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Advances in Materials Technology: MONITOR

16014

Issue Number 7 October 1986

Dear Reader,

The Advances in Materials Technology: Monitor has adopted, already starting with the Issue Number 6, a new format: in double columns and with a smaller size print in order to reduce the number of pages and thus the mailing cost.

You will find again, like in our last issue, a questionnaire attached and it would be appreciated if you completed it and returned it to the editor of the Advances in Materials Technology: Monitor at your earliest convenience. It will help us to update our mailing list, eliminating obsolete addresses while at the same time improving our service to readers who have confirmed their interest in receiving the newsletter. Quite a number of questionnaires have already arrived. They will be reviewed carefully and suggestions, to the extent possible, will be taken into account.

This Monitor deals with Aluminium Alloys and we are happy to be able to present you, inter alia, with an article "Aluminium Alloys" written for UNIDO by an Austrian professor at the Montana University of Leoben, Austria, Dipl. Ing. Dr. mont. Peter Paschen. This Monitor contains further the regular Current Awareness Section and a section on Market Trends, as well with a guide to Information Sources. A list of publications on Aluminium Alloys and information on past events and future meetings on Aluminium Alloys and Materials in general as well as a section dealing with general information are also contained in this issue.

The UNIDO secretariat would welcome suggestions on topics which might be covered in future issues of the Monitor.

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The metal of the century

Development work on alloys, involving adding small amounts of manganese, copper, magnesium and silicon, took place in many countries. A major breakthrough occurred in 1906, when a German scientist, Alfred Wilm, discovered heat-treatable, age-hardening alloys which became well known as Duralumin. This name, for a long while, became synonymous with "strong aluminium".

Wilm's work led to further research on heat-treatable alloys, and to the development of the magnesium-silicon series, which is now widely used commercially and includes the most popular of today's extrusion alloys for engineering and building applications.

More exciting development work has taken place in the past decade, resulting in the aluminium-lithium series. This alloy group combines strength and stiffness with a density lower than even pure aluminium. Although still in the early stages - the first stage in the development of a production plant to melt and cast the new alloy has recently been completed by British Alcan at Birmingham - it is of particular interest to the aerospace industry.

Although aluminium is acknowledged as a highly durable material, because of the tenacious and protective oxide skin that forms around any piece of aluminium exposed to oxygen, the metal's reputation has suffered at times whilst experience was gained in the performance of the different alloy groups.

The aluminium-copper group in particular faced some setbacks in marine applications in the early part of the century - an experience that delayed aluminium's use as a marine material for many years - and in building applications in the 1940s. Experience has clearly shown these alloys, strong and as useful as they are, do not resist corrosion well unless clad with a protective layer of the pure metal. But experience has also demonstrated beyond doubt that other alloys can survive in good condition without any protection for many years.

Aluminium and its alloys are basically easy to work, and this property has led to a variety of metallurgical production processes being developed.

Extrusion: The extrusion process is of particular value in the production of both simple and complex shapes, in either a solid or hollow cross-section. Aluminium is the easiest metal to extrude.

Aluminium extrusions combine all the natural properties of aluminium and its alloys - high strength to weight coefficient, low density, good thermal and electrical conductivity, good durability and corrosion resistance, and a choice of colour finishes - with the shape potential of the extrusion process, to provide many thousands of different profiled sections for a wide range of applications in the home, in industry and transport, and even in outer space.

Alloy development has played a prominent part in the growth of the extrusion industry. The mechanical properties of pure aluminium make the metal suitable for applications where good corrosion resistance and good heat or electrical conductivity are useful, but the relative softness of the commercially-pure metal makes it unsuitable for stressed applications.

Rolling: More than 50 per cent of all aluminium produced finds its way into rolled products ranging from foil with thicknesses as little as 5 μm, through rolled sheet and strip, up to plate 100 mm or more in thickness. Applications range from foil for electrical capacitors to plate for aircraft, ships and storage tanks.

Casting goes right back to the pre-Hall-Heroult days, using sand and investment processes. Gravity and pressure die castings have been widely accepted by the automobile industry. The ability to produce strong, light-weight castings with good accuracy of shape and tolerance has enabled aluminium to compete successfully with the far cheaper alternative of cast-iron.

Forging: Aluminium forgings offer a combination of light weight, strength, accurate dimensions and excellent ductility. These design benefits are widely appreciated for aerospace, automotive and engineering applications.

Impact extrusion: This specialized production technique in which cold metal is forced backwards through a shaped die under impact pressure has been enormously successful for the manufacture of collapsible tubes for toothpaste and other applications. The technique is also used for producing thin-walled precision engineered components and gas cylinders.

Spinning and drawing: One of the earliest products to be manufactured in aluminium was holloware. Produced by spinning from circles of flat sheet, aluminium holloware was soon recognized for its light weight, high thermal conductivity, and ease of cleaning. Spinning is not confined to holloware applications, and the curved aluminium plate ends of many chemical and food carrying tankers have been produced by this method. The craftsman's art of spinning has been supplemented, where the production output warrants it, by drawing. Work on drawing techniques and suitable alloys for drawing has led successfully to the widespread adoption of aluminium for beverage cans - a market that is still growing as the advantages of aluminium, such as its good scrap and recycle value become more important.

Joining: The oxide skin that forms spontaneously on the surface of aluminium, and which gives the metal its excellent corrosion-resistant characteristics, is not entirely a benefit to aluminium. With its affinity for oxygen and its high melting point (2,000°C) it has been for many years a deterrent to the soldering, brazing and welding of aluminium.

Riveting became the accepted joining method, and in the liner "United States", built in 1951, there were well over one million rivets used in the construction of the 2,000 ton aluminium alloy superstructure.

It was the development of the inert gas welding processes that led to aluminium alloys being weldable to engineering and marine standards and, by the 1960s, welding by these methods was established.

Soldering and brazing are also more widespread, thanks to the successful development of non-corrosive fluxes, and flux-free vacuum brazing techniques. Brazed aluminium radiators are now rapidly taking over from copper/brass in cars, where the lighter weight and longer service life of the brazed aluminium component compared with soldered brass are proving particularly beneficial. High-frequency welding is another method now fully established with aluminium, and large tonnages of thin-walled tubing are now made this way.

(This excerpt is from an article which first appeared in Engineering Magazine, London, May 1986)

Some recent developments in aluminium alloys

Aluminium is a widely used metal that is benefiting from advances in formulation and processing technology. For example, ternary alloys of aluminium-lithium-magnesium and aluminium-lithium-copper are less dense and stiffer than aluminium. However, because of lithium's high reactivity, new casting techniques are needed.

Aluminium metal matrix composites containing discontinuous fibres also look promising. Silicon carbide whiskers have been used in the production of large billets of an aluminium metal matrix composite. The addition of SiC whiskers doubles the elastic modulus and strength of extruded, or rolled, products. In addition, advances in processing bring the cost of these superior structural materials down to competitive levels. Al-SiC composites are cost-effective replacements for aluminium, titanium, steel, and other alloys in structural and specialized high-technology components, aerospace, airframe and engine components, ordnance, missiles, and sports equipment.

A silicon-titanium-carbon fibre is also available for reinforcing aluminium in metal matrix composites. The material is stable in molten aluminium, eliminating the need to treat the fibres as is required with silicon carbide fibres which are not stable in molten aluminium.

A new hybrid material combines the high strength of aluminium alloys with the reinforcing capability of aramid fibres. The material retains its plasticity, impact strength, formability, and easy machining while offering a 30 per cent to 40 per cent reduction in weight. It has significantly improved fatigue strength in the unnotched state and of riveted or bolted joints. Any fatigue cracks that might be propagated are arrested by the fibre reinforcement.

The addition of small amounts of vanadium to an aluminium-magnesium-silicon alloy improves the strength, toughness, and cold formability of the alloy. Vanadium promotes the formation of a uniform, fine grained recrystallized microstructure which contributes to the improvement in final properties and processing characteristics.

A novel aluminium alloy has been developed which has all the characteristics of conventional metals but disintegrates when immersed in water. The alloy has high heat resistance, is stable under a wide variety of conditions, but falls apart in water with the release of hydrogen gas. Numerous applications are envisioned including encapsulation of organic compounds, sensors, detectors, and delayed release of marine pesticides.

A new superplastic aluminium alloy has the potential to become the leading technology for aircraft. Under proper conditions of temperature and strain rate, the material can be stretched to elongations of 500 per cent to 1,500 per cent while retaining tensile strengths of 80,000 psi. A structural part produced by superplastic-forming can be made with a weight savings of 32 per cent and at a cost saving of 36 per cent. A conventional part for an airframe consists of 18 details and 187 fasteners while a superplastic alloy part has 5 details and 16 fasteners.

A superplastic aluminium/lithium alloy has been developed that has a lower density and higher elastic modulus than other superplastic aluminium alloys.

Two new superalloys for gas turbine airfoils are nickel-based containing either aluminium and molybdenum (Ni-Mo-Al-X) or aluminium and chromium (Ni-Cr-Al-X) where X is one or more of the elements tungsten, tantalum, carbon, boron, or zirconium. The alloys are made by rapid solidification. High temperature properties are superior to currently available airfoil materials.

The American Society for Metals (Metals Park, Ohio 44073, USA) has published a superalloys source book, a convenient consolidated reference to recent developments in these high performance, high temperature materials. (Extracted from Annual Report on High-Tech Materials ... 1984: The year that was; ... 1985: The year to come. Published by Technical Insights, Inc., January 1985)

ALUMINIUM ALLOYS

Study prepared for UNIDO

by

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1. Applications

Aluminium is the youngest of the seven common metals. Whereas the history of copper, tin and iron goes back ten thousand, five thousand and three thousand years respectively, the first small production of aluminium only started in the middle of the last century - 130 years ago. Today the ranking in the production figures of the seven metals is as follows:

Iron (and steel)
Aluminium
Copper
Zinc
Lead
Nickel
Tin

This means that aluminium occupies the first place among all non-ferrous metals. This success could only be achieved by:

- The availability of raw materials;
- A highly developed production technique;
- Favourable properties; and
- The low price.

Among aluminium's properties is its low density which is probably the most important one, because the advantageous ratio weight per volume compensates for the high energy consumption per ton of aluminium in primary production.

A decisive factor for the high aluminium consumption is the ability of the element aluminium to form alloys with a large number of other metals, by means of which it is possible to create special properties for special applications. This has resulted in the development of more than one hundred aluminium alloys being technically used. Together with the various treatment methods for cast and wrought alloys this adds up to several hundreds of constitutional possibilities.

It is therefore difficult to establish a useful survey of aluminium alloys, which can only be an evaluated selection.

The following tabulated survey of the aluminium alloys' applications reveals their main utilization in:

- Transportation engineering;
- Constructional engineering;
- Mechanical engineering;
- Electrical engineering;
- Household and kitchen utensils;
- General applications;
- Special applications.

There is always a distinction between cast alloys (sand, permanent mould or die casting) and wrought alloys (rolling, extrusion and pressing).

Unfortunately the designations of aluminium alloys differ widely between countries and their standardization institutes. Compiling a survey for an international organization such as UNIDO, means that a choice for one of the national systems has to be made. Since the United States of America is the largest aluminium consumer and since the most recently published book on aluminium alloys is the German "Ullmann" in the English language, the choice for this study was made in favour of the US Aluminium Association System with cross-references to the designations of the Federal Republic of Germany, where applicable.

In the casting alloy designation system, in the 1XX.X group the second and third digits indicate the minimum aluminium percentage above 99.00. In all other groups, the second and third digits have no compositional significance but serve only to identify different alloys within the group. A zero right of the decimal indicates the product form of a casting.

Casting alloy designation system

1XX.X	$\geq$99.00% Al, no major alloying element
2XX.X	Cu as major alloying element
3XX.X	Si plus Cu and/or Mg as major alloying elements
4XX.X	Si as major alloying element
5XX.X	Mg as major alloying element
7XX.X	Zn as major alloying element
8XX.X	Sn as major alloying element.

In the wrought alloy designation system, in the 1XXX group the last two digits indicate the minimum aluminium percentage above 99.00, for example 1060 means $\geq$99.6 wt.% Al. Other groups as above (no composition significance).

Wrought alloy designation system

1XXX	99.00% Al, no major alloying element
2XXX	Cu as major alloying element
3XXX	Mn as major alloying element
4XXX	Si as major alloying element
5XXX	Mg as major alloying element
6XXX	Mg plus Si as major alloying elements
7XXX	Zn as major alloying element
8XXX	Other.

In the case of a modification of an original alloy or impurity limit the alloys can be indicated by a prefixed letter, for example A356.0.

Alloying

Primary aluminium from aluminium molten salt electrolysis contains 0.06 - 0.35 wt.% Fe, 0.05 - 0.15 wt.% Si, 0.005 - 0.02 wt.% Ti, Zr, V, Cr each, 0.002 - 0.004 wt.% Na, Ca, Li each. Small amounts of non-metallics, e.g. Al_2O_3, Al_4C_3 are always present, as well as hydrogen gas 0.00003 wt.%.

Alloying is normally carried out in the temperature range between 700 and 730°C. Alloying elements with relatively low melting points (Zn 419, Mg 650, Cu 1083) are added in elemental form, others with higher melting points in the form of master alloys. Examples for master alloys are: AlCr10, AlMn10, AlZr6, AlMn75, AlCu45, AlSi40, AlCu30Mn6, AlCu30Mn10 (numbers always giving wt.percentage of alloying element).

There are other materials besides aluminium (liquid or solid), pure alloying elements and master alloys, e.g. aluminium scrap, remelted scrap ingots, metallic recycled material.

Molten metal treatment

Most uses for aluminium alloys require low levels of non-metallic impurities. Hydrogen is particularly deleterious. Its concentration corresponds to the square root of the pressure. Therefore all purging gas processes with argon, nitrogen or chlorine lower the hydrogen content by lowering its partial pressure in the melt. Vacuum treatment can also be applied, as well as filtration systems.

ld of lication	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation		Composition (wt.%)					
					US	German	Cu	Mg	Mn	Si	Zn	others
Transportation engineering 1 **Aviation/ aerospace**	Aerospace parts	highest strength, moderate elongation	cast	sand	201.0	-	4,6	0.35	0.35	-	-	0.7 Ag 0.25 Ti
	Aircraft fittings	highest strength, good castability, pressure tightness	cast	sand	355.0	-	1.2	0.5	-	5.0	-	-
	Aircraft, missile parts	stronger and more ductile than 355.0	cast	mould	C 355.0	-	1.2	0.5	-	5.0	-	-
	Aircraft, missile parts	intricate castings with high strength and good ductility	cast	mould	A 356.0	G AlSi 7Mg GK AlSi 7Mg	-	0.35	-	7.0	-	-
	Aircraft, missile parts	good weldability, strength, toughness	cast	mould	A 357.0	-	-	0.6	-	7.0	-	0.15 Ti 0.005 Be
	Aircraft hardware		cast	die	518.0	-	-	8.0	-	-	-	-
	Aircraft fittings	strong and ductile structural uses	cast	sand	520.0	-	-	10.0	-	-	-	-
	Aircraft structures		wrought		2014	AlCuSiMn	4.4	0.5	0.8	0.8	-	-
	Aircraft structures		wrought		2024	AlCuMg 2	4.4	1.5	0.6	-	-	-
	Aircraft engines		wrought		2618	-	2.3	1.6	-	0.18	-	1.0 Ni 1.1 Fe 0.07 Ti
	Aircraft and missile components		wrought		5083	AlMg4, 5Mn	-	4.4	0.7	-	-	0.15 Cr
	Aircraft and missile components		wrought		5086	AlMg4Mn	-	4.0	0.45	-	-	0.15 Cr
	Aircraft structures		wrought		7049	-	1.5	2.5	-	-	7.6	0.16 Cr
	Aircraft structures		wrought		7050	-	2.3	2.25	-	-	6.2	0.12 Zr
	Aircraft structures		wrought		7075	AlZnMg Cu1,5	1.6	2.5	-	-	5.6	0.23 Cr
	Aircraft extrusions and forgings		wrought		7090	-	1.0	2.5	-	-	8.0	1.4 Co 0.4 O
	Aircraft structures, forgings		wrought		7175	-	1.6	2.5	-	-	5.6	0.23 Cr
	Aircraft structures		wrought		7178	-	2.0	2.8	-	-	6.8	0.23 Cr
	Aircraft structures		wrought		7475	-	1.5	2.3	-	-	5.7	0.22 Cr

Field of application	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation		Composition (wt. %)					
					US	German	Cu	Mg	Mn	Si	Zn	others
1.1.2 Rail and road traffic	truck and trailer castings	highest strength, moderate elongation	cast	sand	201.0	-	4.6	0.35	0.35	-	-	0.7 Ag, 0.25 Ti
	gasoline engines, cylinder heads and pistons	" " "	"	"								
	turbine and supercharger impellers	" " "	"	"								
	gear housings	" " "	"	"								
	liquid-cooled cylinder heads	good castability, high strength pressure tightness	cast	sand mould	355.0	-	1.2	0.5	-	5.0	-	-
	transmission cases, truck axle housings, truck wheels, cylinder blocks, cylinder heads, fan blades	intricate castings with good strength and ductility	cast	sand mould	356.0	G-AlSi7Mg	-	0.32	-	7.0	-	-
	auto transmission cases	stronger and more ductile than 356.0	cast	sand mould	A 356.0	G-AlSi7Mg GK-AlSi7Mg	-	0.35	-	7.0	-	-
	gear cases, cylinder heads for air-cooled engines, parts for auto industry	most widely used die casting alloy	cast	die	380.0	G-AlSi8Cu3 GD-AlSi8Cu3 GK-AlSi8Cu3	3.5	-	-	8.5	-	-
	auto cylinder blocks, four-cycle air-cooled engines	excellent die filling capability	cast	die	390	-	4.5	0.6	-	17.0	-	-
	auto trim	for anodic finishes, corrosion resistance	cast	die mould	513	-	-	4.0	-	-	1.8	-
	trucks and bus frame components	strong and ductile for structural uses	cast	sand	520	-	-	10.0	-	-	-	-
	rail road tankers		wrought		1060	-	-	-	-	-	-	>99.6 Al
	" " "		"		1199	-	-	-	-	-	-	>99.99 Al
	truck frames		wrought		2014	AlCuSiMn	4.4	0.5	0.8	0.8	-	-
	truck wheels		wrought		2024	AlCuMg2	4.4	1.5	0.6	-	-	-
	auto body panel sheet		wrought		2036	-	2.6	0.45	0.25	-	-	-
	transportation equipment		wrought		5083	AlMg4,5Mn	-	4.4	0.7	-	-	0.15 Cr
			"		5086	AlMg4Mn	-	4.0	0.45	-	-	0.15 Cr
	automobile body sheet		wrought		5182	-	-	4.5	0.35	-	-	-
	automotive trim		wrought		5252	-	-	2.5	-	-	-	-
	anodized auto trim		wrought		5657	-	-	0.8	-	-	-	-
	truck and railroad car	heavy duty structures	wrought		6005	-	-	0.5	-	0.8	-	-
	automobile body sheet		wrought		6009	-	0.4	0.6	0.5	0.8	-	-
			"		6010	-	0.4	0.8	0.5	1.0	-	-
	truck and railroad car	heavy duty, good corrosion resist.	wrought		6061	-	0.28	1.0	-	0.6	-	0.2 Cr
	omnibus components	high strength	wrought		6101	-	-	0.6	-	0.5	-	-
	auto parts (forgings)	moderate strength, intricate	wrought		6151	-	-	0.6	-	0.9	-	0.25 Cr
	truck/tractor extrusions	heavy duty, good corrosion resist.	wrought		6351	-	-	0.6	0.6	1.0	-	-
	refuse collection truck bodies	heavy duty, good corrosion resist.	wrought		7005	-	-	1.4	0.45	-	4.5	0.13 Cr, 0.04 Ti, 0.14 Zr

Field of application	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation US	Alloy designation German	Composition (wt. %) Cu	Mg	Mn	Si	Zn	others
1.1.3 <u>Waterway traffic</u>	marine hardware	intricate castings with good strength and ductility	cast	sand mould	356.0	G-AlSi7Mg	-	0.32	-	7.0	-	-
	marine fittings	general-purpose alloy	cast	sand mould	B443.0	-	-	-	-	5.2	-	-
	marine fittings	castings with anodic finishes and good corrosion resistance	cast	mould	513.0	-	-	4.0	-	-	1.8	-
	marine hardware		cast	die	518.0	-	-	8.0	-	-	-	-
	marine hardware		wrought		5083	AlMg4,5Mn	-	4.4	0.7	-	-	0.15 Cr
	marine hardware		wrought		5086	AlMg4Mn	-	4.0	0.45	-	-	0.15 Cr
	saltwater service		wrought		5154	-	-	3.5	-	-	-	0.25 Cr
	marine service		wrought		5454	AlMg2,7Mn	-	2.7	0.8	-	-	0.12 Cr
	marine applications		wrought		5456	-	-	5.1	0.8	-	-	0.12 Cr
	marine hardware		wrought		6005	-	-	0.5	-	0.8	-	-
	marine hardware		wrought		6061	-	0.28	1.0	-	0.6	-	0.20 Cr
1.2 <u>Constructional Engineering</u>	architectural fittings	general-purpose alloy	cast	sand mould	B443.0	-	-	-	-	5.2	-	-
	sheet metal work		wrought		1100	-	0.12	-	-	-	-	> 99.0 Al
	sheet metal work, building hardware		wrought		3003	AlMnCu	0.12	-	1.2	-	-	-
	sheet metal work		wrought		3004	AlMn1Mg1	-	1.0	1.2	-	-	-
	residential siding, mobile homes, rain-carrying goods		wrought		3105	AlMn0,5Mg0,5	-	0.5	0.6	-	-	-
	architectural		wrought		5005	-	-	0.8	-	-	-	-
	builder's hardware		wrought		5050	-	-	1.4	-	-	-	-
	sheet metal work		wrought		5052	AlMg2,5	-	2.5	-	-	-	0.25 Cr
	architectural extrusion		wrought		6063	-	-	0.7	-	0.4	-	-
	architectural extrusion		wrought		6463	-	-	0.7	-	0.4	-	-
1.3 <u>Mechanical Engineering</u>	structural castings	highest strength, moderate elongation	cast	sand	201.0	-	4.6	0.35	0.35	-	-	0.7 Ag, 0.25 Ti
	pump bodies, impellers	good castability, high strength, pressure tightness	cast	sand mould	355.0	-	1.2	0.5	-	5.0	-	-
	structural parts	stronger and more ductile	cast	mould	C355.0	-	1.2	0.5	-	5.0	-	-
	lawnmower housings	most widely used die casting alloy	cast	die	380.0	GD-AlSi8Cu3	3.5	-	-	8.5	-	-
	air compressors	low thermal expansion, good abrasion resistance, elevated temperature strength	cast	die	390.0	-	4.5	0.6	-	17.0	-	-
	pipe couplings	parts with anodic finishes and corrosion resistance	cast	mould	513.0	-	-	4.0	-	-	1.8	-
	escalator parts, conveyor components		cast	die	518.0	-	-	8.0	-	-	-	-
	large castings (general)	strength without heat treatment	cast	sand mould	713.0	-	0.7	0.35	-	-	7.5	-
	bearings and bushings	heavy loads	cast	sand mould	852.0	-	2.0	0.75	-	-	-	6.25 Sn, 1.2 Ni

Field of application	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation		Composition (wt. %)					
					US	German	Cu	Mg	Mn	Si	Zn	others
1.3 <u>Mechanical Engineering</u> (continued)	chemical equipment		wrought		106C	-	-	-	-	-	-	≥ 99,6 Al
	fin stock		wrought		1100	-	0.12	-	-	-	-	≥ 99,0 Al
	chemical equipment		wrought		1199	-	-	-	-	-	-	≥ 99,99 Al
	screw machine products		wrought		2011	AlCuBiPb	5.5	-	-	-	-	0.4 Pb, 0.4 Bi
	chemical equipment, pressure vessels		wrought		3003	AlMnCu	0.12	-	1.2	-	-	-
	storage tanks		wrought		3004	AlMn1Mg1	-	1.0	1.2	-	-	-
	engine pistons		wrought		4032	-	0.9	1.0	-	12.2	-	0.9 Ni
	refrigerator trim, coiled tubes		wrought		5050	-	-	1.4	-	-	-	-
	hydraulic tubes		wrought		5052	AlMg2,5	-	2.5	-	-	-	0.25 Cr
	rivets for Mg, screen wire, zippers		wrought		5056	-	-	5.0	0.12	-	-	0.12 Cr
	cryogenics, drilling rigs		wrought		5083	AlMg4,5Mn	-	4.4	0.7	-	-	0.15 Cr
	pressure vessels, cryogenics, drilling rigs		wrought		5086	AlMg4Mn	-	4.0	0.45	-	-	0.15 Cr
	welded structures, storage tanks, pressure vessel		wrought		5154	-	-	3.5	-	-	-	0.25 Cr
	hydrogen peroxide and chemical storage vessels		wrought		5254	-	-	3.5	-	-	-	0.25 Cr
	welded structures, pressure vessels		wrought		5454	AlMg2,7Mn	-	2.7	0.8	-	-	0.12 Cr
	storage tanks, pressure vessels		wrought		5456	-	-	5.1	0.8	-	-	0.12 Cr
	hydrogen peroxide, chemical storage vessels		wrought		5652	-	-	2.5	-	-	-	0.25 Cr
	pipelines		wrought		6005	-	-	0.5	-	0.8	-	-
	pipelines		wrought		6061	-	0.28	1.0	-	0.6	-	0.20 Cr
	pipelines		wrought		6070	-	0.28	0.8	0.7	1.4	-	-
	screw machine products		wrought		6262	-	0.28	1.0	-	0.6	-	0.09 Cr, 0.6 Pb, 0.6 Bi
	fin stock, cladding alloy		wrought		7072	-	-	-	-	-	1.0	-
1.4 <u>Electrical Engineering</u>	electrical industry	most widely used die casting alloy	cast	die	380.0	GD-AlSi8Cu3	3.5	-	-	8.5	-	-
	electrical conductors		wrought		1350	-	-	-	-	-	-	99.5 Al
	welding electrodes		wrought		4043	-	-	-	-	5.2	-	-
	electrical conductors		wrought		5005	-	-	0.8	-	-	-	-
	welding electrodes		wrought		5356	-	-	5.0	0.12	-	-	0.12 Cr, 0.13 Ti
	high-strength electric conductor wire		wrought		6201	-	-	0.8	-	0.7	-	-

Field of application	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation US	Alloy designation German	Composition (wt. %) Cu	Mg	Mn	Si	Zn	others
1.5 <u>Household and kitchen utensils</u>	cooking utensils, waffle irons	general purpose alloy	cast	sand mould	B443.0	-	-	-	-	5.2	-	-
	spun hollowware		wrought		1100	-	0.12	-	-	-	-	99.0 Al
	cooking utensils		wrought		3003	AlMnCu	0.12	-	1.2	-	-	-
	can bodies		wrought		3004	AlMn1Mg1	-	1.0	1.2	-	-	-
	can ends		wrought		5182	-	-	4.5	0.35	-	-	-
	furniture	good corrosion resistance	wrought		6005	-	-	0.5	-	0.8	-	-
	furniture	good corrosion resistance	wrought		6061	-	0.28	1.0	-	0.6	-	0.2 Cr
	furniture		wrought		6063	-	-	0.7	-	0.4	-	-
1.6 <u>General applications</u>	-	highest strength, moderate elongation; elevated temperature strength; energy absorption capacity	cast	sand	201.0	-	4.6	0.35	0.35	-	-	0.7 Ag, 0.25 Ti
		good castability, high strength, tight pressure	cast	sand mould	355.0	-	1.2	0.5	-	5.0	-	-
		stronger and more ductile than 355.0	cast	sand mould	C355.0	-	1.2	0.5	-	5.0	-	-
		intricate castings, good strength and ductility	cast	sand mould	356.0	G-AlSi7Mg	-	0.32	-	7.0	-	-
		stronger and more ductile than 356.0	cast	sand mould	A356.0	G-AlSi7Mg	-	0.35	-	7.0	-	-
		weldability, strength, toughness	cast	sand mould	A357.0	-	-	0.6	-	7.0	-	0.15 Ti, 0.005 Be
		better corrosion resistance than 380.0	cast	die	360.0	-	-	0.5	-	9.5	-	-
		most wiedely used die-casting alloy	cast	die	380.0	GD-AlSi8Cu3	3.5	-	-	8.5	-	-
		abrasion resistance, low thermal expansion, high temperature strength	cast	die	390.0	-	4.5	0.6	-	17.0	-	-
		thin-walled intricate designs, excellent castability	cast	die	413.0	GD-AlSi12	-	-	-	12.0	-	-
		general purpose alloy	cast	sand mould	B 443.0	-	-	-	-	5.2	-	-
		for anodic finishes, good corrosion resistance	cast	mould	513.0	-	-	4.0	-	-	1.8	-
		strong and ductile structural uses	cast	sand	520.0	-	-	10.0	-	-	-	-
		large castings with strength without heat treatment	cast	sand mould	713.0	-	0.7	0.35	-	-	7.5	-
		structural uses at high temperatures, high strength weldments	wrought		2219	-	6.3	-	0.3	-	-	0.06 Ti, 0.1 V, 0.18 Zr
		high strength welded structures	wrought		5456	-	-	5.1	0.8	-	-	0.12 Cr
		heavy-duty structures with good corrosion resistance	wrought		6005	-	-	0.5	-	0.8	-	-

Field of application	Special application	Application remarks	Cast or wrought	Cast in	Alloy designation		Composition (wt. %)					
					US	German	Cu	Mg	Mn	Si	Zn	others
1.6 General application (continued)		heavy-duty structures with good corrosion resistance	wrought		6061	-	0.28	1.0	-	0.6	-	0.2 Cr
		forgings and extrusions for welded structures	wrought		6066	-	1.0	1.1	0.8	1.4	-	-
		heavy-duty welded structures	wrought		6070	-	0.28	0.8	0.7	1.4	-	-
		heavy-duty structures with good corrosion resistance	wrought		6351	-	-	0.6	0.6	1.0	-	-
		heavy-duty structures with good corrosion resistance	wrought		7005	-	-	1.4	0.45	-	4.5	0.13 Cr, 0.04 Ti, 0.14 Zr
1.7 Special application	missile fins	elevated temperature strength	cast	sand	201.0	-	4.6	0.35	0.35	-	-	0.7 Ag, 0.25 Ti
	missile parts	strong and ductile	cast	sand mould	C355.0	-	1.2	0.5	-	5.0	-	-
	missile parts	strong and ductile	cast	sand, mould	A356.0	G-AlSi7Mg	-	0.35	-	7.0	-	-
	missile parts	weldability, strength and toughness	cast	sand mould	A357.0	-	-	0.6	-	7.0	-	0.15 Ti, 0.005 Be
	electrolytic capacitor foil		wrought		1199	-	-	-	-	-	-	≥ 99,99 Al
	military supersonic aircraft		wrought		2124	-	4.4	1.5	0.6	-	-	-
	missile components, ballistic armour		wrought		5083	AlMg4,5Mn	-	4.4	0.7	-	-	0.15 Cr
	missile components		wrought		5086	AlMg4Mn	-	4.0	0.45	-	-	0.15 Cr

2. Mechanical properties

The mechanical properties of aluminium alloys depend on the metallurgical structure, which in turn depends on the composition, solidification process and post-solidification thermal and deformation treatment.

The main alloying elements - copper, magnesium, manganese, silicon, zinc, chromium and zirconium form an eutectic composition with aluminium. In cooling down from the liquid state they show a primary crystallization of mixed aluminium crystal. The primary crystallization starts at the liquidus temperature, lower than the aluminium melting point, and ends at the eutectic temperature, which is at the same time the solidus temperature.

The structure of the alloy at room temperature consists in the most simple form of two different mixed crystals, that of the aluminium and that of the alloying element - a two-phase structure. To improve strength and hardness of the alloy, it is favourable that the alloy when cooling down in the solid state precipitates a new phase. This can be achieved by crossing a line of decreasing solubility in the binary diagram of the alloy. Since all aluminium alloys are more than binary, it becomes more and more difficult to predict and explain all phases and their changes in dependence on temperature. In many cases pre-precipitation stages of new phases are most effective.

The second method for improving strength and hardness is to subject the original cast product (cake, billet) to a cold deformation by rolling, extruding or forging. This deformation destroys the primary cast structure and builds up another one, mostly with finer grain size and stretched in the direction of deformation. Special lattice defaults, so-called dislocations, together with grain boundaries and alloying or impurity atoms form a system of interactions, which yields high strength and hardness.

All these structural effects can be altered by changing the temperature. In this fact all thermal treatments are vested.

Cast alloys do not have this great variety of thermal and mechanical treatments and combinations. Nevertheless, the size of the crystals and the so-called dendrite cell size is influenced by the cooling rate. Die cast parts have finer grain sizes than those cast in a permanent mould, which in turn have a finer grain size than those cast in sand.

Thermal processes

Before a cast intermediate product, e.g. an ingot, cake or billet can be submitted to a deformation process, it usually has to undergo preheating and homogenizing. This is done at a relatively high temperature (only 100° to 50° C below solidus temperature) and lasts from some hours to a few days. Micro-segregations are dissolved by diffusion and alloying elements are brought into solid solution (aluminium mixed crystal). By subsequent controlled slow cooling very fine precipitates are generated as these are desired for most properties.

A typical precipitation sequence is: Supersaturated solid solution - so-called Guinier-Preston zones (one-phase decomposition) - metastable phases - stable phases. The major commercial heat-treatable alloy systems Al-Cu, Al-Cu-Mg, Al-Cu-Mg-Si, Al-Mg, Al-Mg-Si, Al-Zn-Mg-Cu, Al-Li-Cu show these kinds of sequences. In the course of precipitation the strength increases either at room temperature (natural aging) or at slightly elevated temperatures (artificial aging). If the aging procedure is continued over the strength peak, we call it overaging.

Natural aging can take from 10 to 10,000 hours and result in an increase of yield strength to more than double. Elongation decreases slightly. Artificial aging was discovered and is still mainly carried out with Al-Cu alloys. Temperature and time are controlled in such a way that maximum strength and hardness are attained before a distinct two-phase structure takes place (overaging effect). Temperatures range between 130° and 260°C over one to 100 hours. Overaging results in more stable properties, increases toughness, but with a certain decrease in strength and hardness.

The table on pages 13, 14 and 15 indicates the three mechanical properties - yield strength and tensile strength (both in MPa) and elongation (in percentage). These are obtained in the tensile test. The respective heat treatment conditions are indicated and the values measured.

3. Physical properties

The physical properties of aluminium alloys also depend on the chemical composition of the alloy - though to a somewhat lesser extent than the mechanical ones. For comparison some physical properties of the element Al are given:

Atomic number	13
Atomic weight	26.98
Lattice	f. ctr. cubic
Lattice constant at 20°C	4,049 . 10^{-8}cm
Density at 20°C	2.6989 g . cm^{-3}
at 660°C solid	2.55 g . cm^{-3}
at 660°C liquid	2.37 g . cm^{-3}
at 900°C	2.30 g . cm^{-3}
Volume decrease, liquid - solid	7%
Linear shrinkage between 660° and 20°C	1.8%
Average coefficient of thermal expansion, 20° - 100°C	23.86.10^{-6}.K^{-1}
20° - 500°C	27.68.10^{-6}.K^{-1}
Modulus of elasticity	72.0 GPa
Melting point	660.24°C
Heat of fusion	397.3 kJ . kg^{-1}
Boiling point	2,500°C
Specific heat at 20°C	0.90 J.g^{-1}.K^{-1}
at 658°C, solid	1.13 J.g^{-1}.K^{-1}
at 700°C, liquid	1.05 J.g^{-1}.K^{-1}
Electrical conductivity	37.7 m. $^{-1}mm^{-2}$
Thermal conductance	2.3 J.$cm^{-1}s^{-1}K^{-1}$

The table on page 16 lists the four physical properties - melting range, density, average coefficient of thermal expansion and modulus of elasticity for all the above-mentioned alloys.

Alloy and production method		Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
201.0	sand	solution heat treated, artificially aged	345	414	5.0
		solution heat treated, overaged/stabilized	345	414	3.0
355.0	sand	solution heat treated, artificially aged	138	221	2.0
		artificially aged, varied	124	172	
		solution heat treated, overaged/stabilized, varied	152	207	
	mould	solution heat treated, artificially aged		255	1.5
		artificially aged, varied		186	
		solution heat treated, overaged/stabilized, varied	186	234	
		solution heat treated, artificially aged, varied		290	
		solution heat treated, overaged/stabilized		248	
C355.0	sand	solution heat treated, artificially aged	172	248	2.5
	mould	solution heat treated, artificially aged, varied	207	276	3.0
356.0	sand	as cast		131	2.0
		solution heat treated, artificially aged	138	207	3.0
		solution heat treated, overaged/stabilized		214	
		artificially aged, varied	110	159	
		solution heat treated, overaged/stabilized, varied	124	172	3.0
	mould	as cast		145	3.0
		solution heat treated, artificially aged	152	228	3.0
		artificially aged, varied		172	
		solution heat treated, overaged/stabilized, varied		172	3.0
A356.0	sand	solution heat treated, artificially aged	166	234	3.5
	mould	solution heat treated, artificially aged, varied	179	255	5.0
A357.0	mould	solution heat treated, artificially aged, varied	248	310	3.0
360.0	die	as cast	170	315	2.5
380.0	die	as cast	160	320	3.0
390.0	die	as cast	245	280	1.0
		artificially aged	260	295	1.0
413.0	die	as cast	140	300	2.5

Alloy and production method		Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	
B443.0	sand	as cast	41	117	3.0	
	mould	as cast	41	145	2.5	
513.0	mould	as cast	83	152	2.5	
518.0	die	as cast	190	310	6.0	
520.0	sand	solution heat treated, naturally aged (stable)	152	290	12.0	
713.0	sand	artificially aged	152	207	3.0	
	mould	artificially aged	152	221	4.0	
852.0	sand	artificially aged	124	166		
	mould	artificially aged		186	3.0	
					1.6 mm thick	12.5 mm diam.
1100	wrought	annealed	34	90	35	
		strain hardened without supplem. thermal treatment	150	165	5	
2011	wrought	thermally treated, stable tempers by natural aging	295	380		15
		solution heat treated, artificially aged	310	405		15
2024	wrought	annealed	76	185	20	20
		solution heat treated, naturally aged	345	485	18	
		solution heat treated, artificially aged	490	517	5	
2036	wrought	solution heat treated, naturally aged	195	340	24	
2219	wrought	annealed	75	170	18	
		solution heat treated, artificially aged	395	475	10	
3003	wrought	annealed	42	110	30	40
		strain hardened without supplem. thermal treatment	185	200	4	10

Alloy and production method		Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	
					1.6 mm thick	12.5 mm diam.
3004	wrought	annealed	69	180	20	25
		strain hardened and stabilized	250	285	5	6
4032	wrought	solution heat treated, artificially aged	315	380		9
4043	wrought	annealed	69	145	22	
		strain hardened without supplem. thermal treatment	270	285	1	
5052	wrought	annealed	90	195	25	27
		strain hardened and stabilized	255	290	7	
5182	wrought	annealed	140	275	25	
		strain hardened without supplem. thermal treatment	395	420	4	
5456	wrought	annealed	160	310		22
		strain hardened and stabilized	255	350		14
6010	wrought	solution heat treated, naturally aged	170	290	24	
6061	wrought	annealed	55	125	25	30
		solution heat treated, naturally aged	145	240	22	25
		solution heat treated, artificially aged	275	310	12	17
6066	wrought	annealed	83	150		18
		solution heat treated, artificially aged	360	395		12
7005	wrought	artificially aged	345	393	15	
7050	wrought	solution heat treated, overaged/stabilized	455	510		11
		solution heat treated, overaged/stabilized, varied	475	530		11
7075	wrought	solution heat treated, artificially aged	505	570	11	11
		solution heat treated, overaged/stabilized	435	505	13	
7090	wrought	solution heat treated, overaged/stabilized, special	515	565		13

Alloy	Melting range (°C)	Density at 25 °C $g.cm^{-3}$	Av. coeff. therm. expans. (20 - 100 °C) $10^{-6}.K^{-1}$	Modulus of elasticity GPa
201.0	535 - 650	2.77	19.3	71.0
355.0 C355.0	545 - 620	2.71	22.4	70.3
356.0 A356.0	555 - 615	2.69	21.5	72.4
A357.0	555 - 615	2.68	21.6	71.1
360.0	555 - 595	2.63	21.0	71.0
380.0	540 - 595	2.74	21.0	71.1
390.0	505 - 650	2.73	18.0	81.2
413.0	575 - 582	2.66	20.4	
B443.0	575 - 630	2.69	22.0	71.0
513.0	580 - 640	2.65	24.0	
518.0	535 - 620	2.57	24.1	
520.0	450 - 605	2.57	25.0	66.0
713.0	595 - 640	2.81	24.0	
852.0	205 - 635	2.88	23.3	
1100	640 - 655	2.71	23.6	69.0
2011	540 - 640	2.83	22.9	70.0
2024	500 - 635	2.78	23.2	73.0
2036	555 - 650	2.75	23.4	71.0
2219	545 - 645	2.84	22.3	73.0
3003	640 - 655	2.73	23.2	69.0
3004	630 - 655	2.72	23.9	69.0
4032	530 - 570	2.68	19.4	79.0
4043	575 - 630	2.68	22.0	
5052	605 - 650	2.68	23.8	70.0
5182	575 - 640	2.65	24.1	71.0
5456	570 - 640	2.66	23.9	71.0
6010	585 - 650	2.70	23.2	69.0
6061	580 - 650	2.70	23.6	69.0
6066	560 - 645	2.72	23.2	69.0
7005		2.78		72.0
7050	488 - 635	2.82	23.0	72.0
7075	532 - 635	2.80	23.6	72.0
7090	550 - 635	2.85	23.8	75.0

4. Foundry and product characteristics of cast alloys

The foundry characteristics illustrate the suitability for casting alloys, although this suitability cannot be given in exact numerical values. In the following six tables therefore a rating has been established from one to five, one representing the best suitability and five the least. These ratings are relative in each casting category, whether sand, permanent mould or die casting.

Resistance to hot cracking is the ability to withstand contraction stresses during cooling. This cracking may occur during the solidification of an alloy at the change from a thinner to a thicker cross-section. The main influence parameters are the melting range and cooling conditions, e.g. heat transfer, temperature of the metal, temperature of the mould and the grain size resulting from these conditions. There are several methods to improve resistance to hot cracking (i.e. grain refining, oxide removal, constructional design or cooling plates).

Pressure tightness is an indication of the soundness of the cast part and the freedom from leakage to fluids under pressure. Mechanical properties under pressure and porosity of the cast part are the main parameters.

Resistance to corrosion refers to general corrosion behaviour in a standard salt spray test. This test serves as an examination of the behaviour in a maritime climate, the test medium being a 3% NaCl solution. The decrease in strength and elongation is a measure of the corrosion.

Machining is a composite rating based on ease of cutting, chip characteristics, quality of finish and tool life. The comparison possibilities are limited and the test procedures are not standardized.

Polishing means the possibility to polish a part and improve the quality of finish. A smooth surface is a precondition; polishing powders and paste, and their grain size, have a definite influence.

Electroplating indicates the ability to take and hold an electroplated coating. The reason for doing this is either to improve the appearance of the part (decorative) or the wear resistance of the surface, e.g. for the cylinders of a motor. A pretreatment of the surface is necessary; the first layer is normally of copper, whereupon an electroplating of other metals (nickel, chromium and precious metals) can take place.

Anodizing is based on lightness of colour, brightness and uniformity of the clear, anodized coating applied in sulphuric acid electrolyte. The aim of the total procedure is to obtain an increased oxide layer. In the electrolytic process the part to be anodized serves as anode ("anodizing"). Both direct and alternating current are applied; sulphuric acid is the electrolyte most frequently used.

Chemical oxide coating produces an aluminium oxide protective layer as well, but much thinner than in the case of anodizing. A great variety of different processes is applied, most of them leading to chromate or phosphate compounds.

Strength at elevated temperatures is a very important property for many uses of aluminium alloys. Yield and tensile strength and hardness normally decrease and elongation increases at temperatures higher than room temperature. Chemical composition and physical structure dominate the high temperature behaviour. Apart from which, time plays an important role, the structure of an alloy changes in the course of time and under a constant load (creep), especially in the case of cold deformation hardened alloys.

Suitability for welding and brazing is necessary for many aluminium alloy applications. Techniques for welding and brazing have reached a high standard of quality. A great variety of processes can be applied: autogenous, electric arc, protective gas welding (MIG), (WIG), resistance and pressure welding and ultra-sonic, high frequency, electron beam welding. The possibilities for brazing are nearly as good; it must however be borne in mind that the strength of the joint is lower.

Fluidity and die filling capability indicate the ability of the molten metal to flow into all parts of the mould. Characteristic parameters are viscosity, surface tension, heat content of the melt, casting temperature and solidification type (chemical composition and content of impurities). In the case of die casting, the properties of the die itself (surface, temperature) are additionally effective. This corresponds to the phenomenon of:

Soldering to die which must be prevented by special sprays injected into the die after every metal shot;

Solidification shrinkage which means that the alloy is not subject to shrinkage porosity.

5. Evaluation of the alloys with respect to the developing countries

The requirement for the developing countries to build up an aluminium alloy industry will be not to use too great a variety of alloys but rather to use some standard alloys for as many applications as possible. The integrated evaluation of all cited alloys with respect to:

- Mechanical properties,

- Physical properties,

- Foundry characteristics,

- Product characteristics,

gives the following result:

The number one alloy is alloy 357 in case of casting alloys. It is an Al-Si alloy with 7 wt.% Si and with 0.6 Mg, 0.15 Ti, 0.005 Be as further additions. It can be cast in both sand and permanent moulds, and has good mechanical properties when solution heat treated and artificially aged. Polishing and anodizing properties are somewhat poor. Its applications are in transportation engineering (aviation/aerospace) and in all other fields where good weldability, strength and toughness are required.

Of the casting alloys ranks second the alloy 360, a die casting alloy with 9.5 wt.% Si and 0.5 wt.% Mg with very good corrosion resistance. The mechanical properties are good in the "as cast" state already mentioned and there appears to be no weak point among the technological properties.

A very broad field of applications can be covered by using the alloy 355, an Al-Si-Cu alloy with 5 wt.% Si, 1.2 wt.% Cu and 0.5 wt.% Mg. It can be cast in sand and permanent moulds. The mechanical properties are in the range of medium to good; artificial aging after solution heat treating renders the best results. The anodizing appearance is poor, but this is the only weak point in the technological properties. This alloy can be used for transportation engineering, for aviation and aerospace, for rail and road traffic (cylinder heads), for mechanical engineering (pump bodies, impellers etc.).

Resistance to hot cracking		1	2	3	4	5
	sand	355.0 356.0 357.0 443.0				
			520.0			
					201.0	
						713.0 852.0
	mould	355.0 356.0 357.0 443.0				
					513.0	
						852.0
	die	360.0 413.0				
			380.0			
					390.0	
						518.0
Pressure tightness						
	sand	355.0 356.0 357.0 443.0				
				201.0 713.0		
						520.0 852.0
	mould	355.0 356.0 357.0 443.0				
						513.0 852.0
	die	413.0				
			360.0 380.0			
					390.0	
						518.0

Corrosion resistance		1	2	3	4	5
	sand	520.0				
			356.0 357.0 443.0 713.0			
				355.0 852.0		
					201.0	
	mould	513.0				
			356.0 357.0 443.0			
				355.0 852.0		
	die	518.0				
			360.0 413.0			
				390.0		
					380.0	
Machining						
	sand	201.0 520.0 713.0 852.0				
				355.0 357.0		
					356.0	
						443.0
	mould	513.0 852.0				
				355.0 356.0 357.0		
						443.0
	die	518.0				
				360.0 380.0		
					413.0	
						390.0

		1	2	3	4	5
Polishing	sand	201.0 520.0 713.0 852.0				
				355.0		
					357.0	
						356.0 443.0
	mould	513.0 852.0				
				355.0 356.0 357.0		
					443.0	
	die	518.0				
				360.0 380.0		
						390.0 413.0
Electroplating	sand	201.0 355.0				
			356.0 443.0 713.0			
					520.0	
						852.0
	mould	356.0 357.0				
			355.0 443.0			
					513.0	
						852.0
	die	380.0				
			360.0			
				390.0 413.0		
						518.0

		1	2	3	4	5
Anodizing appearance						
	sand	520.0				
			201.0 713.0			
					355.0 356.0 357.0 852.0	
						443.0
	mould	513.0				
					355.0 356.0 357.0 443.0 852.0	
	die	518.0				
				360.0 380.0		
						390.0 413.0
Chemical oxide coating						
	sand	520.0				
			201.0 355.0 356.0 443.0			
				713.0		
						852.0
	mould	513.0				
			355.0 356.0 357.0 443.0			
						852.0
	die	518.0				
				360.0 413.0		
					380.0	
						390.0

		1	2	3	4	5
Strength at elevated temperature						
	sand	201.0	355.0 357.0	356.0	443.0	713.0
	mould		355.0	356.0 357.0 513.0	443.0	
	die	360.0		380.0 390.0 413.0	518.0	
Suitability for welding						
	sand	357.0 443.0	355.0 356.0		201.0 713.0	852.0 520.0
	mould	443.0	355.0 356.0 357.0			513.0 852.0
Suitability for brazing						
	sand	713.0		443.0		
	mould			443.0		

		1	2	3	4	5
Fluidity	sand	355.0 356.0 357.0 443.0				
				201.0		
					520.0 713.0	
						852.0
	mould	443.0				
			355.0 356.0 357.0			
						513.0 852.0
Solidification shrinkage	sand	355.0 356.0 443.0				
					201.0 713.0	
						520.0 852.0
	mould	356.0 357.0				
			355.0 443.0			
					513.0	
						852.0
Die filling capability	die	390.0 413.0				
			380.0			
				360.0		
						518.0
Soldering to die	die	380.0 413.0				
			360.0 390.0			
						518.0

The copper-free alloy 356 (7.0 and 0.35 respectively wt.% Si and Mg) can additionally be used for marine applications. In rail and road traffic applications it is widely used for transmission cases, truck axle housings, truck wheels, cylinder blocks, cylinder heads, fan blades, and transmission cases. The mechanical properties are satisfactory in the aged or even overaged and stabilized conditions; however the polishing quality is bad.

The most widely used die casting alloy, which can also be cast in sand and permanent moulds, is alloy 380. A lot of parts for the automobile industry are manufactured from this alloy (8.5 and 2.5 wt.% respectively Si and Cu). Mechanical and electrical engineering are further uses. It can be applied in the "as cast" condition. The technological properties are satisfactory.

From the point of view of mechanical properties alone, the alloy 201 shows the best results. On the other hand its composition is complicated: 4.6 Cu, 0.7 Ag (!), 0.35 Mg, 0.35 Mn, 0.25 Ti (all in wt.%). It is a sand casting alloy, but has to undergo a solution heat treatment with aging, overaging and stabilizing treatment in order to reach the most favourable properties. The strength remains high even at elevated temperatures.

The binary Al-Mg alloys 518 and 520 with 8.0 wt.% respectively of magnesium can be used for bigger castings, such as aircraft fittings, truck and bus frame components, marine hardware, escalator parts and conveyor components. The heat treatment of the sand cast alloy 520 is simple (only natural aging after solution heat treatment) and the die cast alloy 518 can be used "as cast". Sometimes it will be necessary to bear in mind the high average coefficient of thermal expansion and the low modulus of elasticity. Some technological properties are unfavourable: resistance to hot cracking, pressure tightness, electroplating, suitability for welding and brazing, solidification shrinkage, die filling capability and soldering to die.

The relatively cheap and simple, but not high-quality binary Al-Si alloy 443 with 5.2 wt.% silicon should not be forgotten, because it is a kind of general-purpose alloy, cast in sand or mould and often used for cooking utensils, but because of its poor strength and hardness (the machining, polishing and anodizing quality is bad), it should preferably not be used.

A survey of the wrought alloys shows a predominance of the Al-Zn-Mg-Cu alloys with or without the addition of further elements such as zirconium, chromium and cobalt. These are the alloys 7050, 7075 and 7090. Their tensile and yield strength is excellent, with relatively good elongation figures. Of course, the deformation and heat treatment procedures are not very easy. The density is high. These alloys find their applications in aircraft structures.

For the very important rail and road traffic applications many wrought alloys of different composition exist. The range is from pure aluminium, 1060 and 1199, used widely for tankers, to heavy-duty, corrosion resistant 7005 with zinc, magnesium, manganese, zirconium, chromium and titanium for truck and tractor bodies and extrusion parts. Waterway traffic applications - as always - prefer copper-free alloys, 508X and 545X, with magnesium and manganese as the main and chromium as the minor constituent.

For constructional and mechanical engineering uses it is nearly impossible to pick out some special alloys. Most of them have magnesium as their main component and are thus 5XXX type alloys. In developing countries one has to look for the desired special applications (for example, uses in mobile homes, window frames, chemical equipment, tanks, vessels, pipelines etc.).

For household and cooking utensils the alloys 3003 and 3004 are used, the first containing 1.2 wt.% Mn with 0.12 wt.% Cu and the second 1.2 wt.% Mn and 1.0 wt.% Mg. The satisfactory mechanical properties are reached after annealing and strain hardening with or without stabilization.

General recommendations for the developing countries cannot be given. The state of development is so different between say Chad and Bangladesh or Malaysia and Brazil. In a country where up to now no metalworking industry exists, the recommendation could be given to start with casting alloys and erecting foundries rather than rolling mills, extrusion presses and forging mills. Preference should be given to sand and permanent mould casting; a start could be made with the alloys 355, 356, 520 and 443.

The chemical composition for these is not too complicated:

	Cu	Mg	Si
355	1.2	0.5	5.0
356	-	0.35	7.0
520	-	10.0	-
443	-	-	5.2

This makes scrap handling easier. A broad field of applications could be covered: aviation and aerospace, rail and road traffic, marine uses, architectural parts, mechanical engineering uses such as pump bodies, household and kitchen utensils.

6. Production

Sand casting is the least expensive process, although the mould is not reusable which is formed by ramming a sand mixture with bonding agents around a pattern. Sand casting is always applied if the number of pieces of the same shape is very low or if the cast part is rather intricate, i.e. with cavities or if it is a rather large piece.

The variety, quality, treatment, dressing and retreatment of the foundry sand is a subject of its own, and requires very specific knowledge. A pattern or model of the cast part has to be made out of wood, gypsum, plastic or metal. A rather modern development is the use of polystyrene, which is not taken out before casting, but burnt out by the liquid metal during the casting procedure. Notice has to be taken of the volume shrinkage of the alloys during solidification and cooling.

The moulding is done either by hand or by machines. Some special processes use carbonic acid or the forming of masks (croning). The quality of the cast piece can be influenced to a great extent by the skill used when gating. Cooling plates can prevent shrinkholes.

The sand mould is gravity fed. A principal disadvantage is the slow cooling rate, the poor surface finish and a certain minimum wall thickness (order of magnitude 4 mm).

Permanent mould casting necessitates a series production of the same piece so that the expensive mould can be justified by a large number of pieces. The mould is made of cast iron or steel. The mould is gravity fed so that the pouring rate is still relatively slow, but the freezing and cooling of the metal in the mould proceeds very much quicker than in sand casting.

Alloys with good fluidity and resistance to hot cracking produce sound pieces with satisfactory mechanical properties which can even be improved by subsequent thermal treatment.

The production of a permanent mould needs a good machine-building knowledge and capacity; the gating is very important for the flow of the metal inside the mould. During casting the temperature of the mould has to be continuously controlled and, if necessary, cooled. A rule of thumb is "hot mould, cold metal". Facing and spraying of the mould has to be done at regular intervals.

Special processes for permanent mould casting are centrifugation casting and - a rather novel development - vacuum casting.

Because of the recommendation to start an aluminium alloy manufacturing in developing countries with sand and mould cast parts the description of die casting and rolling, extrusion and forging processes is not included in this study.

7. Present research and future developments

Of the numerous research activities on aluminium alloys being carried out all over the world, only two developments need to be mentioned:

Aluminium-lithium alloys

Saving energy by saving fuel, saving fuel by saving weight in all kinds of transportation systems, especially in aircraft and aerospace transportation is still the main goal. The presently available wrought alloys for these uses, the alloys 2014, 2024, 7005, 7050, and 7075 have densities between 2.77 and 2.82 (pure aluminium 2.7). Al-Li alloys with Li contents between 2.0 and 2.6 wt.% with additions of copper, magnesium and zirconium have a density of about 2.54 which means roughly a 9% decrease. Additionally, the Al-Li alloys show a very high modulus of elasticity, nearly 80 GPa, compared to 72 - 75 mostly used as aircraft alloys at present.

The new type of alloy could be competitive even with carbon-whisker composite materials, for which completely new manufacturing procedures have to be developed.

The second generation of Al-Li alloys will have 4 to 5 wt.% of lithium and will be produced via powder metallurgy.

Powder metallurgy

The so-called S.A.P.-alloys ("sinter-aluminium-powder") have been known for more than 30 years. They had excellent strength properties up to 550°C, because they contained finely dispersed particles of aluminium oxide (6 to 15 vol.%). Manufacturing methods used were pressing, sintering and heat treatment. A disadvantage however was the bad weldability.

Present powder metallurgical research is trying to produce sinter materials from aluminium alloys of the type Al-Zn-Mg-Cu (type 7XXX). The sintering process must be improved by so-called liquid-phase-sintering. Tensile strength values are aimed at reaching 600 MPa.

8. Statistics

World production and consumption of aluminium (1983)

Production:	14,310,000 t
Consumption:	15,470,000 t

The percentage of secondary material (recycled from scrap, etc.) was 26.7% in 1983.

Aluminium consumption in developing countries

	1973	1978	1983	% per year
Latin America	340 000	486 000	543 000	6.0
Asia	353 000	651 000	968 000	17.4
Africa	45 000	82 000	130 000	18.[illegible]
Total	738 000	1 219 000	1 641 000	12.2

Primary aluminium production	1973	1983	% per year
USA	4 108 700	3 353 200	- 1.8
USSR	2 000 000	2 400 000	+ 2.0
European Economic Community	1 508 000	1 924 800	+ 2.8
Canada	930 000	1 091 200	+ 1.7
Germany, Fed. Rep. of	532 700	743 300	+ 4.0
Norway	618 100	715 400	+ 1.6
Australia	207 200	475 100	+ 12.9
Brazil	111 700	400 700	+ 25.9
P.R. China	280 000	400 000	+ 4.6
France	358 900	360 800	+ 0.05
Spain	160 400	357 500	+ 12.3
Venezuela	25 100	335 200	+124.0
Yugoslavia	90 800	258 200	+ 17.3
Japan	1 096 800	255 900	- 7.7
United Kingdom	251 600	252 500	+ 0.04
Netherlands	181 400	236 300	+ 3.0
Romania	141 200	223 300	+ 5.8
New Zealand	116 700	220 100	+ 8.8
India	154 300	205 000	+ 3.3
Italy	184 200	195 700	+ 0.6
Bahrain	102 600	171 700	+ 6.7
Rep. of South Africa	52 800	163 800	+ 21.0
Dubai	-	151 200	-
Egypt	-	140 200	-
Greece	143 300	136 200	- 0.5
Argentina	-	132 800	-
Indonesia	-	114 800	-
Austria	89 100	94 200	+ 0.6
World, total	12 837 300	14 310 300	+ 1.1

Aluminium consumption 1983 (t)

	Primary	Secondary (1)	Total
USA	4 218 900	2 019 400	6 238 300
European Economic Community	2 920 700	1 100 600	4 040 100
Japan	1 800 700	802 400	2 444 000
USSR	1 850 000		
Germany, Fed. Rep. of	1 085 000	425 500	1 554 700
France	613 400	166 000	755 600
Italy	430 000	278 000	755 000
P.R. China	620 000		
United Kingdom	323 400	128 300	437 200
Canada	295 000	56 000	351 000
Brazil	271 000	39 100	310 100
Australia	259 300	37 700	297 000
Belgium-Luxembourg	272 000	1 000	273 000
Spain	217 400	37 400	254 800
India	218 500		
German Dem. Rep.	230 000		
Yugoslavia	152 000	25 400	177 400
Hungary	181 700		
Netherlands	91 700	58 200	149 900
Austria	123 100	16 100	144 600

	Primary	Secondary (1)	Total
Switzerland	115 300	21 100	139 700
Taiwan	136 500		
Korea	127 600	5 200	132 800
Romania	138 000		
Norway	128 600	700	129 300
Poland	128 200		
Sweden	94 600	24 900	119 500
Venezuela	89 000	30 000	119 000
Iran	105 000		

(1) Aluminium recovered from old and new scrap.

Comment on the above-mentioned tables

The peak point in world aluminium production was in 1980 with 16 million tons. The recession brought this figure down in 1982 to 13.9 million tons.

The increase in aluminium consumption by the developing countries has been spectacular. Of course, the percentage values will fall in future.

The most interesting change in the primary aluminium production figures is the sharp drop for Japan from more than 1 million tons per year to a quarter of a million. "Japanese Aluminium" is nowadays produced for instance in Brazil (49% joint ventures). Venezuela, Brazil, South Africa, Yugoslavia, Australia and Spain have had the highest percentage increase over the last 10 years.

The leading three areas, USA, USSR and the E.E.C. accounted for 59.3% of the world's total production in 1973; this figure fell to 53.6% 10 years later; geographically aluminium production was more widely spread in 1983, and this trend seems likely to continue. There are four countries in the statistics which 10 years ago did not produce a single ton of aluminium: Dubai, Egypt, Argentina and Indonesia. Countries to follow in future are probably: Suriname, Guyana, Trinidad and Tobago, Haiti, Nigeria, Liberia, Guinea, Malaysia, Philippines and Thailand. The People's Republic of China will achieve a high production rate within the next 10 years.

The consumption table clearly shows the predominance of the four areas USA, E.E.C., Japan and USSR: here 72% of the total aluminium was consumed in 1983. The aluminium scrap recovery figures for the Eastern bloc countries are not known. The big net importer countries are the USA, the E.E.C., Japan, the Federal Republic of Germany, France, Italy, the People's Republic of China, Belgium-Luxembourg, German Democratic Republic, whereas net exporting countries are Canada, Norway, Australia, Brazil and Venezuela.

Aluminium prices

The growth in sales led to large price increases in 1983:

Aluminium price at the end of 1981: £ 590 per t
Aluminium price at the end of 1982: £ 600 per t
Aluminium price at the end of 1983: £1,090 per t

The reaction to the interplay of supply and demand was reflected in the quotations on the Non-Ferrous Metal Exchanges.

The consumption of primary and secondary aluminium by end-uses is given in the following table for the largest consumer - USA and for the lesser of the big six consumer countries, Italy.

Consumption of primary and secondary aluminium by end-uses, 1983

	USA		Italy	
	tons	%	tons	%
Transportation	1 081 800	16.4	199 000	26.9
Mechanical engineering	361 500	5.5	52 000	7.0
Electrical engineering	600 600	9.1	28 500	3.8
Building and construction	1 307 200	19.8	158 000	21.4
Chemical industry	80 000	1.2	16 000	2.2
Packaging	1 777 200	26.9	76 000	10.3
Household articles	479 400	7.3	72 500	9.8
Powder, iron/steel metal products	428 600	6.5	21 700	2.9

From this it may be assumed that, the more highly industrially developed a country is, the higher is the percentage of packaging and electrical engineering in aluminium consumption. For the developing countries the emphasis will be on transportation, mechanical engineering, building and construction and household articles. This corresponds to the recommendations given with respect to the choice of alloys for countries wishing to start an aluminium alloy industry.

In the following table the per capita consumption of aluminium in various countries is given.

Per capita consumption of aluminium, 1983

(Total consumption, but for Eastern bloc countries only consumption of primary aluminium is given)

Country	Consumption (t)	Population (mill.)	Per capita cons. (kg)
Albania	2 000	2.841	0.7
Austria	144 600	7.549	19.2
Belgium-Luxembourg	273 000	10.222	26.7
Bulgaria	53 000	8.939	5.9
Czechoslovakia	97 500	15.415	6.3
German Dem. Rep.	230 000	16.699	13.8
Denmark	26 200	5.114	5.1
Finland	28 600	4.863	5.9
France	755 600	54.652	13.8
Germany, Fed. Rep. of	1 554 700	61.421	25.3
Greece	88 500	9.848	9.0
Hungary	181 700	10.690	17.0
Italy	755 000	56.836	13.3
Netherlands	149 900	14.362	10.4
Norway	129 300	4.129	31.3
Poland	128 600	36.571	3.5
Portugal	41 000	10.099	4.1
Romania	138 000	22.553	6.1
Spain	254 800	38.228	6.7
Sweden	119 500	8.329	14.3
Switzerland	139 700	6.505	21
United Kingdom	437 200	56.377	7.8
USSR	1 850 000	272.500	6.8
Yugoslavia	177 400	22.800	7.8
Europe (1)	7 756 500	757.542	10.2

(1) Including the Asian part of USSR.

Country	Consumption (t)	Population (mill.)	Per capita cons. (kg)
Cameroon	27 900	9.165	3.0
Egypt	67 000	45.915	1.5
Rep. of South Africa	92 300	30.802	3.0
Other African countries	45 100	436.118	0.1
Africa	232 300	522.000	0.4
Argentina	87 400	29.627	3.0
Brazil	310 100	129.662	2.4
Canada	351 000	24.907	14.1
Colombia	15 000	27.515	0.5
Mexico	70 800	75.103	0.9
Peru	2 800	18.707	0.1
USA	6 238 300	234.496	26.6
Venezuela	119 000	16.394	7.3
Other Latin American countries	32 200	91.189	0.4
America	7 226 600	647.600	11.2

Per capita consumption of aluminium, 1983

(Total consumption for Asian countries, apart from Japan and Korea where only the consumption of primary aluminium is indicated).

Country	Consumption (t)	Population (mill.)	Per capita cons. (kg)
Bahrain	28 000	0.397	70.5
Dubai	5 000	0.093	53.8
Hong Kong	30 600	5.313	5.7
India	218 500	732.256	0.3
Indonesia	44 200	159.434	0.3
Iraq	5 400	14.654	0.4
Iran	105 000	42.071	2.5
Israel	12 400	4.097	3.0
Japan	2 444 000	119.259	20.5
Lebanon	11 000	2.635	4.2
Malaysia	41 400	14.863	2.8
Philippines	20 000	52.055	0.4
Singapore	5 300	2.502	2.1
Korea	132 800	59.136	2.2
Taiwan	136 500	18.400	7.4
Thailand	60 000	49.459	1.2
Turkey	89 400	47.279	1.9
Other Asian countries	102 500	1 407.900	0.1
Asia	3 491 800	2 731.800	1.3
Australia	297 000	15.369	19.3
New Zealand	31 300	3.203	9.8
Oceania	-	5.508	-
Australia and Oceania	328 300	24.080	13.6
World total	20 600 100	4 683.022	4.4

For additional comparison one may subtract Western Europe from the European total. Western Europe accounts for 5,076,100 tons, with a population of 371 million which gives a per capita consumption of 13.7 kg.

The consumption percentage of the continents is given below:

Western Europe	13.7
Australia and Oceania	13.6
America	11.2
Total Europe	10.2
Asia	1.3
Africa	0.4

From this it can be seen that Asia and Africa, representing 70% of the world's population, are well behind. To provide these two continents with the per capita consumption of Argentina or Cameroon would mean installing more than 10 million additional aluminium capacities or 50 new smelters with a production of 200,000 tons per annum each.

A further substantial fall back is presented by the following countries: Albania and Poland in Europe, all America with the exception of USA, Canada and Venezuela.

The higher the population of a country, and assuming that a certain minimum gross national product already exists, the better the chances of building up a national metalworking industry.

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CURRENT AWARENESS

Aluminium and its alloys, numbering in the hundreds, are available in all common commercial forms. The metal does not oxidize progressively because, when exposed to air, a hard, microscopic oxide coating forms on the surface that seals the metal from the environment. The tight chemical bond of oxide is the reason that aluminium is not found in nature; it exists only as a compound.

Aluminium-alloy sheet can be formed, drawn, stamped, or spun. Many wrought or cast aluminium alloys can be welded, brazed, or soldered, and aluminium surfaces readily accept a wide variety of finishes, both mechanical and chemical. Because of their high electrical conductivity, many aluminium alloys are used as electrical conductors. Aluminium reflects radiant energy throughout the entire spectrum, is non-sparking, and nonmagnetic.

Commercially pure aluminium has a tensile strength of about 13,000 psi. Cold-working the metal approximately doubles its strength. For greater strength, aluminium is alloyed with other elements such as manganese, silicon, copper, magnesium, or zinc. Like pure aluminium, the alloys can also be strengthened by cold-working. Some alloys are further strengthened and hardened by heat treatments. At subzero temperatures, aluminium is stronger than at room temperature and is no less ductile. Most aluminium alloys lose strength at elevated temperatures, although some retain significant strength to 500°F.

Wrought aluminium

Wrought aluminium alloys are usually designated by a four-digit number that establishes a specific alloying element combination. This number is followed by a temper designation that identifies thermal and mechanical treatments.

High strength of the heat-treatable wrought alloys is developed by solution heat treatment, followed by quenching and precipitation-hardening. Solution heat treatment is a process that consists of heating the metal, holding at temperature to bring the hardening constituents into solution, then cooling to retain those constituents in solution. Precipitation-hardening after solution heat-treatment increases strength and hardness of these alloys.

Wrought aluminium alloy designations

Major alloying element	Designation
Aluminium (99% or greater)	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium and silicon	6xxx
Zinc	7xxx
Other	8xxx
Unused series	9xxx

The second digit indicates modifications of original alloy or impurity limits.

The last two digits identify the alloy or aluminium or alloy purity.

Some alloys age at room temperature; some require precipitation heat-treatment at an elevated temperature (artificial aging) for optimum properties. Distortion and dimensional changes during natural or artificial aging can be significant. In addition, distortion and residual stresses can be introduced during quenching from the solution heat-treatment cycle. Such distortion and stresses can be removed by deforming the metal by, for example, stretching.

Heat-treatable alloys are also strengthened by cold-working. The high-strength alloys - either heat-treatable or not - work-harden more rapidly than the lower-strength, softer alloys and so may require annealing after cold-working. Because hot forming does not always work-harden aluminium alloys, this method is used to avoid annealing and straightening operations. (But hot-forming fully heat-treated material is difficult.) Generally, formability of aluminium increases with temperature.

Cast aluminium

Aluminium is cast by all common casting processes. Aluminium casting alloys are identified with a unified, four-digit (xxx.x) system. The major alloying element is indicated by the first digit. For instance, 100 series is reserved for 99 per cent pure aluminium with no major alloying element used. The second and third digits in the 100 series indicate the precise minimum aluminium content. For example, 165.0 has a 99.65 per cent minimum aluminium content. The 200-900 series designates various aluminium alloys. The second two digits are assigned to new alloys as they are registered.

The fourth digit indicates the product form. Castings are designated 0; ingots are designated 1 or 2.

Letter prefixes before the numerical designation indicate special control of one or more elements or a modification of the original alloy. Prefix X designates an experimental composition. The material may retain the experimental designation up to five years. Limits for the experimental alloy may be changed by the register.

Commerical casting alloys include heat-treatable and nonheat-treatable compositions. Alloys that are heat treated carry the temper designations O, T4, T5, T6, and T7. Diecastings are not usually solution-heat-treated because the high temperature can cause blistering. (Extracted from Machine Design, 17 April 1986, pp. 47-70)

Temper designations for aluminium alloys - as revised in ANSI-H35.1

F	As fabricated.
O	Wrought products annealed to lowest strength; cast products annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.
H	Strength increased by strain hardening, with or without supplementary heat treatments to produce partial softening. Followed by two or more digits: The first digit indicates the specific combination of basic operations. The second digit indicates the degree of strain-hardening. The third digit, when used, indicates that the degree of control of temper or that the mechanical properties are different from those for the two-digit H-temper designation to which it is added.
H1	Strain-hardened only.
H2	Strain-hardened and partially annealed.
H3	Strain-hardened and then stabilized. Designation applies only to alloys which, unless stabilized, gradually age soften at room temperature.

HX11	Sufficiently strain-hardened after final anneal that it does not qualify as annealed, but not strain-hardened enough to qualify as HX1.
H112	Somewhat tempered by shaping processes not having special control over strain hardening or heat treatment, but for which there are mechanical property limits.
W	Solution-heat-treated. An unstable temper because alloys age at room temperature after solution heat treatment. The designation is specific only when the period of natural aging is indicated (e.g. W1/2h).
T	Heat-treated. A stable temper produced with or without supplementary strain hardening. The T is always followed by one or more digits that indicate specific sequences of basic treatments:
T1	Cooled from an elevated-temperature shaping process and naturally aged to a substantially stable condition.
T2	Cooled from an elevated-temperature shaping process, cold-worked, and naturally aged to a substantially stable condition.
T3	Solution-heat-treated, cold-worked, and naturally aged to a substantially stable condition.
T4	Solution-heat-treated and naturally aged to a substantially stable condition.
T5	Cooled from an elevated-temperature shaping process and artificially aged.
T6	Solution-heat-treated and then artificially aged.
T7	Solution-heat-treated and stabilized.
T8	Solution-heat-treated, cold-worked, and artificially aged.
T9	Solution-heat-treated, artificially aged, and cold-worked.
T10	Cooled from an elevated-temperature shaping process, cold-worked, and artificially aged.

The following additional digits have been assigned for stress-relieved tempers of wrought products:

TX51	Rolled products stress-relieved by stretching after solution heat treatment. No further straightening after stretching.
TX51X	Extruded products and drawn tube stress-relieved by stretching after solution heat treatment.
TX510	No further straightening after stretching.
TX511	Minor straightening after stretching to comply with standard tolerances.
TX52	Stress relieved by compressing after solution heat treatment or cooling from an elevated temperature shaping process to produce a permanent set of one to five per cent.
TX54	Stress relieved by combined stretching and compressing.

The following temper designations apply to wrought products heat-treated from O or F temper to demonstrate response to heat-treatment, and from any temper by the user when such heat-treatment results in the mechanical properties applicable to those tempers.

T42	Solution-heated-treated and naturally aged to a substantially stable condition.
T62	Solution-heated-treated, then artificially aged.

The following temper designation has been assigned for wrought products high-temperature annealed to accentuate ultrasonic response and improve dimensional stability.

O1	Thermally treated at approximately the same time and temperature required for solution heat treatment and slow-cooled to room temperature. Applicable to products that are to be machined prior to solution heat treatment by the user. Mechanical property limits are not applicable.

(Extracted from Machine Design, 17 April 1986, pp. 47-70)

Designations for aluminium finishes

The Aluminium Association, in their specification "Designation System for Aluminium Finishes", classifies aluminium finishes according to the following designations:

M	Mechanical finishes
M1X	As-fabricated surface.
M2X	Buffed surface, usually bright and shiny.
M3X	Directionally textured. Finish has a distinct pattern with features lying predominantly in one direction, as produced by a grinding wheel.
M4X	Nondirectionally textured. Finish has a distinct but random pattern, as produced by grit blasting or shot peening, for example.
C	Chemical finishes
C1X	Cleaned, usually with chemical cleaners, to prepare surfaces for further finishing.
C2X	Etched surface, including chemical milling.
C3X	Brightened. Some aluminium alloys can be brightened to a high luster, but are often clear anodized afterwards.
C4X	Conversion coatings, including chromates, phosphates.
A	Anodic coatings
A1X	General. Includes sulfuric chromic, and hard anodize.
A2X	Protective and decorative. Generally "jewellry" type coatings below 0.4-mil thickness.
A3X	Architectural Class II - coatings between 0.4 and 0.7-mil thick.

A4X Architectural coatings. Class I - coatings over 0.7-mil thick.

R Resins and other organic coatings, including paints, vinyl coatings, epoxies, and fluorocarbons. Powder coatings and fluidized-bed plastic coatings are also included.

V Vitreous coatings, including porcelainizing and ceramics.

E Electroplating and other metal coatings.

(Extracted from Machine Design, 17 April 1986, pp. 67-70)

The structural use of aluminium

The draft for public comment of a new code 85/12254 DC for the structural use of high strength aluminium, which will replace CP 118 was announced in July 1985. The present standard for the structural use of aluminium (CP 118) was published in 1969, and has been widely used both in the United Kingdom and in overseas countries. It was produced on the recommendation of the Institution of Structural Engineers, and it followed a useful report by that Institution on the use of aluminium in structures, published originally in 1962.

Limit state basis

Towards the end of the decade there were pressures to rewrite the code on a limit state basis, and it had also become clear that the range of structures using aluminium was growing rapidly. As a result the present technical committee was assembled in 1979 and after several years of dedicated work, the draft for public comment of a new code is being issued this month.

The new draft code differs from many other structural standards in that its recommendations are applicable to a wide variety of structures, such as bridges, buildings, towers, vehicle bodies, merchant ships, railway rolling stock, cranes, offshore installations and marine structures - in fact they apply to virtually every aluminium structure except aircraft, missiles, rockets, space vehicles, naval vessels or pressure vessels.

The code will also have to embrace a variety of aluminium alloys, with differing characteristics, and will apply to a range of fabrication methods, including riveting, bolting, welding and bonding. The draft code is divided into eight major sections, dealing with materials, design principles, heat-affected zones, static resistance of members, joints, fatigue, fabrication and protection; five of these represent distinct advances over CP 118 and is in many ways a tribute to the quality of the research teams in this field in the United Kingdom.

The task was not easy, bearing in mind that on any one day in, say, the year 1988, the new code might be used in various parts of the world by designers of an aluminium mosque, a swing bridge, a fast patrol boat, a navigation tower, a helicopter landing pad, a truck body, a portal frame for a light building, a metro carriage, the superstructure of a liner, or a big dipper in a fairground.

When published, the new code should help to emphasize the suitability and reliability of high-strength aluminium structures for many tasks, and designers and fabricators will have a solid body of experience and good practice on which to draw. (Extracted from BSI News, July 1985, pp. 8 and 9)

New fine-grained structural aluminium alloys

Users of aluminium alloys for more mundane load-bearing jobs should check out the vanadium modified Al-Mg-Si alloys. Several proprietary formulations have recently been introduced by Swiss Aluminium. The addition of vanadium promotes the formation of relatively uniform fine-grained recrystallized alloy microstructures. You get greater strength, toughness, and cold formability in simple and complex hollow extrusions. The increased toughness comes from a reduction in the slip path of dislocations with decreased grain size. Lower quench sensitivity, another plus, means less distortion in the extruded section, avoiding what can be a costly repair. And the more uniform fine grain microstructure makes for greater uniformity in properties. These modified alloys are particularly useful for hard-to-bend parts, and parts forged from extruded stock have better anodizing surfaces than conventional Al-Mg-Si alloys. Automotive applications seem a good bet. (Details: A. Maitland, Swiss Aluminium Ltd., 8212 Neuhausen am Rheinfall, Switzerland). (Source: Annual Report on High-Tech Materials)

Aluminium boiler

This licence is for a new type of boiler using aluminium alloy in place of cast iron. Although aluminium alloy is more expensive, it has a number of advantages. The heat conduction is four times greater, so that the size of the heat exchanger can be reduced; the alloy has great durability and will not corrode; it is cathodic and foreign matter will be repelled; and the overall weight of the boiler is reduced.

The boiler has an efficiency of over 90 per cent, and an output of 100,000 BTU/hr. (Source: Technology Ireland, March 1986, p. 9)

Japan: The National Research Institute for metals has developed a superconductive metal wire that carries current two times faster than existing equivalents. It consists of a niobium-aluminium alloy processed via electron beam irradiation. Niobium-aluminium powder was placed inside a niobium tube, which was then heated with an electron beam and cooled rapidly. The wire can carry 129,000 Amperes/in^2. (Source: Asian WSJ, 27 January 1986, p. 10)

Metal coatings

Although appearance is often the predominant reason that comes to mind for coating a product, it is usually not the most important reason. More important is protection of the product from corrosive environments, impact, abrasion, heat, or ultraviolet rays.

Despite the many new materials being used today, steel remains the principal construction material for automobiles, appliances, and industrial machinery. But because of steel's vulnerability to deteriorating from aggressive chemical environments or even from simple atmospheric oxidation, coatings are necessary to provide various degrees of protection. These coatings range from hot-dipped and electroplated metals to tough polymers and flame-sprayed metals and ceramics.

Stopping or retarding corrosion is simple in principle. Surrounding a metal part with relatively inert barrier coating prevents corrosives from coming in contact with the metal. Best protection is provided by total encapsulation of the part.

Most corrosive environments contain more than one active material, and the coating must resist penetration by a combination of oxidizers, solvents, or both. Thus, the best barrier is one that resists "broadband" corrosion.

For many applications, however, the physical integrity of the coating is as important as its chemical barrier properties. For instance, coatings on impellers that mix abrasive slurries can be abraded quickly; coatings on pipe joints will cold-flow away from a loaded area if the creep rate is not low; and coatings on flanges and support brackets can be chipped or penetrated during assembly if impact strength is inadequate. Selecting the best coating for an application requires evaluating all effects of the specific environment, including temperature and mechanical conditions.

Two types of aluminium-coated steel are produced, each for a different kind of corrosion protection. Type 1 has a hot-dipped aluminium-silicon coating to provide resistance to both heat and corrosion. Type 2 has a hot-dipped coating of commercially pure aluminium, which provides excellent durability and protection from atmospheric corrosion. Both grades, invented by Armco, the producer of these Aluminized steels, are usually used unpainted.

Type 1 aluminium-coated steel resists heat scaling to 1,250°F and has excellent heat reflectivity to 900°F. Nominal aluminium-alloy coating is about 1 mil on each side. The sheet is supplied with a soft, satiny finish. Typical applications include reflectors and housings for industrial heater panels, interior panels and heat exchangers for residential furnaces, microwave ovens, automobile and truck muffler systems, and heat shields for catalytic converters.

Type 2 aluminized steel, with an aluminium coating of about 1.5 mils on each side is claimed to resist atmospheric corrosion and to outlast zinc-coated sheet in industrial environments by as much as five to one. Typical applications are industrial and commercial roofing and siding, drying ovens, silo roofs, culverts, and housings for outdoor lighting fixtures and air conditioners.

Because zinc and aluminium are, under most conditions, more corrosion resistant than steel, they are the most widely used spray-coating metals. In addition, since both metals are anodic to steel, they act galvanically to protect ferrous substrates.

In general, aluminium is more durable in acidic environments, and zinc performs better in alkaline conditions. For protecting steel in gas or chemical plants, where temperatures might reach 400°F, aluminium is recommended. Zinc is preferred for protecting steel in fresh, cold waters; in aqueous solutions above 150°F, aluminium is the usual choice.

For service to 1,000°F, a thermally sprayed aluminium coating should be sealed with a silicon-aluminium paint. Between 1,000 and 1,650°F, the aluminium coating fuses and reacts with the steel base metal, forming a coating that, without being sealed, protects the structure from an oxidizing environment. And, for continuous service to 1,800°F, a nickel-chrome alloy is used, sometimes followed by aluminium.

In Europe, where thermally sprayed metal coatings for corrosion protection have been far more widely used than in the U.S., many structures such as bridges are still in good condition after as long as 40 years, with minimum maintenance. Other applications include exhaust-gas stacks, boat hulls, masts, and other outdoor structures. (Extracted from Machine Design, 17 April 1986, pp. 199-200)

Structural alloys for superplastic forming

Superplastic behaviour has been demonstrated for a number of aluminium-base alloys, and the related ductilities observed are frequently in excess of 600 per cent and occasionally as high as 1500 per cent. A summary of the superplastic characteristics of a few aluminium alloys of interest is presented in table 1.

The superplastic aluminium alloys are two-phase alloys in which the second phase may constitute a substantial fraction of the volume (e.g. about 30 per cent as in the Al-33%Cu alloy), or it may be a relative small volume fraction (e.g. less than about 2-5 per cent as in the 7475 alloy). The importance of the second phases is in grain refinement and grain size stabilization, as has been discussed in the previous section of this paper.

Depending on the alloy type, aluminim-base alloys may be superplastically deformed in one of two microstructural conditions: (i) in the fully recrystallized condition, or (ii) in the mechanically worked condition, resulting in recrystallization during the superplastic deformation. In the former case, a plastically deformed microstructure is allowed to undergo recrystallization during static annealing, which leads to a fine grain microstructure prior to the start of superplastic deformation. The resulting superplastic deformation occurs by the usual mechanisms of grain boundary sliding and diffusional accommodation. The first group of alloys in table 1 are processed in this way. In the second case above, a plastically deformed microstructure undergoes dynamic recrystallization as the material is superplastically deformed. The mechanisms of this type of dynamic recrystallization remain unclear. The second group of alloys in table 1 are typically processed for dynamic recrystallization.

Aluminium alloys can exhibit large superplastic ductilities for either process. However, the dynamically recrystallizating materials appear to exhibit elongation maxima at strain rates notably higher than the statically recrystallized alloys. Additionally, the dynamically recrystallizing materials deform under higher flow stresses, presumably because of the higher strain rates as well as the somewhat lower temperatures at which the optimum superplasticity is observed.

An important characteristic of superplastic aluminium alloys is that of cavitation, or void formation, which develops during tensile deformation. This cavitation can lead to fracture and thereby reduce the superplasticity that might otherwise be expected. It can also reduce the mechanical properties of superplastic formed parts and is therefore of considerable interest. Cavitation, while not thoroughly understood in aluminium alloys, has been shown to originate, at least in some cases, at constituent particles, often at those containing iron and/or silicon impurities. The extent of cavitation is sensitive to temperature, strain rate, flow stress and impurity content. It can be minimized by deforming at high temperatures (but below the solidus temperature), low strain rates, and using a relatively 'clean' alloy (i.e. one in which the iron and silicon concentrations are low and the related constituent particles are small). The stress state has also been shown to affect cavitation strongly and a superimposed hydrostatic pressure equal to or higher than that of the flow stress can suppress cavitation development altogether.

Table 1. Superplastic properties of several aluminium alloys

Alloy	Test Temp (°C)	Strain Rate (s)	m	Elong. (%)
Statically recrystallized:				
Al-33Cu	400-500	8 x 10^4	0.8	400-1000
Al-4.5Zn-4.5Ca	550	8 x 10^3	0.5	600
Al-6 to 10Zn-1.5Mg-0.2Zn	550	10^3	0.9	1500
Al-5.6Zn-2Mg-1.5Cu-0.2Cr	516	2 x 10^4	0.8-0.9	800-1200

Alloy	Test Temp (°C)	Strain Rate (s)	m	Elong. (%)
Dynamically recrystallized:				
Al-6Cu-0.5Zr	450	10^3	0.3	1000
Al-6Cu-0.35Mg-0.14Si	450	10^3	0.3	900
Al-4Cu-3Li-0.5Zr	450	5×10^3	0.5	900
Al-3Cu-2Li-1Mg-0.2Zr	500	1.3×10^3	0.4	878

(Extracted from Metals Forum, Vol.8, No. 4 - 1985, "Superplasticity in Engineering Alloys: A Review" article written by: C. H. Hamilton, A. K. Ghosh and J. A. West)

New plastic alloy stretches 56 times

Sambo Cooper Alloy Co., the Osaka-based company has developed a superplastic aluminium-bronze alloy that can stretch to 56 times its original length.

Displaying excellent tensile strength and anti-corrosive properties even after deformation, the material is ideal for complete molding of irregular-shaped parts used in the aviation, space, automobile and other industries.

Based on the basic study by researchers at Osaka Prefectural University, this alloy has been developed for commercial purposes by the company in a joint project starting several years ago. As a result of such efforts, a composition made up of 77.5 per cent copper, 10 per cent aluminium, 4.5 per cent iron, 6 per cent nickel, and 2 per cent manganese was found upon heating to approximately 800 degrees centigrade to stretch like toffee from an initial 4-millimetre length to a final 224 millimetres in a period of roughly two and a half hours, representing an astounding 5,500 per cent increase.

The term 'superplastic alloy' refers to such metal compositions which, upon heating and stretching by a comparatively small force, deform by over 100-200 per cent in length. Close to 100 varieties have been produced up to now, with a maximum deformation rate of around 2,000 per cent recorded by a zinc-aluminium alloy. However, few have shown balanced performance regarding force and time required for stretching, strength of deformed material, manufacturing cost, etc.

The new composition, which meets JIS (The Japan Industrial Standard) 'C6301' regulation, is claimed to satisfy all of these conditions. Only a small force of 0.27 kilogram per square metres is necessary for initial stretching, while tensile strength decreased from 120 kg/sq. mm. before to 80 kg/sq. mm. after deformation. (Source: The Japan Economic Journal, Tokyo, 21 September 1985, p. 23)

Al-Li alloys

The new, lightweight aluminium-lithium alloys offer strengths equal to those of the alloys now being used. They can be fabricated on existing metalworking equipment and require no new or special machinery. Although impressive structural weight reductions - on the order of seven to 10 per cent - are possible through direct substitution, even greater reduction - up to 15 per cent - can be realized by developing fully optimized alloys for new designs. Such alloys would be specifically tailored to provide property combinations not presently available but which are the object of second and third generation low-density alloy development efforts. (Extracted from Machine Design, 17 April 1986, pp. 47-70)

Aluminium-Lithium alloys

Aluminium-lithium alloys were not taken seriously until about 1975. Although the weight saving potential of these alloys was widely recognized, they were difficult to make, were expensive and had lower ductility than other aluminium alloys.

Since 1975, however, there have been many research programmes aimed at improving the properties of aluminium-lithium alloys and making them commercial. As a result, the properties have been improved and the alloys are now on the verge of becoming commercial in the next 12 months.

Initially, problem areas included stress corrosion and below normal fracture toughness and tensile elongation. But improvements in composition in terms of small amounts of copper, magnesium and zirconium have resolved these problems and led to better physical properties. The most common Al-Li alloy, designated 8090, has a composition of 1.2% Cu, 0.7% Mg, 0.1% Zr and 2.5% Li. It was developed by the Royal Aircraft Establishment in England and is now being produced by British Aluminium.

Current applications are primarily in the aerospace industry. In fact, some aircraft companies in the U.S and the U.K. predict that Al-Li alloys will replace alloys like 2024 and 7075 completely within the next ten years. Weight savings of about 10 per cent will be possible, which amounts to about 10 tons on the 747.

Areas for potential application include replacement of conventional wrought aluminium alloys in primary aircraft structures such as wing skins, stringers, spar caps, fuselage skins and wheels. Nonaerospace applications are also possible, eventually in military applications such as tanks.

The main advantage of these alloys is the low density, about 10 per cent lower than normal alloys. Also, the modulus is higher, about 10 per cent again, but the alloys also have lower ductility.

Cost wise, the alloys will be more expensive. Lithium costs about $30 per pound, so nearly a dollar a pound is added to the net cost just in terms of lithium. Lithium-aluminium alloys are also more expensive to make because they have to be protected from the atmosphere. While the ultimate price for such castings is not currently known, it is assumed that for general mill products it would be two to three times the normal price of an aerospace alloy like 2024.

There are processing problems in terms of casting these alloys and, in fact, they are very difficult to cast properly. Lithium oxidizes, so the melt must be protected under an inert atmosphere, usually argon. Also, there is an explosion hazard with lithium near water, which also adds to the expense, particulary in direct chill (DC) casting.

Very few people have actually made cast parts. But cast parts are of secondary importance in the aerospace applications considered here. (Extracted from Modern Casting, October 1985, p. 26)

French goals in Al-Li, powder metallurgy

The French company Pechiney needs Fr.300 million to start industrial production of aluminium-lithium, the new workhorse of aeronautic materials.

What makes these alloys so attractive? With at least equal performance, the addition of lithium - 1.5 to three per cent in weight - to aluminium reduces the weight of the final alloy by five to 12 per cent. This means a direct improvement thanks to the effects of density. This weight reduction may reach 15 per cent if the components are redesigned.

For aeronautics, where several thousand francs can be paid for a gain of one kilogram, this is a direct benefit. For aluminium manufacturers, on the other hand, interest lies in resisting the integration of composite materials.

Indeed, the arrival of the new alloys has somewhat disrupted the notion of "materials" in the sector of aeronautic construction. Until recently the choice, if one can call it that, was limited to aluminium and composites, with strong preference for the latter materials. With the "revival" of aluminium the manufacturers must take into account Al-Li when planning their new models. The uncertain availability of Al-Li, however, has forced the manufacturers to work with lightened Al-Li structures; in other words, without using new parts designs. (Extracted from Sciences & Techniques, June 1985, pp. 10-12)

Sumitomo Electric develops ceramic

Sumitomo Electric Industries has developed an aluminium nitride ceramic for packaging integrated circuits. The material has a thermal expansion coefficient close to that of silicon, allowing chips to be placed directly on the ceramic base.

Produced by reprocessing aluminium nitride powder into near single crystal consistency and sintering the refined material under high-density conditions, the ceramic has a heat conductivity that is 10 times greater than alumina. (Extracted from European Chemical News, 25 March 1985, p.15)

Aluminium nitride substrate

Toshiba Corp. has developed an aluminium nitride substrate with a thermal conductivity reportedly 10 times higher than conventional alumina.

The material was developed in response to problems caused by increased volumes of heat generated per unit area because of higher speeds, higher output and higher integration of semiconductors and electronic circuitry.

Toshiba has established a technique for creating a reaction at a temperature of 1500°-1700°C and doping the substrate with a paste containing molybdenum particles.

The price of the material is about six times higher than that of aluminium. The device, however, reportedly can be applied in fields to which aluminium cannot, such as high power and high frequency devices. (Source: Reprinted with permission from Semiconductor International Magazine. Copyright 1986 by Cahners Publishing Co., Des Plaines, Ill., USA)

The ZA family - alloys with engineering appeal

In the past 10 years, a group of aluminium-rich zinc based alloys have caught the attention of the diecasting industry. They have already replaced other non-ferrous materials and cast iron in many applications. Ron Lyon, technical director of the Brock Metal Company explains:

Zinc alloys are traditionally associated with the production of intricate castings in large quantities by the hot chamber pressure diecasting process. Designers have long exploited the excellent finishing characteristics of the materials for decorative trim and toys but, more recently, have begun to realize the engineering potential of the materials.

For many engineering applications, the number of components required does not justify the high cost of a pressure diecasting tool or the parts are too large to be accommodated by the process. Similarly, it can be difficult to justify expenditure on components for a new product until the market is proven.

The development, in recent years, of a family of high strength, zinc-aluminium alloys, designated ZA8, ZA12 and ZA27, has removed the limitations of casting size and numbers and has greatly extended the opportunities for zinc alloys in engineering applications demanding high strength.

Although they were originally developed as sand and gravity diecasting alloys, experience has shown that the new materials may be used in a very wide range of casting processes, including pressure diecasting. The alloys have shown considerable advantages in component design and cost when compared with castings, bearings and fabrications in cast iron, aluminium and copper-based materials.

The compositions of the new alloys are listed in table 2. Tensile strength and hardness increase with aluminium content but this element also gives rise to inter-granular corrosion when low levels of impurities such as lead, tin and cadmium are present. Magnesium, when added in small amounts, offsets this corrosion problem and also hardens the alloy. Copper additions further harden the alloy, improve creep strength and corrosion resistance, but excess copper significantly reduces ductility and leads to dimensional growth on aging.

Table 2. Alloy analysis

Weight %	ZA8	ZA12	ZA27
Aluminium	8.0 -8.8	10.5 -11.5	25.0 - 28.0
Copper	0.8 -1.3	0.5 - 1.25	2.0 - 2.5
Magnesium	0.015-0.030	0.015- 0.030	0.010- 0.20

The principal physical and mechanical properties of the ZA alloys are compared with those of other materials in table 3 (see page 35). This highlights their high strength relative to cast iron and other non-ferrous alloys, they cannot match the cast irons in this respect, although they do have excellent bearing properties.

The low melting point of the alloys is clearly an advantage in the foundry, reducing energy costs and extending the life of dies and tools. Unfortunately, increasing temperature adversely affects the mechanical properties of zinc alloys, reducing tensile strength and hardness but increasing ductility. Creep has been considered a major limitation of zinc alloys but the ZA range has been shown to have substantially improved creep resistance compared to the 'traditional' zinc pressure diecasting alloys described in BS1004.

The strength of the ZA alloys is further reduced by aging and the alloys are not recommended for long term stressed applications at temperatures in excess of 120°C. Dimensional change on aging is well known in zinc pressure diecasting alloys. ZA8 and ZA12 exhibit some shrinkage with time, ultimately returning to their original dimensions. The higher copper level in ZA27, however, leads to an appreciable increase in size due to transformation of the metastable phases formed on solidification. ZA27 castings can be stabilized with an inexpensive heat treatment before service but this is not usually considered necessary.

Table 3. Typical physical and mechanical properties of the ZA alloys and other engineering materials

Properties at 20°C	ZA8			ZA12			ZA27				Brass	Aluminium	Cast Iron		Zinc (BS1004)	
	Sand Cast	Gravity Die	Pressure Die	Sand Cast	Gravity Die	Pressure Die	Sand Cast	Sand HT	Gravity Die*	Pressure Die	BS1400 SCB3	LM24	Blackheart Malleable	Grey	[illegible]	[illegible]
Mechanical																
Ultimate (N/mm²)	240-276	221-255	365-386	275-317	310-345	392-414	400-440	310-324	424	407-441	185-240	180-185	290-345	160-345	283	328
Tensile Strength (ton/in²)	16-18	14-16	24-25	18-20.5	20-22	25.5-27	26-28.5	20-21	27.5	26.5-28.5	12-16	10-12	19-22	10-22	18.5	21
Elongation (% in 50mm)	1-2	1-2	6-10	1-2	1-2	4-7	3-6	8-11	1	1	15-30	5-7	6-12	<0.5	15	9
Young's Modulus (GN/m²)	—	85	-	83	-	—	75	78	—	—	83	71	169	75-145		
Hardness (BHN)	82-88	85-90	95-107	90-110	85-95	95-105	110-120	90-100	110-120	116-122	45-65	55-80	110-140	200-250	83	92
Physical																
Density (g/cm³)		6.3			6.0			5.0			8.5	2.6	7.3	7.3	6.7	6.7
Electrical Conductivity (%IACS)		27.7			28.3			29.7			20	37	—	—	26	26
Thermal Conductivity (W/m °C)		115			116			125.5			88	142	48	42-50	113	110
Melting Range (°C)		375-404			380-430			380-480			920-1000	580-640	1450-1550	1080-1200	382-387	379-386

*Preliminary Data

Other properties of the alloys have been extensively researched and work is continuing. One notable characteristic is that ZA8 and ZA12 do not exhibit 'sparking'. The production of a spark when aluminium alloys are struck with other materials precludes their use in hazardous areas. Castings in ZA8 and ZA12 are currently in service on petrol tankers and in coal mines as alternatives to cast iron or copper-based alloys.

Another important attraction is that the ZA alloys have values for patternmakers' shrinkage which are very close to those for aluminium- and copper-based alloys. This frequently allows ZA castings to be made from pattern equipment or dies designed for other materials. The use of existing dies to make non-sparking castings opens a new market for many products previously unacceptable to BASEEFA or the National Coal Board. Similarly, cast iron or copper-based components are readily converted to ZA alloy with considerable savings in cost and weight while retaining non-sparking characteristics.

Considerable research has been carried out to determine optimum machining conditions and tool design for ZA alloys. The alloys compare favourably with other non-ferrous alloys as regards machined characteristics and most operations can be carried out at high speed, giving a clean, smooth finish.

High-speed steel tools are adequate for most operations but pressure diecastings have a tough 'skin' of metal, with a fine grain structure which increases tool wear, and carbide-tipped tools have been used to advantage on occasions. Tools should generally have large flutes to clear waste, high rake and clearance angles, with sharp cutting edges to reduce friction and prevent galling. Copious quantities of water-based cutting fluids are strongly recommended for all operations and drills should be frequently withdrawn when cutting deep holes to allow lubricant to reach the cutting surface and cool the drill tip.

The weathering of zinc alloys, forming a passive layer on the metal surface which inhibits further attack, has been exploited for many years in rolled roofing sheets and galvanizing. The corrosion resistance of ZA alloys, being similar to the traditional zinc pressure diecasting materials and aluminium alloys, is adequate for most atmospheric environments. However, the availability of zinc anodizing and other protective finishes extends their use to aggressive marine conditions such as on oil platforms.

Most of the finishing processes used for zinc alloy pressure diecastings are equally applicable to ZA8, ZA12 and ZA27. For mild corrosion protection a simple chromate dip is usually adequate. This is often used as a pre-treatment before painting. Greater protection is given by zinc anodizing, in which a complex oxide coating is built up electrolytically on the casting. The olive-green coating is resistant to abrasion and accepts paint readily.

ZA castings are ideally suited to modern paints and lacquers, provided they are correctly cleaned and pre-treated. Powder coatings (based on epoxy resins and polyesters) may be used, but care should be taken to monitor curing temperatures (especially when processing pressure diecastings) to avoid blistering and other detrimental thermal effects on the casting.

Care is also needed when chromium plating ZA alloys. It is particularly important that the plater is aware of the high levels of aluminium in the casting. The cleaning processes prior to plating can be very aggressive to aluminium, resulting in black 'smuts' on the surface which detract from the final finish. This is especially true of ZA27 and consequently it is not generally recommended for plating. Where visual appeal is the primary requirement, ZA8 gives excellent results.

For many components, the alloys can be more economic than cast iron, even though cast iron is usually considered a lower cost material than zinc. While this may be true if only the metal price is taken into account, it is frequently not the case when finishing, rejects and machining costs are included. Consequently, it is vital to consider the total cost of producing a component in each material. The closer, repeatable tolerances and better finish obtained with diecasting immediately reduce processing costs. This, coupled with the faster machining and reduced reject rates possible with the alloys have, in some cases, cut machining times by up to 50 per cent compared with cast iron.

The lower density of ZA alloys can be decisive where weight saving is an important factor - for example in cars and non-sparking hand tools. In addition, when appearance or corrosion protection is important, zinc alloys, with their plated or anodized finishes, offer greater scope to the designer than cast iron.

The lower metal cost and density of ZA alloys also give them a competitive edge over copper-based alloys. They have frequently replaced gunmetal, brass and bronze, materials choosen for their good corrosion resistance and non-sparking properties.

ZA alloys exhibit equivalent or superior properties to the brasses. The elimination of metal treatment in the foundry helps reduce casting defects and machining problems. Where brass has been diecast the same tooling can frequently be used for ZA alloys, and the very much lower casting temperatures extend the life of the valuable equipment considerably.

Zinc alloys have been used for bearing surfaces for some time. Their low melting point puts a limit on operating speed and temperature and they perform best at high loads and low speeds. ZA27 exhibits the best bearing properties of the ZA group but ZA12 is almost as good. Both have equalled or surpassed the life expectancy of copper-based plain bearings in the same application.

The cost savings made possible by using zinc instead of copper-based bearings need little amplification but further consideration should be given to eliminating bushes altogether. Using the casting itself as an integral bearing saves the operation of inserting the bush and at the same time removes an interface which can trap a film of lubricant and restrict the heat flow from the bearing surface into the casting.

In general, ZA alloys can replace aluminium alloy components when their non-sparking characteristics are required, persistent problems with machining or porosity are encountered, or a component has insufficient strength and cannot be redesigned. Although considerably stronger than aluminium alloys, the ZA alloys have twice the density. This clearly influences the cost of any component, even when the weight penalty is irrelevant. When a component is being designed in a ZA alloy, advantage may be taken of its high strength to reduce section thickness and hence weight. This is particularly so in pressure diecasting where thin-wall zinc castings are commonplace.

The problem-solving role of ZA alloys is proving valuable to designers using aluminium alloy castings. The ability to use existing dies and patterns with minimal modification to produce castings of a very much higher strength and integrity has obvious attractions. Tools and dies last longer than when used with aluminium alloys or brass, since they are operated at lower temperatures, and ZA alloys exhibit none of the problems with gas pick-up and hard spots which can occur in aluminium alloy castings. Even apart from hard inclusions, aluminium alloys can be troublesome to machine, picking up or galling on the tool. Providing the correct guidelines are followed, ZA alloys can be fast and easy to machine.

ZA castings may also be attractive alternatives to many fabricated multi-part assemblies. Many fabrications have already been replaced by pressure diecastings in the traditional zinc alloys and the strength available from ZA alloys offers the engineering designer even more scope.

Choosing the appropriate ZA alloy

It is important when selecting a ZA alloy to decide exactly what combination of properties is required as the critical factors are not always clear. The importance of the high strength of ZA27 might be limited by its ability to feed a difficult shape or the fact that the alloy cannot be used underground. Similarly, a design can be more economical in ZA27 than ZA12 because of the difference in density but there may be a requirement for chromium plating which could add to the cost as special treatments are required. The following summary may prove useful as a general guide:

ZA8

Designed for plating but also has good tensile and creep strength (superior to BS1004 alloys). Good dimensional stability. Non-sparking, hence suitable for hazardous applications. Hot chamber diecasting makes the economics of high volume production attractive.

ZA12

Best general purpose alloy as it combines high strength and creep resistance with good plating properties. Easier to cast than ZA27, thus preferred where shrinkage could be a problem. Excellent bearing and wear properties. Non-sparking, hence suitable for hazardous applications.

ZA27

Highest strength, hardness and creep resistance and lightest alloy in the group. May be heat treated (sand and gravity diecastings) to increase ductility. Best bearing and wear properties. Only fair for chromium plating. (This article was first published in Engineering Magazine, London, September 1985)

Zalutite zinc and aluminium alloy coated steel

New zalutite is steel hot-dip coated with an alloy composed primarily of zinc and aluminium (by weight 55 per cent Al, 43.5 per cent Zn, 1.5 per cent Si), giving enhanced corrosion resistance and galvanic protection at cut edges.

Zalutite's coating resists atmospheric corrosion from two to four times as effectively as conventional hot-dip zinc coatings of equal thickness. Zalutite resists heat, oxidation and discolouration up to 315°C, and is heat-reflective.

The low density coating gives an incrased surface area per ton compared with conventional HDG. The surface pattern is especially attractive, and is also easy to paint.

Zalutite can be fabricated using methods similar to those used with continuously annealed hot-dip zinc coated steel, and joined using most conventional techniques together with optimum joining procedures. Recommendations for forming, fabricating and joining are given in the Zalutite Technical Manual, available from Sales Promotion Dept, BSC Strip Mill Products, P.O. Box 10, Newport, Gwent NP9 0XN. (This article appeared first in Engineering, July/August 1986)

Gries/Dynacast (New Rochelle, NY, USA) can now fabricate precision components from a zinc-aluminum alloy using a hot chamber casting process, a development that can reduce the cost of fabricating high performance components by 50-75 per cent. Gries is predicting that its 4-slide casting process will 'revolutionize' the way these types of components are fabricated. The process is the result of a 4-year research programme conducted by Gries and the Noranda Research Center (Montreal, Quebec). Gries said that a ZA-27 alloy, a mixture of 27 per cent aluminium and 73 per cent zinc, has been fabricated for the first time in a high-speed hot chamber die casting machine. The tensile strength of ZA-27, 64,000 psi in a thin wall casting, is equal to SAE 1018 cold rolled steel. The zinc alloy is stronger, harder and 43 per cent lighter than SAE 660 bronze, and it has a 10,000 psi creep strength. (Source: Am Mtl Mkt, 13 January 1986, p. 17)

High-strength aluminium-silicon alloy

Nippon Light Metal Co., Ltd., has developed an aluminium-silicon alloy which is high in strength and abrasive resistance.

The conventional aluminium-silicon alloy had little mechanical strength and did not permit cold working. In the newly developed alloy, special metals were added in addition to aluminium and silicon, and the alloy is produced by a unique casting and extrusion method. There is no loss in abrasive resistance, and a dramatic increase in strength, its tensile strength being 45 kg/mm^2 and its allowable stress being 38 kg/mm^2, comparable to duralumin, a representative aircraft material. Also, the alloy is more corrosion resistant than duralumin, and its Brinnel hardness (Brinnel number) is 140.

The company hopes that the new alloy will be used in VTRs, engine and compressor cylinders, gears, spindles, pulleys, and other practical areas of application.
(Nippon Light Metal Co., Ltd. 3-5, Ginza 7-chome, Chuo-ku, Tokyo).

(Source: JETRO, March 1986, p. 21)

Silicon carbide whisker reinforced aluminium alloy composite

Mitsubishi Aluminium Co., Ltd., has developed a new composite material called "CERAAL" that is an aluminium alloy which has been reinforced by silicon carbide whiskers. Mitsubishi has now begun marketing automobile and aircraft related samples.

The manufacturing process involves making a preform body for the SiC whiskers, placing the body in the mould and pouring molten aluminium into it. A pressure of 1,000 atmospheres is applied and the molten aluminium alloy then impregnates the preforming mould and is allowed to solidify. A high pressure casting press enables the manufacture of 200-mm dia. billets for extrusion. These composite billets are used to supply extrusion material samples for mass production machinery conventionally used for the extrusion of aluminium alloys.

The characteristics of the composite material are such that it has strength at normal temperatures, heat resistance (strength at high temperatures), a Young's Modulus and wear resistance that are all significantly higher than those of a matrix material. There is also a reduced coefficient in thermal expansion. These characteristics are altered with the amount (vf) of whiskers included.

In the case of extrusion material data for the 6061, the composite reinforced alloy with 16 per cent SiC whiskers has a strength of 1.5 times at room temperature and three times the strength at 200°C of matrix alloys, and the influence of the vf is most pronounced for the Young's Modulus and has a practically linear relationship. A vf of 25 per cent gives 14,000 kg/m^2 which is double that of matrix alloys.
(Mitsubishi Aluminium Co., Ltd. Products Development Dept. 1-7, Uchikanda 1-chome, Chiyoda-ku, Tokyo).

(Source: JETRO, April 1985, p. 18)

Diffused Si boosts Gr/Al composite temperature stability

Si may be the answer to boosting high-temperature strength of carbon fibre aluminium composites. Heat is a problem because the carbon fibres and aluminium matrix do not form a chemical bond at their interface. Instead, hot isostatic pressing (HIP) of the preform forms a physical bond due to the difference in their thermal expansion coefficients (CTEs). During the process, however, Al_4C_3 is formed and it causes deterioration in the carbon fibres.

Diffusing silicon into the composite suppresses Al_4C_3 formation. Diffusion is not as hard as it sounds, since high temperatures cause the Al matrix to expand, loosening its bond with the carbon fibres. Si diffuses through the loose interfaces. Over time, it further diffuses along the interfaces of the recrystallized matrix, and even inside the crystals.

The process is simplicity itself. The matrix is heated in a vacuum inside a furnace with a quartz core pipe. At temperatures over 400°C, the Al on the surface of the matrix is vaporized. Aluminium reacts with the SiO_2 that makes up the quartz pipe to form Al_2O_3 and SiO. SiO is then reduced to Si and Al_2O_3 by the Al in the composite.

(Details: Dr. Akimitsu Okura, Research Center for Development of Advanced Materials, Institute of Industrial Science, University of Tokyo, 22-1, Roppongi, 7 Chome, Minato-ku, Tokyo 106, Japan.)
(Source: High-Tech Materials Alert, October 1985, p. 6)

A new venture in aluminium composites

Alcan Aluminium plans to push metal matrix composites based on technology it has acquired from Science Applications International (San Diego). The know-how relates to the manufacture of silicon-carbide-reinforced aluminium (SiC-Al). SiC-Al is a composite material that offers advantages over conventional aluminium alloys, says Alcan, notably in showing greater strength and stiffness at normal and high temperatures. The material is also said to exhibit increased wear resistance and controlled thermal expansion. Alcan plans to produce the new material in nearly finished shape castings, as well as in billets for extrusion, forging and rolling. (Source: Chemical Week, 21 May 1986, p. 40)

Putting more muscle in aluminium alloys

A new generation of aluminium alloys delivers an outstanding combination of strength, corrosion resistance, and fracture toughness. These superior performers are powder-metallurgy alloys, based on advanced rapid-solidification technology.

The basis for the new alloy system, called wrought PM alloys, is the rapid-solidification process. (The term "wrought PM" is used to distinguish this technology from conventional "press and sinter" PM technology.) Twenty years of research, much of it conducted at Alcoa's Research Centre, are behind the development and fabrication processes that produce these state-of-the-art aluminium alloys.

Production of wrought PM alloys begins with prealloyed aluminium, which is air-atomized from the molten state. This causes it to cool at 10^4 to 10^5 degrees Celsius per second, about 1,000 times faster than is possible by ingot metallurgy or direct-chill methods. Rapid solidification allows the molten alloying ingredients to remain in metallurgical solution dispersed homogeneously throughout the alloy. This type of dispersion is not possible in alloys cooled by the conventional methods.

The aluminium alloyed powder is then cold isostatically pressed to approximately 70 per cent density, vacuum preheated, and pressed into billets of 100 per cent density. Billets can then be fabricated using conventional forging, extrusion, or rolling techniques.

The combination of rapid solidification and full-density consolidation provides the aluminium wrought PM alloys with high static and fatigue strengths, excellent resistance to exfoliation and stress-corrosion cracking, and strength/fracture toughness relationships superior to most 7XXX-series ingot-metallurgy alloys.

Farther in the future are PM metal-matrix composites. These materials, with PM aluminium alloys serving as the matrix and silicon carbide as the reinforcement material, have certain properties that are superior to those of both conventional and PM aluminium alloys. These have the potential for much higher stiffness, along with improvements in strength, fatigue, and wear resistance. The near-term objective is to develop metal-matrix composites having densities near those of aluminium and with usable strengths of 115,000 psi or higher. (Extracted from Machine Design, 12 January 1984, pp. 125-129, article written by Robert H. Graham, Project Manager, Wrought P/M Alloys, Aluminium Company of America, Pittsburgh, PA)

Shaping up with aluminium extrusions

Aluminium extrusions are suitable for engineering applications from household goods to space travel. The properties of this metal and the ability of the extrusion process to provide cheap and elegant design solutions make this possible.

Pure aluminium is quite soft. However, by adding small percentages of other elements, it is possible to form alloys with widely differing characteristics. In all there are 17 alloys in the BS 1474 extrusions series, plus others in related aircraft specifications. For most engineering purposes, the main choice is the Al/Mg/Si group. These alloys provide strength comparable to mild steel, coupled with ease of production, ease of forming and welding and good surface finishing and weathering characteristics. These 'work-horse' alloys are known as BS 6063 and 6082. (Previously called HE 9 and HE 30.)

It is the combination of the basic properties of aluminium and its various alloys plus the shape possibilities offered by extrusion that make an aluminium extrusion such an exciting vehicle for designers to use. One-third the density of steel, the metal has high strength, good appearance, and offers high chemical and weather resistance. Good thermal and electrical conductivity are properties that are also exploited.

Reducing machining

The first criterion in designing a shape for an aluminium extrusion is to remember that the restrictions applied with steel need not apply. As a general principle, metal need only be included in an extrusion design where it is actually needed. In the building sector, the use of aluminium extrusions for window frames has revolutionized the replacement window industry. It is also used extensively for commercial vehicles, railway passenger coaches and aircraft components. In those applications, it is the lightness of the metal plus the natural durability of aluminium in its 'as produced' natural finish that are so important. The range of engineering uses is endless. Heat exchangers, appliance trim, ladders, sports equipment and machine parts are just some examples.

The electronics and computer industries are the latest areas where aluminium extrusions are making their mark. In particular, complex hollow shapes are being produced for a variety of casing applications. Strength and electromagnetic screening, as well as inbuilt features to hold batteries and circuit boards, are major advantages. (Excerpt from an article which first was published in Engineering Magazine, London, October 1985)

Aluminium extrusion industry

Belco Industries' revolutionary non-lube walking beam eccentric is for the aluminium extrusion industry. Belco first started out with a heavy aluminium beam to be used for fixed and walking. The beam will work on large presses up to 3,500 tons and allows up to 24 ft. wide cooling beds due to the section modules and shape design. Belco next designed the eccentric holder, eccentric cam and shaft clamp as extruded aluminium shapes. All labour required in Belco's shop is to drill one hole in the shaft clamp and 2 holes in the holder. Aluminium extrusions were chosed due to their design flexibility and light weight and most of Belco's customers are extruders. Advantages of Belco design: no lubrication required, longer life, light weight, double clamping, good support on bearings, easy maintenance, easy alignment and faster installation. (Source: Light Mtl, December 1982, pp. 20-22)

Aluminium's path to higher quality

"Premium" aluminium castings are consistently being produced as foundrymen, more and more, utilize grain refinement, thermal analysis, degassing and filtration technology. Exceptional casting quality is no longer a luxury but a requirement of many casting buyers. A recent AFS/CMI International Molten Aluminium Processing Conference provided an update on processing techniques for producing high quality aluminium castings.

With the advent of improved melt testing equipment, aluminium foundrymen have found it possible to produce high quality, more consistent aluminium castings. Pioneers in the aluminium castings business have set the precedence for current quality control experiments. Newly developed sand binders have improved the ability to hold closer dimensions, minimize sand reactions and increase productivity.

"Use of heat treating equipment improvements, quenchants to minimize distortion and reduce residual stresses and computerized heating and cooling cycles have all added to the knowledge in producing more consistent cast configurations."

These quality aluminium castings are first determined by the proper constitution of the melt, prior to casting. As B. Lee Tuttle, GMI Engineering & Management Institute, explained: "Since the mechanical and physical properties of a casting alloy are determined by the microstructure, not the chemical composition, quality can only be produced when the melt constitution is properly controlled."

Tuttle defines melt constitution as "the cumulative effect of the reaction of the molten metal with its melting environment during the entire melting cycle". Consequently, the as-melted constitution of a known heat of ingot will change from day to day.

"The foundryman must employ molten metal process control techniques to monitor the chemical composition, gas levels, solid inclusion levels, molten metal temperature, nucleation potential and modification potential of the molten metal during the melting cycle," explains Tuttle.

"It should be further recognized that the need for many of these molten metal processing treatments depends on the structure of the charge materials and the type of melting furnace employed," Tuttle added.

The structural characteristics of the phases in an aluminium casting alloy are established by the manner in which the castings are poured. "The manipulation of any one of the structural characteristics can provide significant changes in the mechanical and physical properties of a casting alloy."

Molten metal processing techniques - which include degassing, deoxidizing, purging, fluxing, filtering, controlling thermal cycles, inoculating and modifying - allow foundrymen to produce consistent quality aluminium castings.

Grain refinement

In aluminium casting metallurgy, the process of grain refinement is control of the grain size of the crystallizing primary aluminium phase during solidification, according to Tuttle. Three distinct metallurgical reactions are required to achieve proper grain refinement: constitution control; nucleation control; and growth restriction control.

"Only when the foundryman has achieved regulation of each stage in the grain refinement process can a uniform and consistent microstructure be obtained in an aluminium casting alloy," Tuttle explained.

The grain refinement of aluminium casting alloys has found widespread commercial application. Geoffrey Sigworth, Cabot Corp., noted that "the primary benefit of grain refinement, in most cases, is an improvement in the amount and distribution of porosity in alloys which tend to form microporosity. As a result, there is a significant improvement in mechanical properties, especially under fatigue loading". Sigworth added that "it is also probable that grain refinement affects the formation of shrinkage voids by improving feeding of the casting, but no definite study has been made of the effect".

Procedures available to measure grain size include: average intercept distance; calculated average diameter; ASTM grain size number; and grains per unit area. Several tests have been developed to determine grain size. These include the Alcoa chill test, the Reynold's "golf tee" test, the Alcan "conical mould" test and the KBI "ring test".

Sigworth discussed techniques developed to induce grain refinement. One is vibration or stirring of liquid metal in the mould, which will break solid aluminium dendrites into smaller pieces when the casting is partially solidified. Proper stirring can eliminate undesirable centerline segration and change the non-metallic oxides. "However," he said, "stirring is just beginning to be used commercially to make concast steel and would not yet appear to be useful to the aluminium foundryman".

Another method of inducing grain refinement is with the use of grain refining salts. The salts' active ingredients react with molten aluminium to release titanium (Ti) and boron (B). Ti-Al_3 and/or various boride particles are formed in the melt and act as heterogeneous nuclei for the formation of solid primary aluminium crystals, according to Sigworth. "Salts can produce excellent refinement, but offer several disadvantages: they are hygroscopic and, unless stored very carefully, will release moisture into the melt; they may produce a corrosive fume, which is irritating to personnel and harmful to equipment; they react with modifiers, sodium (Na) and strontium (Sr), present in Al-Si alloys, perhaps causing a loss of modification; and the reaction and efficacy of the salts is sensitive to temperature and stirring present in the melt and recovery of Ti and B is not always predictable," Sigworth said.

The addition of Al-Ti-B master alloys is another way of inducing grain refinement. Grain refiner master alloys are made by reacting salts with aluminium under controlled conditions, so that an aluminium alloy rich in microscopic aluminide and boride particles is produced. "The best all round performance was found to be at a master alloy composition having a unit Ti:B ratio and a new Al-Ti-3%B alloy has been developed specifically for aluminium casting alloys," Sigworth said.

Sigworth noted that grain refinement may favorably alter a casting's mechanical properties. He outlined the possible effects that a grain refiner has on a casting by: changing the amount or distribution (or size distribution) of microporosity in the casting; changing the feeding of the casting and location of shrinkage voids; changing the shape, size or distribution of brittle second-phase intermetallics; decreasing the distance between eutectic boundaries and thereby reducing the solution time prior to aging; and changing the distribution of stress among grains during plastic deformation.

"It should be stated that we have excluded the most important factor in structural control: the cooling rate of the alloy during solidification. Lowering the casting temperature, placing a chill in the casting, cooling the mould or using conductive mould coatings all tend to reduce the grain size with dramatic effect on mechanical properties. However, most of the change in tensile strength is not due to the change in grain size, per se, but to a decrease in the secondary dendrite arm spacing (DAS)," Sigworth noted.

The major benefit of grain refinement seems to be an improvement in the distribution of porosity and shrinkage in a casting. "Porosity is found mainly between grains (not within the dendrite arms) and the total boundary area is changed greatly by refiement." Sigworth said.

Carl Vass, Fansteel/Wellman Dynamics, provided results of a study indicating that the new Ti-B grain refiner gives outstanding results in slowing the fade rate of effective grain refinement. Vass concluded that "the use of 3%Ti-3%B is most advantageous. This grain refiner provided the longest lasting effective grain refinement and could be used in both batch and continuous melting applications". He added that this grain refiner will eventually allow the Ti to settle out, but with smaller additions (lower Ti levels), the Ti does not appear to settle out as fast.

Finally, Vass' study suggests that "it is not the level of titanium in the melt or the size of the addition which most affects the mechanical properties or grain size but possibly another factor not investigated in this study, such as timing of the addition".

Thermal analysis

"Correct chemistry alone will not produce quality castings," stated Thomas Acklin, Phillips Foundry, Inc. Acklin noted the transfer of thermal analysis from the laboratory to the foundry floor as the most important improvement in the industry during the past decade. "The ability to closely control grain size and shape is one of major importance and a giant step forward in the ability to control or solve numerous casting problems on the foundry floor."

The use of thermal analysis as a process control tool can allow foundrymen to consistently produce quality castings. "It can help overcome casting problems of inconsistency of grain size, shrinkage, subsurface porosity, mechanical and physical property deficiencies," Acklin said.

He added that over-refinement of grains is unnecessary and expensive, but can be controlled by thermal analysis. Another benefit of thermal analysis is its ability to determine the silicon eutectic phase in molten aluminium. Many of the factors improved by grain refinement are also improved by silicon eutectic modification, Acklin noted.

"In many cases, grain refinement in combination with modification will dramatically improve casting quality. In addition to improved mechanical and physical properties and greatly improved feeding characteristics, an increased ability to have consistent pressure tightness is noted," Acklin said. Additional benefits of silicon eutectic modification include a quicker response to heat treat and a more consistent casting quality.

Processing variables

The effect of processing variables on the grain refinement and eutectic modification of Al-Si foundry alloys was discussed by D. Apelian and J. Allen Cheng, Drexel University. The types of master alloys used, the levels of Ti and B in the melt, the level of Sr, cooling rate, etc., are all processing variables which can affect casting quality. (Their study was limited to A444 and A356 aluminium alloys.)

"The effect and interaction of processing variables which have a major influence on the cast aluminium structure are: the choice and amount of master alloy used to grain refine; the amount of Sr added to the melt; the mould in which the melt is poured; casting cooling rate; and the presence and amount of alloying elements, such as copper (Cu) and iron (Fe)," according to Apelian and Cheng.

"Comparing the grain refining response of Al-5Ti, Al-5Ti-0.2B and Al-5Ti-1B master alloys, the latter is the most potent. Both the aluminide and boride nucleants play a role in the grain refinement of Al-Si alloys. Furthermore, the role of boron is critical and extremely beneficial," Apelian and Cheng noted.

Other conclusions from their study include: the presence of Sr does not influence the grain refinement of Al-Si foundry alloys; alloying elements Cu and Fe do not affect grain refinement; and if the melt is not grain refined, the cooling rate will influence the resultant grain size of the casting. High cooling rates give rise to small grain sizes and as the melt is grain refined, the cooling rate will not influence the resultant grain size of the casting.

Primary silicon refinement

Hypereutectic Al-Si alloys with silicon contents in the range 15-35 per cent possess good wear resistant properties, said Dr. Allen Clegg, University of Technology, Loughborough, England. "It is commonly believed that the wear characteristics and machinability of the hypereutectic alloys are improved when the silicon polyhedra are small in size and uniformly distributed throughout the cast structure," Clegg said.

The wear resistance of the hypereutectic Al-Si alloys is dependent upon the silicon content, according to Clegg. "The higher the silicon content the greater the resistance of the alloy to wear. However, a high silicon content, in the range of 25-40 per cent, presents manufacturing problems both during casting (due to feeding difficulties) and in machining (due to excessively high tool wear)," he added.

Experimental results show that sulfur provides superior primary silicon refinement when compared with arsenic and phosphor-copper, at a similar weight percentage of addition. "The addition of a small amount of sulfur to a melt refined with either arsenic or phosphor-copper does not appear to influence the eutectic structure. However, the degree of primary silicon refinement is considerably improved," Clegg said.

In addition, he noted that the increased rate of cooling produced by a metal die generally increases the degree of primary silicon refinement and from the wear test results obtained, it appears that structural modification does not significantly affect the wear resistance of the hypereutectic Al-Si alloy.

Melt cleanliness control

Aluminium's natural affinity for oxygen and the large difference between the solubility of hydrogen in liquid and solid aluminium present many opportunities for potentially harmful defects in castings, said John Jorstad, Reynolds Metals Co.

"Oxide films, skim or dross, and the extremely hard corundum or spinel phases are potential forms of oxide macro-inclusions in aluminium castings. When they do occur, large inclusions decrease mechanical properties of castings and cause rapid deterioration to cutting tools," Jorstad said, but "they can be controlled by appropriate fluxing and skimming of melts, by avoiding turbulence during transfer of molten alloys and during normal stirring and pouring operations, by avoiding overheating of melts and by applying filters at the point of pouring and in moulds."

Jorstad added that "hydrogen remaining in solution in a melt at the time it is cast will precipitate as a molecular gas during solidification, to be trapped as porosity in castings". This hydrogen porosity reduces both the strength and ductility of a casting, detracts from the appearance of machined and finished surfaces and can contribute to leakage of pressurized castings in service.

In addition, he suggested the use of filtering equipment to give molten metal a final cleaning at the point of pouring and even in moulds. "There is little reason indeed to experience oxide macro-defects in modern aluminium castings."

Filtration systems

While there are other process methods capable of removing inclusions or oxides from a molten melt, "the use of filtration is gaining in popularity because of the ease of use, minimal capital investment and general efficiency of the process," commented Daniel Groteke, MetCast Assoc. Filtration can provide better mechanical properties, machinability, fluidity, electrical properties and increased mould or die life. In addition, filtration can reduce pinholes and rework costs.

Several filtration techniques are commercially available for ferrous and non-ferrous foundries. One method available to most aluminium casters is a point-of-pour system, which cleanses the melt at the last possible point before introducing it to the casting runner/shot system, Groteke said. "While the systems do allow a low level of contamination to redevelop in a faulty runner system, the basic nature of the process allows a cleaner melt to be produced than is possible with in-gate filters," Groteke explained.

The system should be tolerant of abuse from operator inattention or careless maintenance practices, be readily maintainable by foundry personnel and, finally, the system should have a low cost of operation that justifies its general application to the production of commercial castings, according to Groteke.

Gas injection pump

In various aluminium alloy melting processes for primary, secondary, diecast and foundry applications it is necessary to control or refine minor alloy impurities, inclusions and gas content, reported David Neff, Metaulics Systems. One technique developed to enhance the upgrading of molten aluminium quality is the gas injection pump.

"The gas injection pump can be used in conjunction with down-stream filtration devices using ceramic foams or bonded-particle filters to enhance filter life and further improve cast metal quality," Neff said. The gas injection pump is a patented device consisting of a centrifugal molten metal pumping system interphased with gas injection.

"The gas injection pump has been presented as a particularly useful technology to remove magnesium and other alkali metals in secondary aluminium processing and to remove hydrogen and inclusions in aluminium foundry melting," he added.

Neff explained that the ability to remove magnesium from molten aluminium is made possible by "a favourable chemical reaction between magnesium and chlorine". This technology accomplishes both demagging and degassing, while facilitating inclusion removal through the effects of the sparging gas. Neff explained that "the effectiveness of this approach is a result of the ability of the high velocity jet stream of the molten metal emerging from the impeller to shear the incipient bubble formation emerging from the flux tube".

Neff believes that the gas injection pump's ability to circulate metal and refine by removing magnesium is advantageous to a secondary operation or to scrap remelting in the foundry. He added that "scrap can be melted and purified in situ, with the attendant benefits that forced circulation improves melt rates, minimizes temperature stratification and greatly enhances the alloy homogenization in the melt".

He noted that it is beneficial to couple the gas injection pump process in the melting or holding furnace with other filtration systems employed, in order to facilitate longer performance life.

Advantages of Grain Refinement

The use of grain refiners:

Promotes increased pressure tightness
Reduces hot tears during solidification
Increases mechanical properties of heavy sections
Promotes ductility
Reduces mechanical failures
Promotes quicker response to heat treatment
Increases feeding properties of riser systems
Increases machinability and better appearances in anodized castings
Reduces "mottling" as seen in X-ray
Reduces apparent hydrogen porosity

(Source: Thomas Acklin, Phillips Foundry)

Melt degassing

During melting and melt processing, aluminium alloys are highly susceptible to oxidation and the absorption of hydrogen, reported Dr. Clegg. In order to produce aluminium castings of acceptable quality, he said, the presence of aluminium oxide and hydrogen must be minimized. Degassing and filtration treatments can achieve this objective.

Molten aluminium can dissolve large quantities of hydrogen; however, at the temperature of solidification most of this hydrogen is rejected from the solution thus promoting the occurrence of gas porosity in the final casting.

Regardless of the care taken, oxide films or particles will be present in the melt and, consequently, in the casting in conventional melting and pouring practice, Clegg stated. Other sources of hydrogen contamination include: humidity; presence of lubricants on charge material; products of combustion when furnaces are fired by either gas or oil; moisture on tools which comes into contact with the molten alloy; moisture in furnaces and crucibles; and damp fluxes.

Six degassing methods are available. Natural degassing relies on the relationship between metal temperature and hydrogen solubility. "As the temperature of the melt decreases, so too does its capacity to hold hydrogen in solution. A progressive reduction of the melt temperature will therefore provide some degree of natural degassing," Clegg said.

Gas purging provides an efficient method of hydrogen removal by bubbling the atmosphere through the melt. Clegg pointed out that "the efficiency of this method depends upon the purging gas employed, its purity, the furnace atmosphere and the method of its introduction to the melt".

Another method of hydrogen removal is tablet degassing. This process degasses aluminium alloys by plunging and holding tablets containing gas-evolving salts into the melt. Chlorides of aluminium or zinc, aluminium fluoride or hexachlorethane are the most common active ingredients, Clegg said. "This method does not require the equipment necessary when using a purging gas and is favoured by small foundries. However, degassing results can be inconsistent and the process generates dross."

Combined cleaning/degassing treatments are peformed to simultaneously degas and clean the melt. Several in-line processes for this degassing method have been developed to accomplish both treatments concurrently.

Ultrasonic treatment utilizes ultrasonic vibrations to effect the escape of gases by diffusion and coalescence of smaller gas bubbles. Clegg explained that "the efficiency of this technique depends upon the alloy system being treated and degassing of Al-Mg alloys is reported to be quite slow. Due to these limitations, it has not been pursued commercially".

Vacuum degassing can also provide a number of advantages, including the extraction of dissolved gases through the influence of reduced pressure on gas-metal equilibria. "In the case of aluminium alloys, vacuum degassing of the melts produced conventionally can be conducted in special chambers or, if bulk processing is relevant, by dynamic vacuum treatment", Clegg said. Limitations of this process can be high operating and capital costs.

Measuring hydrogen

"An ability to measure the hydrogen concentration in aluminium alloy melts is of considerable benefit to the foundry operator since it can lead to an improvement in product reliability and quality and can provide financial savings in the form of reduced scrap rates, increased throughput and lower energy costs," stated D. A. Hilton, Severn

Science Instruments, Ltd., Bristol, U.K. Consequently, an instrument capable of providing a rapid quantitative measurement of the gas level in the melt before the casting operation was developed.

"If the pressure above the melt is reduced, then the gas bubbles increase in size and quickly reach free surfaces where they are released; total extraction of the gas can be achieved in this manner," according to Hilton. It is a gas extraction technique, coupled with a total pressure measurement which forms the basis of the instrument design.

Another method of hydrogen measurement is the Severn Science Hydrogen in Aluminium Analyzer. Robert Atkinson, Bodine Aluminium Corp., explained that this analyzer determines the hydrogen content in cubic centimeters per 100 grams and no interpretation is necessary by those performing the test. "The test takes approximately five minutes and does not require a highly trained technician to perform or to interpret the results."

Telegas is another instrument used for measuring hydrogen in aluminium alloy melts. D. A. Granger, Alcoa Laboratories, described Telegas as a reliable, *in situ* measure of hydrogen content.

"The quantitative in-line measurement not only allows hydrogen content of ingot to be monitored, but allows the effectiveness of the molten metal treatment units to be determined and process parameters to be adjusted as needed," Granger said, adding that "Telegas has a role in enabling the desirably low hydrogen content to be achieved without resorting to excessive molten metal treatment".

Another test, the vibrated vacuum solidification test, provides a combined assessment of the hydrogen and inclusion content of the melt if properly applied, according to John Miller, Reynolds Metals Co.

The vibrated vacuum gas test was designed as an improvement to the older vacuum solidification test. This newly developed test "appears to be able to respond to both hydrogen and inclusions. We found that by measuring hydrogen content independently and controlling it to a low level, the pass-fail pressure would vary with the number of inclusions found," Miller explained.

He also noted that "it is certain that quite a bit of improvement will be necessary before conventional foundry gas testing is suitable as a quantitative quality control tool and before this type of testing can be used successfully as part of the foundry's statistical process control programme".

The pursuit of quality

Continual advancements in molten aluminium testing equipment have made the age of "trial and error" castings obsolete. Shipments of premium aluminium castings are commonplace for those foundries engaging in these emerging technologies. With the utilization of modern molten aluminium processing techniques, castings of high quality can be produced on a consistent basis.

(Proceedings from the AFS/CMI International Molten Aluminium Processing Conference will be available from the AFS Publications Dept., Golf & Wolf Roads, Des Plaines, IL 60016-2277.)

(Source: *Modern Casting*, May 1986, pp. 27, 31. Ann Marie Arzt, Assistant Editor)

Aluminium alloy casting by graphite mould

Ogiso Chuzai Kenkyusho has developed a "Graphite Mould Process" for casting aluminium.

The process involves controlling the atmosphere when sintering the graphite, improving the compatability of the graphite for aluminium by means of a secondary treatment and providing conditions suitable for graphite moulding.

Aluminium casts using this graphite mould process have between 20 per cent and 30 per cent greater mechanical and compression strength, and a cast surface 6 to 10 microns smoother than ordinary cast aluminium. It also has a shinier surface, fewer pin or blow holes and better teflon coating properties.

The company is planning to produce casts which meet great durability and high density needs. (Ogiso Chuzai Kenkyusho, 8-12, Goryo, 3-chome, Daito City, Osaka).

(Source: *JETRO*, December 1985, p. 20)

Low pressure sand casting process for aluminium components

Austin Rover (UK) is developing a low pressure sand casting process for aluminium components. The process will be used on a cylinder head for the xx executive car, to be launched in 1986. Details of the process will be announced closer to the launch date of the xx car, but Austin Rover claim it does not infringe any patents. Austin Rover originally investigated developing the low pressure sound process with Cosworth (UK), but the firms could not agree commercial terms. Cosworth has meanwhile developed its own process and is in the process of patenting it. Article discusses the Cosworth process and details the negotiations held between Austin Rover and Cosworth. (Source: *Engineer*, 14 November 1985, pp. 22-26)

Squeeze casting technology

Battelle's Geneva Research Center may conduct an experimental programme to assess how squeeze casting technology can produce reinforced aluminium materials for aerospace parts, auto engines or other industrial uses. With squeeze casting, pressure is applied on a liquid alloy, making it possible to infiltrate a reinforcing preform such as a ceramic. Battelle (Switzerland) said the process is a key technology for producing aluminium-based composites, the market for which could reach billions of dollars within a few years. The proposed programme, expected to be supported by several firms in several countries, reportedly is of interest to carmakers; parts suppliers for the auto and aerospace industries; producers of reinforcing materials, including ceramics and metallic wires; metal converting firms; aluminium producers; and press and foundry equipment producers. The programme will develop technical information to help enable squeeze casting to produce lightweight materials that can resist fatigue and heat. During the programme, Battelle will conduct experiments using two types of aluminium alloys along with commercially available ceramic and metallic reinforcing materials. (Source: *Am Mtl Mkt*, 23 December 1985, p. 15)

Light alloy castings

Light alloy castings continue to make inroads in the auto market, as the number of new users in MY86 will attest. Aluminium is the big gainer although some significant new uses for magnesium also have been approved. The new aluminium uses mainly involve sand castings, semipermanent mould castings, conventional die and porosity-free die castings, low-pressure castings and evaporative castings. The most important new use for aluminium sand casting in MY86 probably involves the 23+ lb cylinder heads for the 5.7-L Chevrolet Corvette V-8 engine. The most

important new use for aluminium die castings in MY86 probably involves the 32 lb case, or housing, for Ford Motor Co.'s first domestically built, 4-speed, automatic fwd transaxle, the AXOD. New uses for pore-free die castings include the gear housings for the power rack-&-pinion steering systems in Ford's new compact-size Aerostar vans, and the hinges for the rear hatches on American Motors Corp.'s Jeep Cherokee and Wagoneer sports utility wagons.
(Source: Am Mtl Mkt, 6 September 1985, pp. 11 and 12)

Computers improve aluminium castings

Despite short-term problems, the aluminium foundry industry is assured of a bright future, says Dr. Robert Smart. (Dr. Robert Smart was until recently research manager of the Light Metal Founders' Association. He is now Director of the British Investment Casting Trade Association). Recent developments in technology have enabled the foundries to produce more complex, high-quality castings with thinner walls and therefore become more competitive.

Aluminium alloy castings are used in all sectors of manufacturing industry, with 60 per cent going for automotive applications. As many as 400 foundries cast aluminium to give a total UK output running at an estimated 100,000 tons/year. (The figures published by the Aluminium Federation include an output of about 77,500 tons for 1984. The figure of 100,000 tons is an estimate upon the earlier survey by the Business Statistics Office.) Many of these foundries are small. The Light Metal Foundries' Association (LMFA), the major trade association for the industry, has 45 members and accounts for nearly half of all the UK light metal castings. A recent Business Statistics Office survey has highlighted the regional concentration in the West Midlands where over 45 per cent of the tonnage is cast. Diecasting predominates throughout the industry with 43 per cent of production attributed to gravity and 36 per cent to high-pressure diecasting.

The industry has suffered considerably during the recent recession with output almost constant in 1982, 1983 and 1984 at about 60 per cent of the tonnage produced in 1978. This situation reflects the fact that aluminium castings are rarely sold as finished products but tend to be incorporated in larger goods (cars and washing machines, for example) so that the prosperity of the founder depends very largely on the ability of his customer to sell his finished product. It is no coincidence that the downturn in aluminium casting sales parallels the decline in the sales of cars and commercial vehicles during the recession.

This decline has now stabilised and recently there have been signs of a real recovery beginning. However, in a situation of over-capacity, the founders that are succeeding best are those that are flexible, efficient and responsive to customer pressure for improved casting quality and consistency.

Many foundries are installing new equipment and, where necessary, developing new technology aimed at improving control of the production processes, be they sand, gravity or pressure casting. The LMFA, with financial support from the Department of Trade and Industry, has sponsored substantial projects in recent years to improve casting quality and process efficiency. The development studies, carried out at BNF Metals Technology Centre and BCIRA, have been fully validated by extensive in-factory trials and investigations in LMFA foundries.

Among the work that is being done to enhance casting soundness are: the development of instrumentation to measure gas (hydrogen) in molten aluminium and the improvement of degassing techniques; the evaluation and comparison of binder systems for sand moulds and cores; the development of improved methods for gravity diecasting design to help designers optimise feeding, running and gating; and the use of die cavity evacuation techniques to improve high-pressure diecastings.

In addition to such studies, foundries individually are tackling such areas as more efficient melting procedures, techniques for swarf recovery and improved 'housekeeping'. Overall this adds up to a significant upgrading of the traditional foundry processes and among the benefits already apparent are sounder castings, more consistent products, lower scrap levels and better machine utilization.

Automation is being introduced into the foundry industry, with robots and microprocessor control being actively developed. Robots are already applied to diecasting extraction, machine loading, core dipping and mould spraying as well as to fettling operations. As robot development continues, with enhancements in vision and tactile sensing, so operations such as sorting and inspection can be considered. The use of computers in foundry activities extends to many other aspects as well, including melt composition control, adaptive machine control and fault diagnosis, and CADCAM techniques for tool manufacture.

The overall state of the economy and the present over-capacity of the foundry industry are likely to cause problems, at least in the short term, for some aluminium foundries. In the longer term however, the future seems bright. The inherent properties of aluminium and its alloys - such as lightness, strength, and corrosion resistance - will continue to make the materials attractive for a great many applications.

The casting of aluminium alloys differs in one very important respect from the casting of other materials (such as cast iron and steel) because the process options are much wider. Sand, gravity diecasting and pressure diecasting are all well established and widely used; low pressure diecasting is advancing and investment casting of light alloys, hitherto largely confined to aerospace and defence applications, is getting orders from other sectors. More recent process developments, such as squeeze casting, extend the options further. This range of process choices is of great value to the designer who elects to use an aluminium casting.

The technical developments described are offering the industry the potential to offer high quality, more complex (and possibly thinner-walled) castings which allow foundries to be more competitive, both at home and when facing international competition.

References

1. Survey of non-ferrous foundries, 1982, Business Statistics Office, Department of Trade & Industry.

2. Smart, Dr. Robert, 'Quality Improvements in Aluminium Castings', Aluminium Industry, 1984, 3, (4), 25-29.

(This article was first published in Engineering Magazine, London, September 1985)

Aluminium master alloy rod

Milward Alloys, Inc., Lockport, NY, USA, is constructing a new manufacturing facility to produce aluminium master alloy rod. This expansion will incorporate new state-of-the-art melting and casting equipment. Slated for start-up in January 1986, the 40,000 sq. ft. facility will initially produce titanium and titanium-boron aluminium alloy rods.

Expansion and modernization of their quality control laboratories will be coupled with company-wide implementation of new statistical process control techniques. Offices and warehousing facilities are also being expanded. (Source: *Modern Casting*, December 1985, p. 18)

Lighter aluminium engines

For decades the world's automakers have tried to produce auto engines entirely of aluminium. Now Scandia Steelumin AB, a small engineering company in Norrtälje, north of Stockholm, claims to have solved the problem. With patents in a host of countries, their method of toughening aluminium and aluminium alloys beat out even the major giants of the auto industry.

Behind the breakthrough is Waldemar Serbinski, Doctor of Engineering and an immigrant Pole now resident in Sweden.

What makes building engine blocks in aluminium so attractive is the major reduction in weight, which in turn reduces fuel consumption. Production costs are reduced, while engine parts are tougher and longer-lasting.

The method can also be used in other fields requiring aluminium or aluminium alloys. Scandia Steelumin is offering the industry giants the opportunity to manufacture its products under licence, but wishes to retain sole marketing rights for itself.

Those companies currently producing aluminium engines utilise an electrolytic method, whereby the surface is covered with another, tougher material.

Scandia Steelumin AB is now starting to market a completely new and different method of toughening aluminium and aluminium alloys. This method has proved most suitable not least for toughening pistons for all kinds of petrol and diesel engines.

The method can of course also be used in toughening all types of construction blocks of aluminium or the hundres of aluminium alloys available. Everywhere that a light but tough surface is required will find the method ideal. Compressors, all manner of fans, parts for the aircraft and space industries, to name a mere handful.

What makes this new patented method so different is that the effect is not to form a layer on the surface but by means of fusion to combine with the foundation. This compositional layer has excellent tribological properties along with great toughness (HV 500-1,000).

The method also gives 300 per cent greater durability compared with untreated aluminium. Moreover pistons toughened by means of the new method require a 30-50 per cent shorter time to produce, with evident costing gains as a result.

Scandia Steelumin AB, Lars Hansson, Finsta 5400, S-762 00 RIMBO.

(Source: *New Swedish Technology*, p. 17, 1986, Vol. 5, No. 1)

Heavy-duty aluminium wheel for trucks and buses

A heavy-duty aluminium wheel for trucks and buses that weighs 15 kg less than standard steel wheels and significantly reduces tire and brake wear because of its unique heat-transferring property has been developed in Sweden and is being marketed by Bomex, a trading and consulting firm based in Eskilstuna.

The wheel features a special wing-like design on the rim that functions like a fan to provide maximum ventilation and cooling of both the rim and brake. According to Bomex, the wheel also ensures less wear on chassis components because of its perfect roundness and balance, achieved through the use of computer analysis and the latest technology.

More than two years of testing on city buses operated by the Stockholm Transit Company (SL), which has a fleet of more than 2,000 buses, have demonstrated that the wheel can reduce brake wear by 25 per cent and tire wear by 20-40 per cent, and that far fewer tire bodies need be removed for recapping because of heat damage. It was also noted that the drivers experienced greater comfort due to the overall efficiency of the wheels.

Made of low-pressure die-cast alloy designated SIS 4245, the wheel requires a minimum of maintenance. Because of its low weight, the wheel also offers greater load capacity, up to 300 kg for certain vehicles and for a normal 12 m bus an extra 120 kg or the equivalent of two additional passengers.

Special wheel nuts are supplied so that the wheel can be fitted to the hub without the necessity, expense and inconvenience of altering the studs. (Source: *Science & Technology*, September 1985, p. 2)

Engineered with style - the case for alloy wheels

Alloy wheels are here to stay. Eight per cent of cars are so equipped, and the number continues to rise. T. Bewick shows that one UK producer, GKN Kent Alloys Ltd., has achieved remarkable success in the production of the most visual of all the safety-critical components which go to form today's top-quality motor cars.

Alloy wheels are nothing new! By the first World War, sand-cast aluminium wheels had already made their appearance on commercial vehicles. Even then, the advantages were recognized of employing a lightweight one-piece cast wheel, which offered almost limitless design possibilities when it came to spoke configuration and rim contour. However, interest was short-lived - when it came to quantity production it was the steel wheel which found universal adoption.

It was the introduction of magnesium-alloy wheels in motor racing which re-awakened designers' interest in the potential of the casting process, as a means of obtaining deeply sculpted and aesthetically-pleasing components. Such wheels would have an obvious attraction to the car driver who sought to be different.

Low-pressure diecasting

Fortunately, as far as the automobile industry was concerned, there was a post-war casting process available which was to prove ideal for the quantity production of high-integrity aluminium-alloy wheels. The technique was low-pressure diecasting. In this approach, a metal die is mounted directly over a sealed furnace vessel containing a crucible of molten aluminium. Immersed in the metal alloy is a vertical hollow tube, connecting at its upper end with the centre of the die cavity. The application of a few pounds air pressure is sufficient to cause the molten aluminium to well up the inside of the tube and enter the die in a non-turbulent manner. After a predetermined time, sufficient for the casting to solidify, the air pressure is released, allowing the remaining metal to subside down the tube and re-enter the furnace bath. The dies are subsequently parted for the removal of the casting.

Today, the vast majority of alloy automobile wheels are produced by the low-pressure diecasting route.

Alloy wheels are a success story. Four years ago, 4 per cent of cars worldwide were equipped with cast wheels as original equipment. Today, the number has doubled and the growth rate shows no sign of abating. Demand continues to forge ahead of manufacturing capacity. The fact that the cast aluminium wheel is likely to cost four times that of its pressed-steel equivalent is not an inhibiting factor. To a certain section of the automobile-owning public, the stylish contours of the alloy wheel are a highly-desirable status symbol.

Today's car builders are well aware of the attraction. It is hardly surprising that top-of-the-range models are now almost certain to be equipped with alloy wheels as standard. Not only is the visual quality of the vehicle enhanced by such wheels, but there is much more profit for the manufacturer at the end of the day. The preference for the cast aluminium product has hardly been dinted by plastics wheel trim designed to produce a look-alike effect. The customer knows the difference and he or she is pretty certain the onlooker is also aware of the difference!

One-product manufacturer

The major UK manufacturer of wheels is GKN Kent Alloys Ltd., of Rochester, Kent. This one-product firm is a world leader with over 60 per cent of current production destined for the USA. Kent Alloys employ twin-die low-pressure machines to achieve the highest-possible productivity.

To maintain a position as a major independent supplier to the automotive sector in today's highly competitive climate is an achievement in itself. The company has long been at the forefront of technical innovation.

Amongst some of the more recent developments have been increasing adoption of numerically-controlled machine-tools, a switch to all-electric melting and holding, and extensive use of computers - both for management purposes and for machine control. Outstanding in the latter context has been computer-control of die cooling.

Using air-cooled dies, the largely automatic cycle of die filling, solidification, and the retrieval of the pair of castings takes seven minutes. However, a switch to water-cooled dies fitted with a series of thermocouples has almost halved production time. A central computer, sited at a point remote from the casting shop, switches the water-cooling on and off in each individual die, according to the signals received from the thermocouple array.

Auto wheels are safety-critical components. As a result, testing and control at every stage of the production cycle is exhaustive. Kent Alloys set out to obtain, by the low-pressure diecasting route, components which have the same high structural integrity that most people have come to associate with forgings.

Central to the inspection process is 100 per cent fluorescent X-ray examination of each and every wheel. However, even this searching test can fail to reveal the presence of very fine micro-shrinkage cavities or gas porosity. Such defects can become all too apparent during the subsequent machining and painting cycle. After all, the alloy wheel is unique amongst automobile castings in that as much as 90 per cent of the surface area is subjected to machining. If problems go unrecognised, then the first evidence of trouble is the discovery of tiny surface blisters as the finished wheels emerge from the powder painting plant.

To ensure that defective wheels never progress to the very expensive finishing operations, Kent Alloys proof-machine a representative percentage of each batch of components with a diamond-tipped tool; a control test calculated to reveal the smallest discontinuity in the metal structure.

Statistical process control

To survive in the production of safety-critical car components, it is certain that a manufacturer is already involved in statistical process control (SPC). Kent Alloys' commitment to SPC is total. In the diecasting process alone, no fewer than 18 variables are monitored and charted, ensuring that manufacturing parameters have little opportunity to deviate from the rigid standards calculated to produce a quality component.

The alloy wheel will always be a luxury item. However, the design possibilities offered by the casting process are almost endless. This factor alone will ensure that in a world of continually changing fashion, the aluminium wheel will remain a highly-desirable asset to any top-quality car. And as long as there are alloy wheels, then GKN Kent Alloys are likely to remain one of Europe's leading independent manufacturers. (Source: Metals Industry News, March 1986, p. 12)

Steel-aluminium 'sandwich composites'

Auto engineers are moving into production with steel-plastic or steel-aluminium 'sandwich composites' that reportedly are more than short-term attempts to match US thermoplastic developments. The merits of sandwich composites include lighter weight, compatibility with present stamping equipment and superior resonance suppression. The drawbacks are higher cost and some production and welding problems, but engineers believe these will be solved as use becomes more widespread. The sandwich composite is already established in prototype and production vehicles in Japan. (Source: Am Mtl Mkt, 3 February 1986, pp. 20, 23)

New adhesive for bicycle frame

Bridgestone Cycle has developed an adhesive for binding new materials such as aluminium, carbon, boron, amorphous substances, and whiskers, and at the same time developed a bonding method using the new agent. The company has thus made it possible to mass-produce bicycle frames made of new light-weight materials. The newly developed adhesive, made of a high-quality modified acrylic substance, has great adhesive strength. By using this for bonding frames, it will be possible to prevent a lessening of material strength and any deterioration. The company will put on the market road-racer type cycles of a carbon fibre frame. According to the company, the weight of the new car using aluminium alloy in addition to carbon fibre is 34 per cent lighter than that of the conventional cycle using chrome molybdenum steel. Using this method, Bridgestone Cycle will introduce new materials into high-grade type cycles. (Source: Chemical Economy & Engineering Review, Vol. 18, No. 3, March 1986)

Lightweight aluminium vehicle body

The Mercedes 2421K rigid six-wheeler fitted with Tel-loy alloy body and the new 'C' ram tipper gear was recently launched on the market.

The Tel-loy body, manufactured from a lightweight aluminium alloy by Telehoist Limited of the UK, provides the user with the maximum possible payload. This complements the recent move by Mercedes to reduce the tare weight on all of their rigid six-wheelers by the incorporation of revised axle and suspension designs.

Further weight saving on the 2421K is gained by use of the new Telehoist 'G' ram tipper gear. The construction is a breakaway from conventional design, dispensing with threaded gland nuts. The result is a lower stack height, a more rigid construction and simplified servicing. (Source: African Technical Review, February 1985, p. 51)

Nissan Motor is testing its new composite material consisting of fine ceramics and aluminum for use in car exhaust manifolds. It can make manifolds 45 per cent lighter than conventional cast-iron types and greatly increase turbocharger capacity (Source: Jpn Econ J, 21 December 1985, p. 9)

Uses and production techniques for nickel aluminide alloys are being developed by Oak Ridge Natl. Lab. (Oak Ridge, TN, USA), working with 24 US metal producers and potential end-users. Commercial production of nickel aluminide is still 2 years away, but development of a new alloy has progressed rapidly since the Oak Ridge project began in early 1983. The alloy now under development at Oak Ridge is composed of 85 per cent nickel, 13 per cent aluminium, 0.2 per cent boron, and 0.5-2 per cent hafnium or zirconium by weight. The Oak Ridge laboratory and NASA are studying another nickel aluminide alloy containing 50 per cent aluminium, but that alloy is still a long way from perfection. Industry experts believe that alloys containing nearly 50 per cent nickel and 50 per cent aluminium, when perfected, will produce a quantum leap forward in jet engine performance by increasing the temperatures that gas turbine components will be able to withstand. Nickel aluminides will have a higher melting point than present superalloys and will not require air cooling. (Source: Am Mtl Mkt, 21 October 1985, pp. 17, 28)

Squeeze-forming of aluminium alloys is ideal for automotive components, following success in using the process for aerospace parts. The process has the advantage of being continuous from liquid alloy to finished component. Liquid alloy is poured into a ready-prepared die-set, mounted in a hydraulic press, coated with graphite release agent and preheated. Once the die-set is filled, the press closes and solidification of the alloy takes place under pressure. Components display properties of both die-casting and forging, while pressure required is 31-108 mn/m^2, lower than that for conventional aluminium alloy forging. Article details component design and suitable alloys. (Source: Eng Design, July 1983, pp. 28-31)

Ceramic fibre strengthens aluminium connecting rods

Reinforced-aluminium connecting rods, developed for an experimental high-performance engine, may be the forerunner of more metal-matrix components in future automobiles. The reinforcement is a new ceramic fibre invented by Du Pont Co. scientists, and the rods were developed by Toyota Motor Corp., working in a joint programme with Du Pont.

The ceramic fibre, called Fibre FP, is a polycrystalline aluminium oxide, described by its inventors as having "a high degree of stiffness, high compressive strength in composites, moderate tensile strength, and high-temperature stability, all of which make it well suited for reinforcing nonferrous metals. Aluminium and magnesium reinforced with 35 to 50 per cent by volume continuous-filament Fibre FP have three to four times greater stiffness, up to four times the fatigue strength, and higher temperature capability than the same metal castings without reinforcement".

Replacement of steel connecting rods with reinforced aluminium rods, which are some 35 per cent lighter, could lead to increased fuel efficiency and reduced engine vibration. In addition to its use in metal-matrix composites, Du Pont spokesmen suggest the potential of Fibre FP in reinforcing ceramics and epoxy and polyimide resins.

The new fibre is only available at present in small quantities for experimental use, at $200/lb. If the material goes commercial, the decision on which is years away, according to Du Pont, the price could come down to about one-tenth of that. (Source: Machine Design, 19 April 1984, p. 5)

Fibre-reinforced aluminium

Nippon Oil has started development work on fibre-reinforced aluminium using carbon fibre. With a tensile strength of 150 kg/mm^2, it can maintain a high thermal resistance of up to 500°C. Its practical use is anticipated as a material for aircraft and automobiles. (Source: Chemical Economy & Engineering Review, June 1985, p. 44)

Aluminium alloy twin hulled high speed passenger boat

Mitsui Engineering & Shipbuilding Co., Ltd., has manufactured an aluminium alloy high speed twin hull passenger ship, the Mitsui Supermaran CP30MKII, or "Marine Shuttle".

The CP30MKII, through a unique ship body shape which makes possible both high speed and energy conservation, excels in high speed performances while simultaneously delivering superb navigability and riding comfort even in waves as high as 3 m.

The economical improvement in the CP30MKII is made possible because of the durable, anti-corrosive aluminium alloy welded construction, and also through the use of a lightweight, high speed diesel engine, making it an extremely polished, high speed catamaran.
(Mitsui Engineering & Shipbuilding Co., Ltd., Public Relations Dept., 6-4, Tsukiji 5-chome, Chuo-ku, Tokyo).

(Excerpted from JETRO, April 1986, p. 37)

MARKET TRENDS

Japan aluminium boost

Japan's production and consumption of secondary aluminium and aluminium-base alloy ingot rose slightly last year compared with 1984 totals.

Production rose by about 3.1 per cent to 866,126 short tons, while consumption increased 2.35 per cent to reach 1.028 m st. according to figures compiled by the Japan Aluminium Federation on the basis of MITI statistics. (Extracted from: Metal Bulletin, 22 April 1986, p. 17)

First license granted for Ni and Ni-Fe Aluminides

Martin Marietta Energy Systems Inc. and Cummins Engine Co. Inc. have signed a license agreement for the first commercial application of heat and corrosion resistant nickel and nickel-iron aluminide alloys developed by Oak Ridge National Laboratory (ORNL). Cummins has exclusive rights involving large diesel engines and turbochargers, while Martin Marietta retains rights for all other applications.

Nickel and nickel-iron aluminides, which become stronger at higher temperatures, are the first of a new class of high temperature alloys made of readily available, inexpensive materials. Most intermetallic compounds are brittle; however, the ORNL-developed alloys are ductile and can withstand temperatures up to 1000°C (1830°F).

Cummins expects to use the aluminides for high temperature components in diesel engines. Other potential applications include parts for high performance jet engines, gas turbines, advanced heat engines, and heat exchangers in nuclear and coal-fired steam plants.

ORNL is operated by Martin Marietta Energy Systems Inc. for the U.S. Dept. of Energy. The licensing agreement "is a direct result of policies initiated by the federal Government - specifically the DOE - to increase transfer of advanced technology to American industry, says ORNL director, Herman Postma. (From Metal Progress, American Society for Metals 1986, with permission)

The U.S. aluminium industry: into its second century

Along with modern process capabilities, the U.S. aluminium industry is offering new products and invading new markets. The most notable new product is the recent introduction of aluminium-lithium alloys for aerospace applications. These alloys, when compared to previously used alloys, offer equal strength with an approximate 10 per cent reduction in density. Aluminium is also making inroads into such new areas as rail cars for carrying coal, new automotive applications, and food cans. New geographic markets for established uses are being pursued, namely aluminium beverage cans in Canada.

In addition, new aluminium processing technology and aluminium composite materials are being developed. Aluminium alloys produced via rapid solidification technology offer unique properties. Components fabricated by superplastic forming of specially developed aluminium alloys result in significant cost savings when compared to advanced composites. Aluminium matrix composites, aluminium strengthened by fibres of either graphite, boron or other strong materials, and aluminium-plastic laminates are evolving into very useful engineering materials. (Extracted from an article written by Joseph J. Tribeudis, Ph.D, first appeared in Materials and Society, Vol. 10, No. 2, 1986)

Weldable aluminium alloy

Kobe Steel, Ltd., and Furukawa Aluminium Co., Ltd., have announced the development of a weldable aluminium alloy.

The new aluminium alloy developed by Kobe Steel, KS7055 aluminium alloy, possesses a high base metal strength and allows ordinary welding into high welded joint strength that has high resistance to stress-induced corrosion cracking.

The KS7055 has Al-Zn-Mg as the base components to which is added a trace quantity of a special substance, which, combined with the manufacturing conditions provides excellent SCC resistance and weldability.

Since the alloy can permit lightweight structural designs and streamlining of design implementation, most conceivable applications are as structural materials for vehicles and other transportation equipment.

Characteristics

(1) It allows ordinary welding including arc welding and electric resistance welding.

(2) Welded joint strength is higher than the 2219, a conventional high-strength weldable aluminium alloy, by 30 per cent in both tensile and yield strengths.

(3) It provides SCC resistance equal to that of the 7075-T73 that has the highest SCC resistance of all the high-strength aluminium alloys.

(4) Its base metal tensile strength (50 kgf/mm^2) is higher than the high-strength aluminium alloys 2024-T4 and 7075-T73.

The Furukawa aluminium alloy, called "2219", was developed for applications in the fuel tank of the "H-II Rocket" and mass production techniques have been formulated to produce the alloy and marketing activities have begun.

The "2219" alloy has more copper cast and magnesium removed, and vanadium and zirconium are added to produce a high-strength hardened alloy that possesses significant heat resistance, cold brittleness, toughness and formability while remaining weldable.
(Kobe Steel, Ltd., Publicity Sect., 8-2, Marunouchi 1-chome, Chiyoda-ku, Tokyo and Furukawa Aluminium Co., Ltd., 6-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo)

(Source: JETRO, February 1985, p. 21)

High-strength aluminium alloy for cold forging

Kobe Steel, Ltd., has also developed, and has commenced production of the "D20" and "D60" high-strength types of new aluminium alloys.

Aluminium alloys have been widely used as their malleability makes them suitable for cold forging processes. Recent cost reductions have led to a trend towards cold forging the aluminium to as close as the near net shape as possible, in order to reduce the expense of cutting processing. This has led to a further increase in the use of cold forging.

The alloys that have been conventionally used harden in the short time that they are left to cool down to normal temperature after tempering (the normal temperature time effect) and this has the disadvantage of causing difficulties in the cold forging. This has meant that the once-tempered material is softened and cold forged and then given annealing-tempering processing to achieve the required strength. The process of annealing-tempering has the following inherent problems.

(1) The quenching temperature must be strictly controlled or else temperature rises will cause partial melting that will result in strength and tenacity reductions. Inadequate strength can also result if the metal is inserted while the temperature is too low.

(2) It is necessary for the quenching to be performed by the user.

(3) Quenching after cold forging generate quenching distortion that causes deformations in the product. (This is particularly so for thinly forged products.) Furthermore, quenching also enlarges the crystal particles to give a less attractive appearance.

However, the newly developed alloys have a special component element added within the alloy and the presence of this component causes practically no hardening to occur after tempering when the metal is returning to normal temperature. Cold forging is still possible for long periods in the state (the W-state) after quenching. The required strength can therefore be obtained by simply cold forging and annealing the material once it has been supplied from the steel manufacture after quenching.

The main features of the alloys are as follows.

(1) The manufacturer performs the temperature process that must be strictly controlled (to ±3°). Therefore, there are great reductions in the procesring that the user must perform. In addition, there is no necessity for the user to perform quenching.

(2) There is no quenching processing once cold forging has been performed; therefore, no quenching distortion is generated (in the case of thin-forging manufacturer in particular). There is also no enlargement of the particles because of quenching and so there is no deterioration in the appearance.

(3) The cold forging characteristics after quenching are excellent and the alloy has a flexibility (before quenching) equal to that of conventional alloys. (Source: JETRO, May 1985, p. 21)

New aluminium alloys for computer magnetic disc

Three types of new aluminium alloys for computer magnetic discs have been developed, again from Kobe Steel. It will increase the production of magnetic disc blanks and substrates. The new alloys have a high storage density and a capacity three times or more that of conventional alloys. Under its production capacity increase plan, the blank production capacity of the Mooka works (Tochigi Prefecture) was increased from 2 million sheets/month to 6 million, and test operation was begun. The monthly production capacity of substrates was increased from 100,000 to 250,000 sheets by September 1984, and will be further increased to 600,000 this year, and 1 million by 1987.

The world demand for magnetic discs is estimated at 40 million/year at present and a further increase is predicted. Kobe Steel is one of the world's top blank manufacturers. However, since 1983, Sumitomo Light Metal Industries, Nippon Light Metal, etc. have increased the production of blanks and substrates, to meet growing demand.

Due to the rapid increase of small-size computers, demand is increasing for smaller diameter, higher density and larger capacity magnetic discs. In parallel with this, requirements of aluminium substrates are becoming strictier. The alloys recently developed makes it possible to produce higher density disc substrates. (Source: Chemical Economy and Engineering Review, June 1985)

Joint aluminium rolling plant project in Bahrain

An aluminium rolling plant for GARMCO (Gulf Aluminium Rolling Mill Co.), the first joint project of Arabian countries on the Gulf, has been completed at the North Sitra industrial district in Bahrain, and put into full-scale operation. The plant for which the Japanese group of Kobe Steel, C. Itoh & Co. and Nichimen secured an order in August 1983 will promote product export.

The plant, the joint project of GOIC (Gulf Organization for Industrial Consultation), established for efficient economic management by Gulf countries, was constructed by GARMCO which was jointly set up in February 1981 by six countries - Saudi Arabia, Kuwait, Bahrain, Iraq (20 per cent investment each), Oman and Qatar (10 per cent each).

The 40,000 ton/year aluminium rolling plant produces sheet, coils, formed sheets and foil. The plant consists of various furnaces, hot and cold rolling mills, and refining line. Kobe Steel obtained a full turn-key order for design, manufacture of plant machinery and queipment, and civil engineering. Since April 1985, the company provided education and training at its Maoka works. (Source: Chemical Economy and Engineering Review, May 1986, Vol. 18, No. 5)

Sources of know-how of semis and finished aluminium goods manufacture

Product/technology	Source
Continuous casting	Alcan Research and Development Ltd., Canada
	Vereinigte Aluminiumwerke A.G. P.O. Box 100440 40480 Grevenbroich 1, FRG
	ALUSUISSE Feldeggstrasse 4 CH-8034, Zurich, Switzerland
	National Southwire Company (NSC) Fertilla Street P.O. Box 1000, Carrolton Georgia 30117, USA
Aluminium casting, die casting	Mitsubishi Light Metal Ind. Corp., Japan
	Toshiba Machinery Corp., Japan
	Kaiser Aluminium and Chemical Corp., 300 Lakeside Drive Oakland (Ca) 94643, USA
Separation of aluminium from scrap	R. Fischer, FRG VEB Mansfeld-Kombinat Wilhelm Pieck, Frieberg, GDR
Recycling aluminium scrap	Vereinigte Aluminium Werke A.G. D-5300 Bonn, FRG
Aluminium extraction from scrap	Sharkey Metals Ltd., UK
Permanent mould castings	Fuso Light Alloys Co. Ltd. Japan
Low pressure die-casting	Reynolds Metals Co. One Union National Place Little Rock, Arkansas 72201 USA
Melting furnace design	Outokumpu Oy P.O. Box 27, SF-022201 Espo 20 Finland
Castable aluminium alloys	Nippon Light Metal Research Lab. Ltd. 7-3-5 Ginza, Chuoko, Tokyo Japan
Wire drawing	Fujikura Cable Works Ltd., Japan
	ALUSUISSE Feldeggstrasse 4 CH-8034, Zurich, Switzerland
	National Southwire Co. Fertilla Street, P.O. Box 1000 Carrolton, Georgia 30117, USA
	Nippon Light Metal Research Lab. Ltd. 7-3-5 Ginza, Chouoko, Tokyo Japan
Cold rolling	Sumitomo Metal Industries Ltd. Tokyo, Japan

Product/technology	Source
Cold rolling	Norsk Hydro, Norway
Extrusion	Sumitomo Light Metal Ind. Ltd. Tokyo, Japan
Welding	ALCOA International Inc. Av. d'Ouchy, CH-1006 Lousanne Switzerland
Electric colouring, anodizing	Pechiney Ugine Kuhlmann, France
	Sumitomo Aluminium Corp., Japan
	ALCAN Research and Development Lab., Canada
	Nippon Light Metal Research Lab. Ltd. 7-3-5 Ginza, Chuoko, Tokyo, Japan
Building structures	ALUTERV-FKI Hungalu Engineering and Development Centre H-1133 Budapest, Pozsonyi ut 56 Hungary
Deep-freezing storage houses	ALUSUISSE Feldeggstrasse 4 CH-8034 Zurich, Switzerland
	Energy Management Institute (EGI) H-1027 Budapest, Bem rakpart 33-34, Hungary
Doors and windows	Factory of Metal Works (Fémmunkás Vállalat) H-1394 Budapest, P.O.B. 380 Hungary
Container-type elements	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
Hothouses (greenhouses)	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
Automotive wheels	ALUSUISSE Feldeggstrasse 4 CH-8034 Zurich, Switzerland
	Ardal Og Sunndal Verk A.S. P.O. Box 2469 Solli N-Oso 2, Norway
Aluminium truck frames	Reynolds Metals Co. One Union National Place Little Rock, Arkansas 72201 USA
Cooking utensils	Aluminium Ware Factory H-1142 Budapest Erzsébet királyné utja 57-61 Hungary
Soda-water siphons, beer barrels, radiators	"Lehel" Refrigerator Works H-5101 Jászberény P.O. Box 64, Hungary
Heat exchangers radiators	"Lehel" Refrigerator Works H-5101 Jászberény P.O. Box 64, Hungary
Sea-water desalting	Société Egico, Paris, France

Product/technology	Source
Installations	Energy Management Institute (EGI) H-1027 Budapest Bem rakpart 33-34, Hungary
Mine props	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
Aluminium alloy conductor wire	ALUSUISSE Feldeggstrasse 4 CH-8034 Zurich, Switzerland
	Sumitomo Electric Industries Ltd. Japan
Raw material of aerial conductors and cables	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
	Research Institute of Electrical Engineering (VEIKI) H-1168 Budapest, P.O.B. 233 Hungary
Cables stranded from alumoveld wires	Vereinigte Metallwerke Ranshofen-Berndorf Uraniastrasse 2 A-1010 Wien, Austria
Stranded cables	Hungarian Cable Works (MKM) H-1117 Budapest, Budafoki ut 60 Hungary
Insulated conductors and cables	Hungarian Cable Works (MKM) H-1117 Budapest, Budafoki ut 60 Hungary
	ALCAN Ltd. Dufourstrasse 43, Zurich, Switzerland
Electric assembly units	Allgemeine Elektrizitätsgesellschaft (AEG) Bebelstrasse 24 D-7 Stuttgart, FRG
	Electric Equipment and Apparatus Works (VBKM-EKA) H-1457 Budapest, Füzér u. 37-39 Hungary
Telecommunication cables	Southwire Company Fertilla Street P.O.B. 1000, Carrolton Georgia 30117, USA
Electric busbars, cable channels	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
	Székesfehérvár Light Metal Works H-8001 Székesfehérvár Adonyi u. 64, Hungary
	Balassagyarmat Metalworking Enterprise H-2660 Balassagyarmat P.O.B. 30, Hungary
	Electrical Installation Enterprise (VIV) H-1400 Budapest, Sip u. 23 P.O.B. 67, Hungary

Product/technology	Source
SF6 insulated switching equipment	BBC Aktiengesellschaft Brown-Bovery, Postfach 85 CH-5401 Baden, Switzerland
	Ganz Electrical Works H-1525 Budapest, Lövőház u. 39 P.O.B. 63, Hungary
Transformers	Csepel Transformer Factory H-1751 Budapest, P.O.B. 72 Hungary
	Transformatoren Union, A.G. Katzwanger Strasse 150 Nürnberg, FRG
	Westinghouse Electrical Company Shargon, Pa. 16146, USA
Capacitors	Mechanical Works H-1502 Budapest, P.O.B. 64 Hungary
	GIPROCVETMET, Moscow, USSR
Lighting fixtures	Electrical Equipment and Apparatus Works VBKM-EKA H-1457 Budapest, Füzér u. 37-39 Hungary
Deep-drawn lightweight containers	R. Rosch GmbH, FRG
Welded containers	VEB Transformatorenwerk, GDR
Collapsible tubes for toothpaste etc.	Sumitomo Aluminium Smelting Co. Ltd. 7-9-2 Chome, Nihonbashi Chuo-ku, Tokyo, Japan
Containers with stamped base	Reynolds Metals Co. One Union National Place Little Rock, Arkansas 72201 USA
Beverage cans	Pechiney Ugine Kuhlmann France
Gas cylinders	Aluminium Ware Factory H-1142 Budapest Erzsébet királyné utja 57-61 Hungary
High-pressure tanks	Scanaluminium Vika Oslo, 1. P.O.B. 1857 Norway
Storage and transport cans	"April 4" Machine Works (Április 4. Gépipari Müvek) H-6100 Kiskunfélegyháza Csáni ut 2, Hungary
Barrels, small containers, pallets	Hungarian Aluminium Corporation (HUNGALU) H-1133 Budapest, Pozsonyi ut 56 Hungary
Beer and drink boxes	Aluminium Co. of America 1501 Alcoa Building Pittsburg, Pa. 15219, USA
Cans	CEBAL, Paris 8^{e} 47 rue de Monceau, France
	Karges-Hammer Maschinen GmbH Frankfurter Str. 36 Braunschweig, 330, FRG

Product/technology	Source
Bottle closures	Pano-Verschluss GmbH KG Gesstrasse 29, Itzehoe, FRG
Collapsible tube	CEBAL, Paris 8^{e} 47 rue de Monceau, France
	CHEMIMAS H-1103 Budapest, Moszlopy ut 1 Hungary
Solar energy technology	Sumitomo Light Metal Ind. Ltd. Japan
	Développement des Applications de l'Energie Solaire F-75016, Paris 28, rue de la Soure France
	Phenol Engineering S.A.R.L. Av. de Lattre de Tassigny 69 330 Meyzieu, France

Any mammoth company (Pechiney, ALCAN, ALCOA, ALUSUISSE, Reynolds, Kaiser, Montecatini) and also the Hungarian Aluminium Corporation (HUNGALU) together with ALUTERV-FKI, its engineering and development centre possess know-how concerning technologies for semi-production of different kinds, such as rolling, extrusion, extrusion press, forging, casting and special technologies for finished goods such as welding, surface treatment in the aluminium industry. (Excerpt from UNIDO document (IO/601), 17 October 1984, Aluminium Production and Use in Developing Countries with Special Emphasis on the Manufacture of Aluminium Semis and Finished Products; conducted by a working team of ALUTERV-FKI, Budapest, Hungary.)

United Nations and UNIDO reports on aluminium

UNIDO/IOD.318	Select and Annotated Bibliography on Aluminium Metal Processing and Use (Prepared and published by the Hungarian Central Technical Library and Documentation Centre TECHNOINFORM)
UNIDO/IOD.320	Select and Annotated Bibliography on Alumina (Prepared and published as above)
UNIDO/IOD.321	Select and Annotated Bibliography on Primary Aluminium Metal (Prepared and published as above)
UNIDO/IOD.335	The Economic Use of Aluminium (Based on Hungarian Experience)
UNIDO/IOD.363	The Development of Aluminium Sales up to 1990 (Analysis and Forecast of the Aluminium Consumption in Selected Markets and Industries, conducted by a working team of PROGNOS AG, Basle, Switzerland)
UNIDO/IO.512	Status of the Semi-Products Aluminium Industry in Some Developing Countries
UNIDO/IO.561	Present and Future of the Aluminium Industry in the Arab World
UNIDO/IO.565	Manufacture of High Alumina Products - Basic Information

UNIDO/IO.586	Design Study of an Aluminium Extrusion and Anodizing Plant
UNIDO/IO.601	Aluminium Production and Use in Developing Countries with Special Emphasis on the Manufacture of Aluminium Semis and Finished Products
ID/WG.446/6	Development Trends in the Alumina Productions
UNIDO/IO.619	Guidelines for Processing Aluminium Semi-Fabricated Products
UNIDO/IO.621	Study on the Establishment of Laboratories for Aluminium Semi-Fabricated Products
UNIDO/ID/324	The Economic Use of Aluminium, Development and Transfer of Technology Series, No. 21

Development and Transfer of Technology Series No. 21

"The Economic Use of Aluminium"

United Nations Conference on Trade and Development: TD/B/C.1/PSC/19/Rev.1

"Studies in the Processing, Marketing and Distribution of Commodities" - The Processing and Marketing of Bauxite/Alumina/Aluminium: Areas for international co-operation

UNIDO meetings on aluminium

1981 7-11 Dec.	Workshop on Centres for Metallurgical Research and Development, Jamshadpur, India
1983 24-26 Oct.	Group Training on the Production of Alumina from Bauxite with Special Emphasis on Energy Conservation Technologies and Environmental Aspects, Budapest, Hungary
1985 18-21 March	Expert Group Meeting on Restructuring of the Non-ferrous Metals Industry, Vienna, Austria

Two tentative dates for 1987:

23-26 Feb.	Expert Group Meeting on Strategies and Policies of the Non-Ferrous Metals - Aluminium, Georgetown/Guyana or Vienna/Austria
April	The Global Preparatory Meeting on the Non-Ferrous Metals Industries, Vienna/Austria

UNIDO Consultation on Non-ferrous Metals to be held in Budapest, Hungary

30 November - 4 December 1987

(1) Furthering the processing of non-ferrous metals in developing countries

(2) Selection of technological alternatives in the non-ferrous metals industries adequate for developing countries

(3) Financial constraint to develop the non-ferrous metals industry

PUBLICATIONS

The Effective and Economic Use of the Special Characteristics of Aluminium and its Alloys, Proceedings of an Int. Conf., Institute of Metals, Sept. 1982, published by the Institute of Metals, London.

The World Aluminium Industry, Vol. II, published by Australian Mineral Economics Pty. Ltd., March 1982.

Handbook of Aluminium, Aluminium Company of Canada, 1961.

The Technology of Aluminium and its Alloys, P.C. Varley, London, Newness-Butterworths, 1970.

Creep of Metals and Alloys by R.W. Evans and B. Wilshire, ISBN 0904357597, published 1985, Institute of Metals, Subscribers Services Dept., 1 Carlton House Terrace, London SW1Y 5DB.

ZA Alloy Foundry Practices Guide (16 p), details processing parameters, casting methods, and performance properties of ZA-8, 12 and 27 zinc-aluminium alloys. Eight processes are covered. Zinc Institute Inc., 292 Madison Ave., New York, N.Y. 10017.

Aluminium Master Alloys Business Unit, Cabot Corp., P.O. Box 1462, Reading, PA. 19603, USA has published:

Alloy ratings. Bulletin MA-PD12 (4 p) outlines a silicon phase modification rating system for the structure of hypo-eutectic aluminium-silicon casting alloys. System is based on data developed for aluminium alloy 356.

and also

Product Data: KBI Aluminium Based Master Alloys Information on data on braod list of aluminium based master alloys used by primary and secondary aluminium producers as grain refining, hardening agents and special purpose alloys. Prepared by metallurgists and research and development engineers.

Aluminium Processing - Four-page bulletin lists chemical treatments to clean, etch, deoxidize/desmutt, and chromate conversion coat aluminium extrusions, sheet, and castings. Processing techniques may be spray washer, immersion tank, or wipe-on type. Industrial Chemical Products, 12801 Newburgh Rd., Livonia, Mich. 48150, USA.

Alloy Powders. Data Sheet PM-1.3 describes four Solocoat one-step, self-bonding powder alloys for thermal spray metalizing: two stainlesses, an aluminium bronze, and a Ni-Al-Mo composition. Wall Colmonoy Corp., 19345 John R. St., Detroit, Mich. 48203, USA.

Aluminium. Brochure (16 p) explains company's capabilities in producing cold rolled aluminium coils and cut-to-length sheets. Alloys include the 1000, 3000, 5000 and 6000 series, in thicknesses ranging from 0.005 to 0.250 in. (0.13 to 6.4 mm). Aluminium Mills Corp., P.O. Box 1, Prairie View, Ill. 60069, USA.

Kaiser Chemicals has published a new brochure on its alumina products and technology. The brochure is divided into six categories according to specific grades of alumina. Charts are included, showing typical chemical analyses and the typical physical properties of each alumina grade in the respective category.

Metals & Alloys in the Unified Numbering System, 4th Ed. (HSJ1086) is a reference guide to more than 3500 metal and alloy designations used by individual societies, trade associations, government organizations, producers and users. Hardback, $90; paperbound, $78, from the Society of Automotive Engineers (SAE), Dept. 676, 400 Commonwealth Dr., Warrendale, PA. 15096, USA.

Aluminium. Publications & Audiovisuals Guide (36 p) contains 130 publication titles and 26 audiovisual presentations. Sections include millproducts and castings finishing and joining processes, and major markets such as construction, packaging, and transportation. For a free copy write to Aluminium Association Inc., 818 Connecticut Ave., N.W. Washington, D.C. 20006, USA.

Aluminium for Engine Applications - Int. Congress and Exposition, Detroit, Mich., USA, 28 Feb. - 4 March 1983, Society of Automotive Eng., Warrendale, PA., USA, 1983, 61 p.

Aluminium: Profile of the Industry by J. Keefe, K. Berk., New York, McGraw-Hill, 1982, 201 p.

Fabrication of Composite Materials Source Book, includes also articles on aluminium alloys (American Society for Metals, Metals Park, Ohio 44073, 1985, ISBN 0-87170-198-7)

Aluminium-lithium alloys III

Proceedings of the Third International Aluminium-Lithium Conference organized by the Institute of Metals at the University of Oxford from 8-11 July 1985.

Papers cover the fundamental metallurgy of Al-Li alloys, together with the production and processing aspects. The mechanical properties and fabrication parameters in comparison with existing aerospace alloys are emphasised as well as the requirements and applications of the alloys for airframes and engines in fixed wing aircraft and helicopters and uses in other defence applications. Book 358 280x210 mm 640pp, Casebound, ISBN 0 904357 80 5. Publ. January 1986. The Institute of Metals, Subscriber Services Department, 1 Carlton House Terrace, London SW1Y 5DB.

The following five titles of books were taken from a catalogue of the Metallurgical Society Inc., 420 Commonwealth Drive, Warrendale, PA. 15066, USA.

Aluminium-lithium alloys II

Edited by T.H. Sanders, Jr. and E.A. Starke, Jr.

Proceedings of the Second International Aluminium-Lithium Conference, Monterey, California, 12-14 April 1983. Hardback, 693 pages, illustrated, index.

Significant advances in the study of Al-Li alloys have almost doubled the scope of this recent volume. The 38 papers cover methods of alloy preparation, effects on microstructure and properties, superplastic deformation, fundamentals of physical metallurgy, weldability. Na and H effects on fracture, corrosion behavior, and other important topics. ISBN 0-89520-472.

High-strength powder metallurgy aluminium alloys

Edited by Michael J. Koczak and Gregory J. Hildeman.

Proceedings of a symposium held at the 111th AIME Annual Meeting, Dallas, Texas, 17-18 February 1982. Hardback, 425 pages, illustrated, index.

These 22 papers highlight fatigue and stress corrosion cracking behavior of commercial high-strength 7XXX aluminium powder metallurgy alloy; development of emerging aluminium powder metallurgy alloys; and exploratory research directed at developing low-density Al-Li powder metallurgy alloys. ISBN 0-89520-453-3

Thermomechanical processing of aluminium alloys

Edited by James G. Morris.

Proceedings of a symposium at the TMS-AIME Fall Meeting in St. Louis, Missouri, 18 October 1978. Hardback, 233 pages, illustrated, index.

Houses 11 papers examining the effects of thermomechanical treatments on a broad range of aluminium alloys. While basic effects and mechanisms are discussed, primary focus is on the response of microstructural characteristics and specific mechanical properties to various types of thermomechanical treatments. ISBN 0-89520-354-5

High conductivity copper and aluminium alloys

Edited by E. Ling and P.W. Taubenblat

Proceedings of a symposium at the 113th TMS-AIME Annual Meeting in Los Angeles, California, 26 February - 1 March 1984. Hardback, 190 pages, illustrated, index.

Presents up-to-date material on copper and aluminium alloys in applications requiring conductivity. Composition, design and process control are stressed to retain high conductivity while achieving other desired properties. ISBN 0-89520-479-7

Superplastic forming of structural alloys

Edited by N.E. Paton and C.H. Hamilton

Proceedings of symposium held in San Diego, California, 20-24 June 1982. Hardback, 440 pages, illustrated, index.

Groups 19 papers emphasizing superplasticity applications rather than fundamental science. The four major sections are: superplasticity, mechanisms and characteristics; superplastic materials; superplastic forming processes and applications; and caviation in superplastic forming. Alloys discussed include titanium, aluminium, iron, nickel, and superalloys. ISBN 0-89520-389-8

A technical data sheet on "Aluminium - 1 per cent Magnesium Alloy Bonding Wire", which is used extensively in ceramic packaged semiconductor devices and can be supplied in diameters ranging from 2.5 mil to 0.7 mil. The technical data sheet includes information on mechanical properties of the material, tensile properties, quality control data, dimensional tolerances, spooling specifications and related required information. Hydrostatics, Inc., Bethlehem, Pa., USA.

Duramic Products Inc., 426 Commercial Ave., Palisades Park, NJ 07650 has published a six-page brochure featuring a three-page chart listing detailed electrical, physical, and thermal characteristics of 16 machinable ceramic materials.

Included are various grades of alumina, aluminium silicate, graphites, nitrides, machinable glass ceramic, and composite materials. Applications are also discussed, as are the the company's capabilities in the design and manufacture of precision nonmetallic parts. Bulletin 502-PD1.

and

Alumina fabrication

Precision fabrication of intricate parts and components is discussed in the 8-page Technical Data Sheet AX-3000, on alumina ceramics. The material is discussed in detail, and its characteristics are covered individually. A full-page table lists properties. Also covered are grain structure and design tolerances on machined alumina parts.

Rapidly solidified (RS) aluminium alloys - status and prospects (130 pp; May 1985); Distribution limited to Government Agencies; DTIC AD B058026.

A committee of the National Materials Advisory Board (National Research Council, 2101 Constitution Ave., N.W., Washington, D.C. 20478, USA) has conducted a study to evaluate the potential of particulate (rapidly solidified) aluminium alloys for a broad range of structural applications. The study included analysis of current experiemental and near-term production alloys; selection of representative target properties and analysis of structural performance in representative aircraft systems; evaluation of alternative methods for producing sheet, plate, extrusion and forging mill products with emphasis on approaches for processing particulate directly to mill products; assessment of structural fabrication and assembly processes and potential associated problems; review of the metallurgical state of the art of these alloy systems; and extensive examination of potential applications in aircraft, military, and space systems and commercial products. Significant conclusions and recommendations are presented that identify the future work required to support adequately the continued development of particulate aluminium alloys and to ensure the eventual availability of large-scale production quantities of these alloys.

Eastern Alloys Inc., Box EA, Maybrook, NY 12543, USA has published brochures on

Zinc-aluminium foundry alloys

Casting alloys for gravity and pressure die casting are featured in this comprehensive, eight-page brochure. Comparison chart lists typical casting alloy properties. Discussion covers alloy characteristics, composition, design features, cost, selection, and process details. Separate charts detail alloy comparison ratings and typical process recommendations. Other available literature are listed. Bulletin ZACA/6M/MP/485.

and

Zn-Al casting alloys

High-strength zinc-aluminium alloys ZA-8, ZA-12, and ZA-27 are the subject of a 6-page foldout brochure. The alloys are described, and their uses are discussed briefly. Typical properties are listed. A number of representative parts are illustrated and discussed.

Zinc-aluminium die-casting alloys

Metallurgy and energy requirements are two of several topics discussed in a 16-page brochure on ZA-8, ZA-12, and ZA-27 zinc-aluminium die-casting alloys. Also covered are performance factors, weight, strength, hardness, bearing characteristics, and wear resistance. Processing is discussed. Aluminium Smelting & Refining Co. Inc., Certified Alloys Co., 5463 Dunham Rd., Maple Heights, OH 44137, USA.

Zn-Al foundry alloys

Three zinc/aluminium foundry alloys are covered in a 12-page, full-colour brochure. Compositions and advantages of the alloys are discussed, and tables list physical and mechanical properties. Recommended foundry practice is described. Finishing, corrosion resistance, machining, and joining are also discussed. Photographs illustrate typical parts. Cominco Ltd., 120 Adelaide St. W., Toronto, Ontario, Canada, K5H 1T1.

Aluminium casting alloys

Eight-page brochure presents data on aluminium-alloy 390. Among topics covered are metallurgical characteristics, physical and mechanical properties, and alloy characteristics. Performance characteristics are shown in graphical form. Processing information is also provided. Aluminium Smelting & Refining Co. Inc., Certified Alloys Co., 5463 Dunham Rd., Maple Heights, OH 44137, USA.

Specifications on copper, brass, aluminium alloys

Booklet is a guide to government and engineering-society specifications. It correlates ASTM, SAE, AMS, ASME, Federal, and Military specifications with the company's own copper, brass, bronze, and aluminium-alloy identification numbers. Chemical, mechanical, and physical properties of proprietary copper-base and aluminium alloys are also given. Catalog FM-4083, 36 pages, Mueller Brass Co., Port Huron, MI 48060, USA.

Sheet, Plate & Extrusions is a 24-page color brochure showing a variety of products utilizing aluminium advantages such as cost, light weight, and ease of fabrication. Product sections include heat-treatable and nonheat-treatable wrought aluminium alloys, sheet and plate, and extrusions, including tube and pipe. Charts detail product availability, alloy and temper designations, mechanical and physical properties, and end-use applications. Mill Products Div., Reynolds Metals Co., Richmond, VA 23261, USA.

Guide to Selecting Carpenter Specialty Alloys provides 32 pages of descriptions for a wide selection of alloys. Individual sections highlight stainless steels, high-temperature alloys, tool and die steels, nickel copper alloys, valve steels, bearing steels, special purpose alloy steels, products for electronics, fine wire and ribbon special alloys, and related products. Easy-to-follow selection guide categorizes materials in terms of corrosion resistance and strength factors. Each material is listed with chemical composition and pertinent engineering facts. Carpenter Technology Corp., 101 W. Bern St., Reading, PA 19603, USA.

Permanent-mold aluminium casting

Economic advantages of using permanent and semipermanent mold castings are featured in this applications brochure. Topics covered include replacement of assemblies or joined components with castings, design flexibility, complex shapes, and foundry production capabilities. Brochure also includes a comprehensive table covering typical properties and characteristics of aluminium permanent-mold castings. 12 pages. Permanent Mold Castings Div., Aluminium Company of America, 2210 Harvard Ave., Cleveland, OH 44105, USA.

Aluminium Company of America, 1501 Alcoa Building, Pittsburgh, PA 15219, USA has published

(a) Aluminium plate, plate shapes

Form FO-4-14689 provides eight pages of detail on company's capabilities to produce a variety of aluminium plate and shapes. The development of aerospace alloys and the new aluminium-lithium alloys, CAD operations for programming numerically-controlled equipment, shape parameters, and equipment for specific plate sizes are discussed. Sections cover plate-making facilities, quality-control standards, and available sizes and types of products. Two pages are devoted to photographs of typical parts and shapes. A complete listing of sales offices is included; and

(b) Alcoa Aerospace Capabilities which provides an in-depth look at developments in aerospace alloys and new technology. Featured sections cover research and development, new alloys and materials, plant production capabilities, forging operations, casting production, extrusion/tube processes, and technical innovations. Materials section describes each alloy in terms of development, performance, and applications. Aluminium-lithium alloys, wrought P/M alloys, CU78 P/M alloy, and 7XXX P/M alloy are detailed.

Aluminium forging

Company's 5,500-ton screw press for precision forging of aluminium is featured in this four-page capabilities brochure. Discussion covers computer-controlled operation, close tolerances, design refinements, and productivity gains. Capabilities with machining, heat treating, presses, quality control, and custom services are featured. Waltec Components, Box 190, Marine City, MI 48039, USA.

Free literature on: continuous premium quality aluminium production made easy

Can be obtained through: Frank W. Schaefer, Inc., P.O. Box 1508, Dayton, Ohio 45401, USA.

Metallurgical aspects of environmental failures, Briant, C.L., NY: Elsevier, 1985. 237 p. $64.75. (Materials Science Monographs; 12) 85-6908. ISBN 0-444-42491-1.

Corrosion of metals. Stress corrosion cracking. The effect of irradiation on the properties of materials. Sensitization of austenitic nickel alloys. Corrosion and stress corrosion cracking of aluminium alloys. Stress corrosion cracking and hydrogen embrittlement of titanium alloys. Subject Index.

The author emphasizes the metallurgical aspects of problems of environmental failures caused by factors such as corrosion and irradiation. It is suitable as a text for an undergraduate level course given to engineers, metallurgists, or materials scientists. Literature references and a subject index are provided. The author is with General Electric Corporation. For engineering libraries.

Alloy Thermo-Sorter

Alloy classification is now made easy with the Alloy Thermo-Sorter, Model ATS-6044, being introduced by Walker Scientific, Inc. of Worcester, MA, USA. The ATS-6044 is a light-weight, portable and rugged instrument designed for use in a demanding industrial environment. Part size or geometry is not critical, so the Alloy Thermo-Sorter can identify or sort alloys ranging in size from fine wire to large girders. It is a fully non-destructive test that can be used on precision bearing surfaces.

Portable alloy, metals analyzer

A 12-page colour brochure from Columbia Scientific Industries describes the versatility of this portable X-MET 840 metals and alloy analyzer in identifying thousands of alloy types, with up to 100 stored in memory at any one time. Specifications, features and application examples for this nondestructive, hand-held, microprocessor-based multi-element X-ray fluorescence analyzer are provided. Four different probes are available.

Aluminium: properties and physicalmetallurgy

Edited by John E. Hatch, Metals Park, Ohio: American Society for Metals, 1984, 424 p. $70. 83-21338. ISBN 0-87170-176-6.

Constitution of alloys. Microstructure of alloys. Work hardening, recovery, recrystallization, and grain worth. Corrosion behavior. Aluminium powder and powder metallurgy products. Index.

This volume is a revision of Volume I of the three volume series Aluminium published in 1967 by the American Society for Metals. Each chapter was revised by a team of professionals from organizations such as Kaiser Aluminium & Chemical Corp., the Alcoa Technical Center, and Alcan International. Includes updated bibliographies, a list of contributors, subject index, and alloy index. For science and engineering collections in public, university, and special libraries.

Aluminium windings list

Technical brief/price list presents pure ceramic oxide treated anodized aluminium magnet wire and strip. Brochure explains unique performance advantages over other resistive winding products, power capabilities, and operating temperature ranges from 400 to 1,000°F. Discussion also describes how oxide film insulation structure improves on an aging curve, and how windings are used on applications such as CAT scanners and lifting magnets. National Ano-Wire Inc., 231 Diana Ave., Muskegon, MI 49442, USA.

A pocket guide to high performance alloys and product forms is an expanded chart of high-performance alloys, stainless steels, and tool and high-speed steels. Alloy grades and product forms are listed. Reverse side details available processes, including electric furnace melting, argon/oxygen decarburization, vacuum induction melting, vacuum arc remelting, electroslag refining, and consolidation by atmospheric pressure. 2-page folder. Cytemp Specialty Steel Div., Cyclops Corp., Titusville, PA 16354, USA.

Hard alloy extrusion capabilities explains the extrusion process in detail, and provides data on hard alloys, comparisons with other processes, and company capabilities. Discussion covers hard alloys in the 2000, 5000 and 7000 series, plus other available materials for international specifications. Emphasis is placed on metal quality and assurance, plant capacities, and R&D backup systems. Several pages are devoted to colour photographs and details of available products and typical aerospace applications. Company services also are described. 16 pages. Extrusion Tube Div., Aluminium Company of America, Box 7500, Lafayette, IN 47903, USA.

Aluminium casting technology

296 pages, 15 chapters, 2 appendices, 8 1/2 x 11 in., Casebound. More than 250 illustrations.

Contains features of maximum benefit of producers, researchers, and students including:

- General and specific design recommendations for all casting methods
- Complete descriptions of primary and secondary alloys, including castability, machinability, weldability, finishing, corrosion resistance, and thermal treatment
- Extensive, comprehensive chapter on metallography with diagnostic photomicrographs
- Numerous defect checklists
- Discussions of the advantages and disadvantages of each casting method
- Examination of nondestructive and destructive testing
- Special appendices of Aluminium Association alloy designations and age, temperature, and time curve charts.

Publications Department, American Foundrymen's Society, Inc., Golf & Wolf Rds., Des Plaines, IL 60016-2277, USA.

Aluminium casting technology is a comprehensive text, handbook and operations manual covering all phases of technology, processes and operations for the casting of aluminium alloys. This completely revised and expanded version of the fomer Kaiser Aluminium Handbook is the only such reference available that can serve the foundryman as a total operations guide to the production of quality aluminium castings. 400 pages; casebound; order No. NF8501; $40 AFS members, $80 non-members. Contact: American Foundrymen's Society, Inc., Publications Sales, Golf & Wolf Roads, Des Plaines, IL 60016-2277, USA.

Corrosion, failure analysis and metallography presents the proceedings of the 17th Annual Technical Meeting of the International Metallographic Society, co-published by ASM and IMS. The 39 published papers include such topics as the aspects of microhardness testing and its applications as well as a wide range of physical metallurgy, microstructural and metallographic topics concerning stainless steels, aluminium, zirconium, irons and steels, thoria fuels, dental amalgams, nickel-molybdenum and vanadium. Also covered are corrosion problems and failures of materials ranging from semiconductors to a tantalum heat exchanger. Emphasis is on fractographic procedures. 628 pages; order No. 6362; $49.60 ASM members, $62 non-members. Contact: ASM Member/Customer Service, Metals Park, OH 44073, USA.

Alumina-silica castables brochure available

C-E Refractories has issued a new brochure covering the company's complete line of alumina-silica castables and gunning refractories. This 12 page, four colour brochure provides installation recommendations, product specifications and other technical data relating to this product line.

Information contained in this literature applies to the use of castables and gunning refractories in steel, foundry, aluminium, HPI power generation, rock products and other industrial applications.

C-E Refractories manufactures a broad line of alumina-silica and basic refractory specialities and ceramic fibre products.

ISO (International Organization for Standardization, Case Postale 56, CH-1211, Genève 20, Suisse)

Handbook 30

Non-ferrous metals

ISO has published many International Standards for non-ferrous metals and non-ferrous metal products; they provide the standardization requirements for international communication and trade involving the most important metal products other than iron and steel. Metals dealt with in the new ISO Standards Handbook 30 Non-ferrous metals, about to be published are aluminium, copper, magnesium, nickel and zinc. The standards apply to the crude metals and intermediate stages up to semi-finished products as supplied to industry and include classification, terminology, chemical analysis, test methods, specifications, dimensions and tolerances.

The handbook is in four parts, presented in one volume:

Part 1 Aluminium, magnesium and their alloys

Part 2 Copper and copper alloys

Part 3 Nickel and nickel alloys

Part 4 Zinc and zinc alloys

They represent the complete work of four ISO technical committees, ISO TC 18 Zinc and zinc alloys, ISO TC 26 Copper and copper alloys, ISO TC 79 Light metals and their alloys (a collection which also deals with anodising and includes standards on magnesium) and ISO TC 155 Nickel and nickel alloys.

Standards for mechanical testing of non-ferrous metals are to be included in a future handbook to be devoted exclusively to that subject. (Source: ISO Bulletin, July 1986)

FUTURE MEETINGS - PAST EVENTS RELATING TO MATERIALS

1985

9-12 Sept. 5th Int. Symposium on Extraction Metallurgy, London. Institution of Mining and Metallurgy, London.

18-20 Sept. Secondary Aluminium Meeting, Turin, Italy. Metal Bulletin Inc. New York.

5-7 Nov. Materials Engineering, Exhibition and Conference, London. Sponsors were:
The Institue of Mechanical Engineers
The Institute of Ceramics
The Institute of Metals
The Plastics and Rubber Institute
The Materials Forum

The "New Materials Exhibition '85" was held from 28 to 31 October 1985 in Sunshine City, Ikebukuro, Tokyo. The theme of the exhibition was "The Meeting of Needs and Seeds".

Modern materials and high-performance products, together with various related equipment, were displayed, and information on the state of development of these new materials, their technical standards and future outloook were handed out.

The items on display in the field of fine ceramics included zirconia, silicon carbide, alumina, gallium arsenide, as well as boron products, optical fibres, rare-earth elements and electronic materials. On display in the field of new metallic materials were silicon materials, amorphous materials, shape memory alloys, hydrogen storing alloys, ultra fine powder metals and superalloys, such as titanium. Composite materials included PAN-based carbon fibres, pitch-based carbon fibres, alumina fibres, steel fibres, alamide fibres and other fibre materials.

In the field of high polymer materials, engineering plastics, photosensitive resins, electrically conductive resins, water absorbing resins, ion exchange resins, high-performance separation membranes, etc. were displayed. Equipment included new material manufacturing equipment, vacuum hollow molding equipment, super uniform pulverization equipment, high-pressure/explosion pressure molding machines, pressure vapour deposition equipment, chemical vapor deposition equipment, thin membrane production equipment, injection molding machines, structural analysis/material designing equipment, material property testing/analysis equipment, non-destruction inspection equipment, and CAD/CAM systems for material design.

The exhibition was sponsored by Nihon Keizai Shimbun, Inc., and the Federation of New Materials.

1986

16-18 Feb. Monterey, California, USA. The Outlook for Injection Molded and Sintered Ceramic. Metal and Cement Components.

17-18 Feb. From France and England, Canada, Mexico and the US, aluminium foundrymen united in Southern California to discover new technological advancements in aluminium processing. More than 200 people participated in AFS's two day International Molten Aluminium Processing Conference. The Conference included 25 presentations, covering topics such as melt constitution, grain refinement, thermal analysis, alloy modification and filtration.

25-27 Feb. Industry-University Advanced Materials Conference, Golden, Colo. Advanced Materials Inst., Colorado School of Mines, Golden, Colo. 80401, USA.

17-20 March, Birmingham, UK. 8th Materials Testing Exhibition and Congress.

17-22 March. In co-operation with the Geological Society of Jamaica, Metal Bulletin organized the International Bauxite Symposium VI. Entitled "Technological Innovations in the Bauxite/Alumina/Aluminium Industry and Their Market Impact". The symposium brought to Kingston, Jamaica, representatives of the industry from around the world. Included in the presentations were papers from Alcan, Kaiser Aluminium, Gerald Metals and others dealing with the problems and opportunities of the industry today. Financing the modernizations of the production facilities, finding a balance to the raw materials oversupply problem and the promotion of new uses for the metal was addressed at the symposium. (Brian Nolk, Metal Bulletin Inc., 708 Third Avenue, New York, NY 10047, USA)

7-11 April, San Diego, Calif. USA. International Conference on Metallurgical Coatings (Naval Res. Lab., Code 6675, Washington D.C. 20375, USA)

9-16 April, Hannover, FRG. New Materials '86 Hannover Fairs USA, Inc. P.O. Box 7066, 103 Carnegie Center, Princeton, NJ 08540, USA

14-17 April, Lübeck, FRG. Second International Congress on Ceramic Materials and Components for Engines.

15-16 April. The Spring Meeting of the Materials Research Society, Palo Alto, California, USA.

18-21 May, Boston, MA, USA. 1986 Annual PM Conference and Exhibition (Metal Powder Industries Fed. and American Powder Metallurgy Inst., Princeton, NJ., USA)

20-23 May, Göttingen, FRG. Hauptversammlung der DGM (General Meeting of the German Society of Metallography) Deutsche Gesellschaft für Metallkunde, Ardenauerallee 21, D-6370 Oberursel 1.

22-23 May, Wuppertal, FRG. Seminar Wirtschaftliches Umformen von Aluminium-Strangpressen (Sem. of economical recasting of Al-Extrusion press) Technische Akademie, Wuppertal, FRG.

26-30 May, Trondheim, Norway. 5. Int. Kursus Prozessmetallurgie Aluminium (Fifth International Course of Metallurgy Processing of Aluminium). Institute of Inorganic Chemistry, Trondheim, Norway.

26-30 May, Balatonfüred, Hungary. Fourth International Conference on age-hardenable Aluminium Alloys. (Organized by Metal Physics Group, Eötvös University, Budapest, Hungary.)

27-30 May, Cleveland, Ohio, USA. International Conference on Composite Interfocus (H. Ishide, Dept. of Macromolecular Science, Case Western Reserve University, Cleveland, OH 44106, USA)

10-13 June, Beijing, People's Republic of China. International Symposium on Composite Materials and Structures.

12-18 June, Beijing, WELDEXPO '86 (Organized by China International Convention Service Ltd., and China Council for the Promotion of International Trade)

15-20 June, Charlottesville, USA. International Conference on Aluminium Alloys. (Sponsored by University of Virginia and Al. Assoc., 818 Connecticut Ave., NW, Washington, DC 20006, USA)

17-19 June, Atlantic City, NJ, USA. Plas-Tech '86 Conference on high-tech materials such as eng. resins, alloys, high-strength composites, multi-resin structures, liquid crystal polymers (Delia Assoc., Whitehouse, NJ, USA).

19-24 June, Düsseldorf, FRG. METAV '86. The Market for Metalworking, Exhibition for Manufacturing Technology, Automation and New Materials.

23-27 June, Milan, Italy. World Congress on High Tech Ceramics.

24-26 June. Advanced Materials '86. The event combined exhibition, conference and seminars and was staged at the Wembly Conference Centre in London. (Pam Howard, Online Int., London, UK)

2 July, Rolls-Royce, Derby, UK. High temperature alloys. (Organized by the Institute of Metals, London)

7-11 July, Düsseldorf, FRG. International Conference on Powder Metallurgy. PM '86 Conference and Exhibition

8-12 July. Impact Dynamics of Metals and Composites, Los Angeles, CA. UCLA, Dept. of Engineering and Science, P.O. Box 24901, Los Angeles, CA 90024 USA.

17-18 July, Aachen, FRG. Second Seminar on Steel-Raw Materials Technic. (Institut für Eisenhüttenkunde, Aachen)

17-21 August. Centre de Recherche Noranda, International Symposium on Zinc Aluminium Casting Alloys, Toronto, Canada.

19-21 August. Conference on Nondestructive Testing and Evaluation of Advanced Materials and Composites, Colorado Springs, CO. Contact: US Air Force Academy, Colorado Springs, CO, USA.

25-29 August. International Symposium on Engineering Applications of New Composites. Patras, Greece. S. A. Paipetis, Dept. of Mechanical Engineering, University of Patras, Patras 260 01, Greece.

8-9 September, Berne, Switzerland. SYMATEC. 1 Int. Kongress für Werkstoff- und Schichttechnik (1st Congress on raw materials and laminated plastics). Berner Handelskammer, Gutenbergstrasse 1, CH-3001 Berne, Switzerland.

9-11 Sept., Tokyo, Japan. ZIRCONIA '86. The Ceramic Society of Japan.

14-17 Sept., San Francisco, Calif., USA. Fourth Int. Aluminium Congress (Metal Bulletin Inc., 708 Third Ave., New York, N.Y. 10017)

15-19 Sept. London. Engineering with Ceramics (Institute of Ceramics).

16-18 Sept. Guildford, UK. IPC Second International Conference on Testing Evaluation and Quality Control of Composites. (IPC Science and Technology Press, Guilford, UK)

21-25 Sept. World Congress III of Chemical Engineering will be held at the Keio Plaza Hotel in Shinjuku, Tokyo, Japan. (AIChE Co-ordinator: Dr. Ralph A. Buonopane, Northeastern University, Dept. of Chemical Engineering, 360 Huntington Ave., Boston, MA 02115, USA).

Technical sessions are planned for the following areas:

1. International Co-operation: a. International Co-operation in the Field of Chemical Engineering; b. Technology Transfer.

2. Economic and Technological Outlooks: a. Economic Outlook for the Chemical Industry in the 1990s; b. Technological Prospects for the Chemical Industry in the 1990s.

3. Management and Marketing: a. Management and Uncertainty Analysis; b. Research and Development Strategy; c. Marketing; d. Manufacturing Productivity in the Chemical Industry.

4. Engineering Education: a. University Education, Continuing Education and In-house Training Programmes; b. The Impact of Computer Developments on Cehmical Engineering Education.

5. Chemical Engineering in Newly Developing High Technology Fields: a. New Materials Including Ceramics; b. Robotics in the Chemical Industry; c. Scope of Chemical Engineering in the Microelectronics Industry; d. Novel Processing in the Chemical Industry.

6. Energy and Resources: a. Energy Conservation and Analysis; b. Coal and Oil Utilization; c. Renewable and Alternate Energy; d. Thermal Energy Storage; e. Topics in the Nuclear Industry; f. Energy Efficient Chemical Processes.

7. Fundamentals: a. Physical Properties, Phase Equilibria and Thermodynamics; b. Rheology and Flow of Fluids; c. Heat Transfer; d. Mass Transfer.

8. Unit Operations: a. Evaporation; b. Drying; c. Distillation; d. Gas Absorption; e. Extraction and Leaching; f. Adsorption; g. Ion Exchange; h. Crystallization; i. Powders and Aerosol Properties and Powder Technology; j. Solid-Liquid Separation; k. Membrane Technology; l. Mixing and Agitation; m. Fluidization.

9. Reaction Engineering: a. Reaction Kinetics; b. Reactor Design; c. Catalysis.

10. Biotechnology: a. Bioengineering and Bioreactor Design; b. Food Processing; c. Biomedical Engineering; d. Genetic Engineering.

11. Materials: a. Materials and Their Applications; b. Corrosion Control and Prevention; c. Solid Polymer Processing.

12. Computer Applications in Chemical Engineering: a. Modelling of Process Systems; b. Knowledge Engineering; c. Computer Aided Design; d. Process Control.

13. Environmental Chemical Engineering: a. Waste Water Treatment; b. Air Pollution Control. c. Solid Waste Disposal; d. Control of Toxic Substances and Clean-up Techniques; e. Monitoring and Information Systems for Pollution Control.

14. Safety in Chemical Plants: a. Risk and Benefit Analysis; b. Predictive and Preventive Means; c. Techniques in Process Safety.

15. Others.

23-25 September. Cleveland Institution of Engineers, Middlesbrough. Second Autumn Meeting of The Institute of Metals including a conference on materials and their fabrication for energy and chemical process plant. Inst. of Metals, London/ The Cleveland Institution of Engineers.

29 Sept. - 3 Oct. Testing and Inspection of Composite Materials, Davos Congress Centre, Switzerland. (Continuing Education Institute for Europe, Rörstorpsvägen 5, S-612 00 Finspang, Sweden; phone +46(0122)17570; Telex 64471 CEIEUR S.)

4-9 Oct. ASM Materials week, Orlando, Florida, USA (American Society for Metals, Metals Park, Ohio 44073, USA).

5-9 Oct. ASM Joining of Light Materials Symposium. The Symposium on Joining of Light Materials was held during the ASM Materials Week, 5-9 October, in Orlando, Fl. Featured topics covered processing and materials aspects of light alloys and composites, fracture behavior, corrosion, solidification, process control, and applications. Complete details are available from the American Society for Metals, Metals Park, OH 44073.

6-9 Oct. Third Conference on High Temperature Alloys for Gas Turbines and Other Applications, 1986 (Liège, Belgium, Centre de Recherches, Métallurgiques "CRM")

6-10 Oct. '86 International Ceramics Conference in Limoges, France (Conseil régional du Limousin, Limoges)

14-15 Oct. Washington, DC., USA. International Symposium and Workshop on Sulphur Concrete - A New Construction Material (Jointly sponsored by US Bureau of Mines, The Sulphur Institute).

20-22 Oct. 1986 Powder Metallurgy Group Meeting (The Metals Society London).

13-15 Nov. Speciality plastics conference '86. This conference has adopted "lldPE, vldPE and polar polyethylene markets and economics" as its theme. Topics to be discussed centre around speciality applications for lldPE, vldPE, polar EVA, EBA and acid copolymers. A discussion of future markets for speciality vldPE, lldPE and other ethylene copolymers in Japan, Europe and the US will close the conference. For further information contact Maack Business Services, CH-8804, Au, Zurich, Switzerland.

25-27 Nov. Materials Engineering '86 (The Plastics and Rubber Institute, London).

1-5 Dec. Materials Research Society Fall Meeting in Boston, MA, USA. (Materials Res. So., Pittsburgh, PA., USA).

15-19 Dec. Engineering with Ceramics, Institute of Ceramics meeting, London.

1987

18-21 Jan. 11th Annual Conference on Composites and Advanced Ceramics. (Engineering Ceramics Division Meeting), Cocoa Beach Hilton, Cocoa Beach, FL.

21-23 Jan. Conference on Composite Materials (Sponsored by Advanced Composites Working Group, in Co-operation with DoD and NASA), Cocoa Beach Hilton, Cocoa Beach, FL.

23-27 Feb. 3rd International Conference on Ultrastructure Processing of Ceramics, Glasses and Composites, Catamaran Resort Hotel, San Diego, CA.

25-27 Feb. University-Industry Advanced Materials Conference, Colorado School of Mines, Golden, CO.

6-9 April. Advanced Materials Technology '87, Anaheim Convention Center, Anaheim, CA.

7-9 April. Conference on Electric Melting of Aluminium, Copper and their Alloys. University of Aston in Birmingham. (The Institute of Metals, 1 Carlton House Terrace, London, SW1Y 5DB).

11-15 May. MATERIALS '87, Institute of Metals, 1 Carlton House Terrace, London, SW1Y 5DB. Within the broad field of materials engineering, this international conference and associated technical exhibition will bring together scientists, technologists, and engineers concerned with the use of materials processing for the control of structure and properties.

A major aim of the conference is cross-fertilization between the different fields dealing with metals, ceramics, polymers, composites, and electronic materials. Attention will be focused on fundamental considerations of structure and property control as well as the technological aspects of materials process engineering.

17-22 May, Tokyo, Nippon Toshi Centre. World Conference on Advanced Materials for Innovations in Energy, Transportation, and Communications (Co-sponsored by International Union of Pure and Applied Chemistry; the Science Council of Japan and The Chemical Society of Japan).

22-26 June. 8th International Light Metals Congress, Institut für Metallkunde und Werkstoffprufung, Montana Universität, A-8700 Leoben, Austria. The main topics in the field of properties and materials science are: physical metallurgy and metallography of aluminium; solidification; structures and properties; strength and toughness; fatigue and fracture behavior; formability, including superplastic behavior; thermo-mechanical treatment; corrosion, surface and surface treatment; and new light metal alloys.

In the field of manufacturing and processing, the main topics include: the Bayer process; electrolysis of alumina including anode manufacture; alternative extraction techniques; melting treatment; ingot casting; production of semis by forming; forming techniques; secondary aluminium production, including treatment of scrap and dross; aluminium on its way into its second century, including new applications, primarily in the aviation, space, automobile and engineering industries, packaging, electrical engineering and electronics; and aluminium and the environment.

18-20 August. The Materials Engineering and Sciences Division of AIChE is sponsoring the Conference on Emerging Technologies in Materials at the Downtown Holiday Inn in Minneapolis, Minn., USA. Programme Co-Chairmen: C. Thomas Sciance, Dupont Co. Experimental Station Bldg. 304, Wilmington, Del. 19898; Christopher J. Durning, Dept. of Chem. Eng. and Applied Chemistry, Columbia University, New York, NY 10027. The technical programme will be divided into five areas: composites, electronics, ceramics, polymers and membranes, and metals.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300,
A-1400 Vienna, Austria

Advances in Materials Technology: Monitor
Reader Survey

The Advances in Materials Technology: Monitor has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this newsletter. Kindly, therefore, answer the questions below and mail this form to: The Editor, Advances in Materials Technology: Monitor, UNIDO Technology Programme at the above address.

Computer access number of mailing list (see address label):

Name:

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Do you wish to continue receiving issues of the Advances in Materials Technology: Monitor?

Is the present address as indicated on the address label correct?

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Which section in the Moni : is of particular interest to you?

Which additional subjects would you suggest be included?

Would you like to see any sections deleted?

Have you access to some/most of the journals from which the information contained in the Monitor is drawn?

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Please make any other comments or suggestions for improving the quality and usefulness of this newsletter.

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Readers' comments

We should appreciate it if readers could take the time to tell us in this space what they think of the 7. issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.