensive than equivalent bridges in steel, but the expected lower life-cycle costs were planned to compensate for this difference. However because of some deficiencies in design and fabrication this compensation was not always achieved. While the general experience with many showed that they performed perfectly over a 30 - 40 year period some corrosion problems occurred as a result of incorrect alloy choice and/or wrong fastening methods.

While a great number of aluminium applications were developed and commercially introduced during the first 6 - 7 decades of this century, not all of them can be reported to have developed into substantial commercial success.
During the period 1970 - 1990 the following major trends can be identified:

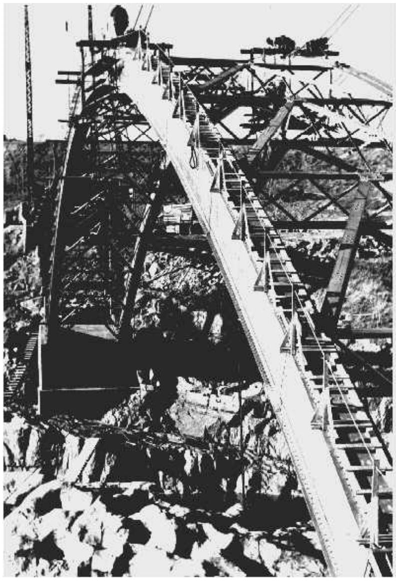
- In the traditional shipping industry a trend back to steel for hulls and superstructures has been observed.
- In some ships aluminium also has had a limited utilization, partly as a consequence of the availability of new materials (GRP) and partly as a consequence of a turn back to steel.

- In fastgoing personnel boats, however, a very positive development has taken place. The transition from 20 knots to over 35 knots speed levels, introcuced by the catamaran concept, resulted in a need for all-aluminium designs for reasons of fuel economy **(Figure 2201.01.04)**.

TALAT alu Training in Aluminium Application Technologies	All Aluminium Catamaran Passenger Vessel Built 1991	2201.01.04

- Aluminium is still the preferred material in the civil aeroplane industry, and had a very positive development in the rail as well as the road transport industries.

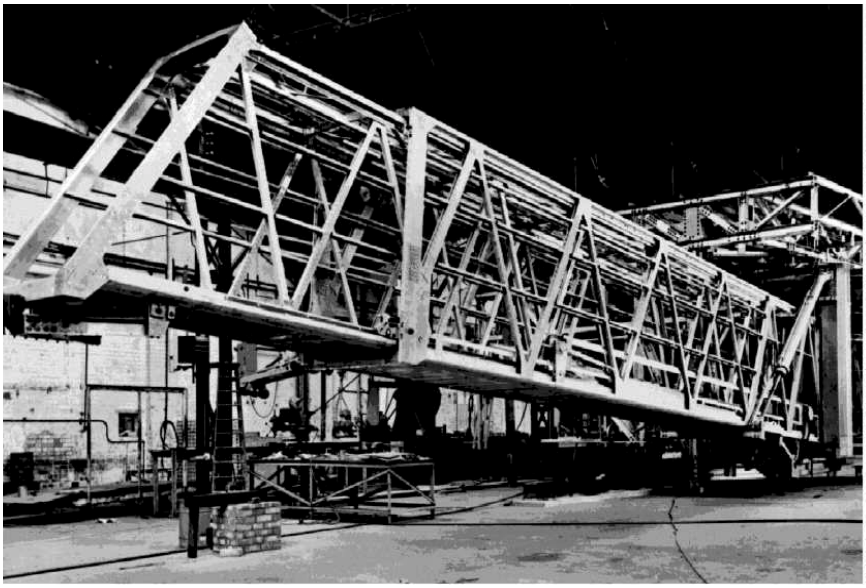
- In the civil engineering industry, aluminium has problems in maintaining its position in many major applications, among those in bridge constructions (**Figure 2201.01.05**).



TALAT	Arvida Aluminium Bridge, Quebec, Canada Built 1947	2201.01.05

- The offshore industry is one new application for structural applications: Helidecks (**Figure 2201.01.06**), telescopic bridges (**Figure 2201.01.07**), walling systems (**Figure 2201.01.08)**, gangways (**Figure 2201.01.09**), stairs, stairtowers, floorings, housings (**Figure 2201.01.10**) etc. were developed during the 1980s.

TALAT Training in Aluminium Application Technologies	Offshore Aluminium Helimodule (Helideck, Helihangar, Stairtowers and Support Structure). Built 1986	2201.01.06



TALAT Training in Aluminium Application Technologies	Telescopic Aluminium Gangway for Ocean Terminal Built 1948	2201.01.07

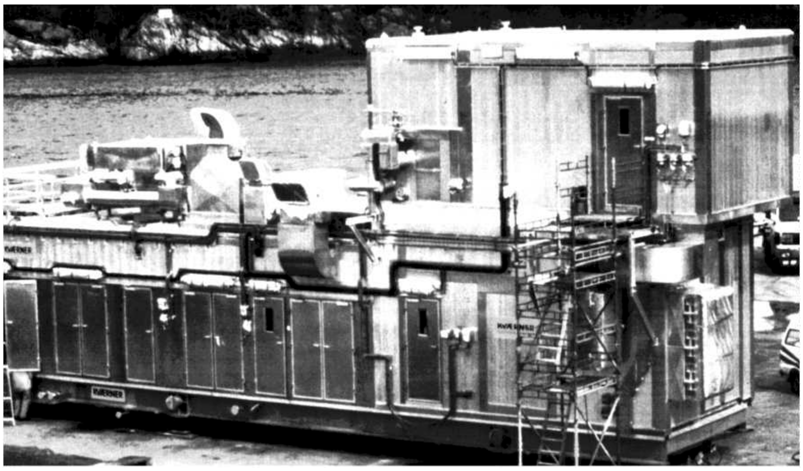
As a consequence relevant technologies and methods for protecting aluminium structures against fire had to be developed (**Figure 2201.01.11)**.

Both the methodology as well as classified fire design examples will be described later.

TALAT Training in Aluminium Application Technologies	Offshore Aluminium H 120 Fire Wall Built 1991	2201.01.08

TALAT Training in Aluminium Application Technologies	Oil Terminal Pipes Access and Support System Built 1988	2201.01.09

TALAT | Aluminium Gas Turbine / Generator Housing Built 1991 | 2201.01.10



TALAT | Offshore Aluminium H 120 Fire Classified Office Module Built 1987. | 2201.01.11

Presence and Perspectives

The present status of aluminium utilization in stressed structures can be summarized as follows:

- Despite the existence of good textbooks and codes of practice, the lack of teaching material is obvious. As a consequence aluminium does not achieve the status of an accepted structural material in engineering education (The TALAT material will hopefully help to compensate this situation).

- A lack of sufficient knowledge - often accompanied by prejudices- leads to decisions against the use of aluminium.

- Aluminium structures can mainly be found in applications like the rail and road transport industries, speed personnel boats and aeroplanes where weight saving is at a premium.

- For those applications where traditional building materials like steel and concrete are prevailing, aluminium is facing a stiff competition and sometimes suffering set-backs.

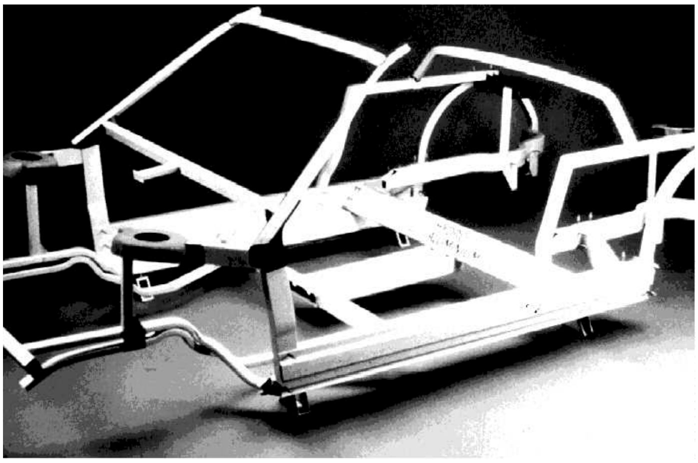
The lack of formal education, competence and obvious commercial interests are probably the major reasons for this situation.

Aluminium has a bright future as a structural material, but only based on following prerequisites:

- A comprehensive upgrading of the materials position at the educational institutions.
- The development of detailed cost studies for the respective potential applications.

An example is the rapid and comprehensive use of aluminium in structural components in the automotive industry. This development takes place as a joint development between strongly motivated commercial interests, i.e. of the aluminium and the automotive industries (**Figure 2201.01.12**) and (**Figure 2201.01.13**).

Provided the required development regarding education and commerciality takes place, aluminium has a great potential for making its way into new industries and applications as well as regaining most of the lost positions.



TALAT Training in Aluminium Application Technologies	Car Body Frame Used for Racing Cars Built 1990	2201.01.12

TALAT | An Aluminium Bodied Landrover Used for Off Road Racing | 2201.01.13

Criteria for Selecting Aluminium

All structural materials have different properties and technical characteristics, and consequently differ in their suitability for a given application. For some obvious cost reasons, aluminium will not become an alternative structural material in all cases, even though its use would be technically possible.

In order to evaluate whether aluminium could be the right material in a specific application some decision criteria must be considered:

- Weight reduction
- Maintenance aspects
- Product costs
- Load criteria

Lightweighting

Since, for all structural applications, aluminium will provide substantial weight saving compared with traditional structural materials such as steel and concrete, all applications where lightweighting has a commercial value are obvious candidates for aluminium utilization.

Consequently, in the transport industry where fuel consumption is crucial for the economy of a product, aluminium has a very strong position (aeroplanes, boats, railways) as well as the greatest development potential (automotive).

A very often overseen effect of the lightweighting aspect is the downsizing effect. This can be illustrated by focusing on a cable bridge where a substantial weight saving of the bridge deck structure will also result in the possibility of downsizing towers, cables and fundaments. A total application economy should therefore be introduced in order to find the right solution for any structure.

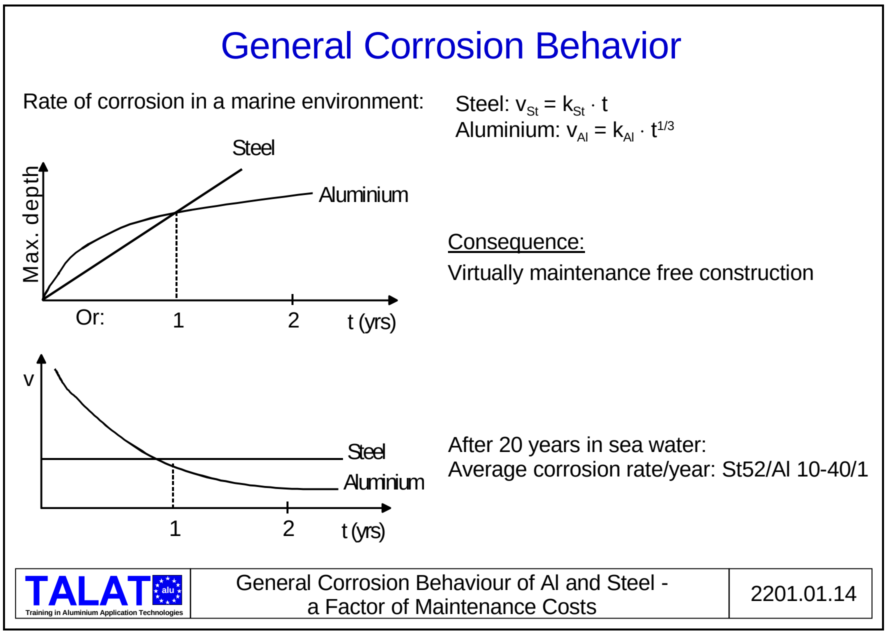
Maintenance Aspects

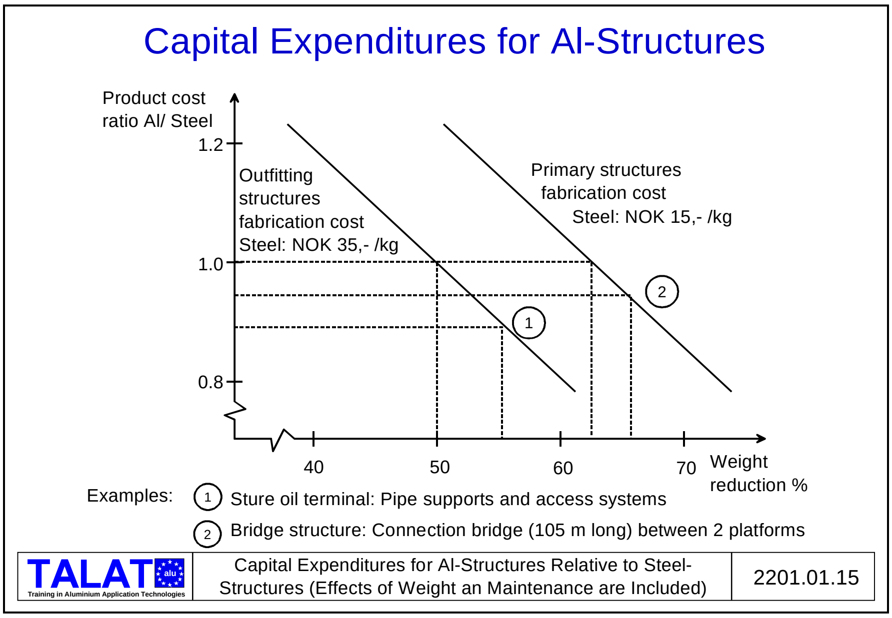
Most aluminium alloys require low maintenance because of their good corrosion resistance. This can be illustrated by **Figure 2101.01.14**. Therefore, aluminium is an excellent candidate for all applications where the benefit of freedom from initial protection and maintenance yields a commercial benefit. A general problem in many product developments is still the lack of life-cycle cost evaluations.

A tendency to select the cheapest alternative at the initial cost level could very well result in higher life-cycle costs compared with other, initially more expensive solutions. There is an increasing experience that life-cycle cost decision criteria will lead to growing utilization of aluminium.

Product Costs

Aluminium is a more expensive material (per kg) than most alternative structural materials. However, due to its low weight (resulting in cheap handling) as well as due to modern joining technologies and the possibility of developing functional combinations through utilizing especially shaped extrusions, labour costs become relatively low compared to cheaper alternative materials.





In **Figure 2101.01.15**, an illustration of the consequences of this phenomenon is presented.

This diagram (**Figure 2101.01.15**) is developed based on competitive bidding of aluminium applications in competition with equivalent steel alternatives. The diagram shows that with a weight saving of 50% compared to steel in conventional outfitting structures (stairs, stairtowers etc.), the aluminium alternative yields the same initial costs as the steel alternative. If the aluminium product becomes more than 50% lighter, aluminium is the cheapest material alternative - the lightweighting and maintenance aspects having been considered.

For primary structures (bridges, etc), approximately 63% weight saving is required before product cost equivalence aluminium/steel is achieved. If such a weight saving is not achievable, secondary effects like lightweighting, downsizing and low maintenance costs are needed to evaluate whether aluminium is an optimum material selection or not.

Load criteria

Theoretical weight savings close to 70% compared with steel and 95% compared with concrete are achievable. Consequently, aluminium has the potential of becoming the cheaper alternative already on a product cost level.

Whether such weight savings are achievable or not depends on the load criteria. The higher the dead load/live load ratio, the higher the weight saving which can be expected By the example of a 105 m long bridge **Figure 2101.01.15** illustrates where the dead load for the steel alternative represents 80% of the total load. By changing to aluminium the dimensioning load was reduced resulting in 65% weight saving and product costs 10% less than for the steel alternative. Consequently, long span constructions especially with high dead load/live load ratio are obvious candidates for aluminium utilizations.

Literature

Aluminium-Zentrale Düsseldorf (Editor): Aluminium-Schienenfahrzeuge, Entwicklungen-Technologien-Projekte. 174 pages, Hestra Darmstadt, 1992

Joliet, Hans (Editor): Aluminium, die ersten hundert Jahre. 338 pages, VDI Düsseldorf 1988/89

Koewius, A., Gross, G. and Angehrn, G.: Aluminium-Konstruktionen des Nutzfahrzeugbaus. 358 S., Aluminium-Verlag Düsseldorf, 1990

Woodward, A.R.: Gegenwärtige Probleme und zukünftige Bestrebungen bei der Verwendung von Aluminiumlegierungen auf dem Bausektor. Aluminium, Leoben 1968

Woodward, A.R. and Mc Laughton, B.D.: The Fatigue Strength of Structure Joints in Aluminium. Institution of Structural Engineers, Sheffield, July 1970 (12 References)

Woodward, A.R.: The Use of Aluminium for Stressed Components. Institution of Mechanical Engineers, Sheffield, Sept.1973 (22 References)

Woodward, A.R.: The Future Uses of Aluminium Alloys, Sixteenth John Player Lecture. The Institution of Mechanical Engineers, Sheffield, Feb. 1980

Woodward, A.R.: Developments in Aluminium and Aluminium Alloys for Extrusion. Designing with Aluminium Extrusions, Oct. 1983

Woodward, A.R.: Future Uses of Aluminium, The Metallurgist and Materials Technologist, Jan 1984

Woodward, A.R.: New Development and Applications, Aluminium Industry, July 1984

Woodward, A.R.: Developments in Aluminium Alloys, Materials and Design Sept/Oct 1989 (25 References)

Woodward, A.R.: The 80's and Beyond. Aluminium Today, Feb. 1989 (30 References)

Woodward, A.R.: Development in Aluminium - a Review. Metals and Materials, Feb. 1991

List of Figures