A. SMOLEJ, E. SLAČEK, R. TURK

ISSN 0543-5846
METABK 41 (3) 149 (2002)
UDC - UDK 669.715:669.717=20

STATE AND DEVELOPMENT OF SOME WROUGHT ALUMINIUM ALLOYS FOR SPECIAL AND GENERAL APPLICATIONS

Received - Primljeno: 2002-04-03
Accepted - Prihvaćeno: 2002-05-15
Review Paper - Pregledni rad

Aluminium is introduced into use in all industrial fields. Demands for lighter and stronger semi products and products are driving force for continuous improvement of standard alloys in regard of composition, properties, and manufacturing technologies. The competition with non-metallic materials demands further development of new aluminium alloys. The paper presents a short review of development of some aluminium wrought alloys intended mainly for rolled products. As the first group, Al-Li-X and super plastic alloys are described, both being used for specific purposes. The second group consists of alloys which were developed on the basis of standard alloys, and are intensively used for series products like wrapping and packing materials, and automobiles.

Key words: *aluminium alloys, application, products*

Stanje i razvoj nekih kovkih aluminjskih legura specijalne i opće namjene. Aluminij je uveden u sve industrijske oblasti. Zahtjevi za lakšim i jačim poluproizvodima i proizvodima pokretačka su snaga poboljšanja standardnih legura, glede sastava, svojstava i proizvodnih tehnologija. Natjecanje s nemetalnim materijalima zahtijeva daljnji razvoj novih aluminjskih legura. Članak predočuje kratki pregled razvoja nekih kovkih aluminjskih legura namijenjenih uglavnom za valjane proizvode. U prvoj su grupi opisani Al-Li-X i superplastične legure koje se koriste za posebne svrhe. Druga se grupa sastoji od legura razvijenih od standardnih legura i koje se intenzivno koriste za serijske ambalažne materijale i automobile.

Ključne riječi: *aluminijske legure, primjena, proizvodi*

INTRODUCTION

Characteristic properties of aluminium and its alloys are low specific density, wide interval of strength properties, good workability, corrosion resistance, electrical and thermal conductivity, harmlessness for human health, and recyclables, and therefore aluminium is ranked among the most important materials of presence and future. Life today can scarcely be imaged without aluminium with its wide range of applications on account of its outstanding properties [1]. It is used in all the essential engineering fields, as transport, civil engineering, electrical engineering, electronics, machinery, equipment and for packing. (Figure 1.). Aluminium constitutes numerous alloys with various elements like magnesium, manganese, silicon, zinc, copper, iron and lithium. The basic effects of alloying elements on the properties of aluminium have been identified early in the twentieth century leading to the establishment of the system of the commercial aluminium alloys still used today. Subsequent work concentrated on the improved control of the processing conditions in order to be able to guarantee distinct, closely controlled property limits [2]. With varied composition and suitable combinations of heat treatments, and mechanical working, semiproducts and products of standard and spetial alloys with a wide range of mechanical, technological, and chemical properties can be produced. The main groups of aluminium alloys which are the most often used in practice next to technically pure aluminium are AlMn, AlMg, AlMgMn, AlMgSi, AlZnMg, and AlZnMgCu alloys. They are wrought alloys which are shaped into products by rolling, extrusion, and forging. Each of the mentioned groups consists of numerous subgroups, regarding to contents and amounts of main and additional alloying elements, having adequate properties in narrower limits. All the mentioned alloys have tensile strength values between 70 and 600 MPa.

Steady production of primary aluminium in the recent year rises the question: Has the consumption of aluminium

A. Smolej, R. Turk, Faculty of Natural Science and Engineering, University of Ljubljana, Ljubljana, E. Slaček, Impol, Aluminium Industry, Slovenska Bistrica, Slovenia

after more than hundred years of extreme growth reached the culminating point? Reply is no, because of dynamic development in the field of aluminium materials and production processes. Results of this development are products of higher quality which enables the reduction of weight and also price for numerous products. A big demand or a

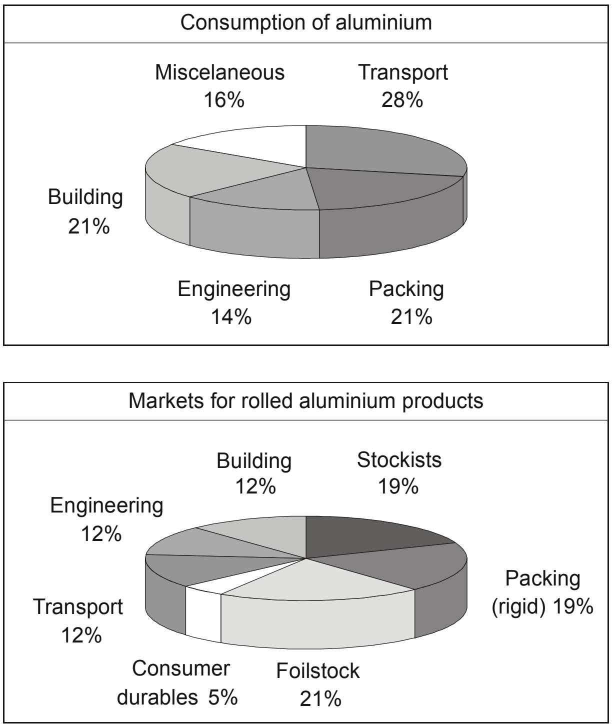

Figure 1. **Markets for rolled aluminium products in Europe and consumption of aluminium in various industrial branches in USA, Japan and Europe**

Slika 1. **Tržište valjanih aluminjiskih proizvoda u Europi i utrošak aluminija u raznim industrijskim granama u USA, Japanu i Europi**

strong growth will be recorded for applications where the advantages outweigh the costs, and where the extraordinary technical properties of aluminium come best in to their own: transport and constructions. Nevertheless, the classical markets maintain their importance owing to their size [1]. Improvement of standard aluminium alloys makes at present "smaller steps" than in the past. Most of standard alloys for working were discovered in the period of 1930 s to 1960s [3]. The development of hose alloys was based mainly on empirical experiences. Further research of industrial alloys in the near past was directed mainly towards the optimisation of properties and the rationalization of technological processes of manufacturing and working. Though the composition of those alloys was not essentially changed, the main result of these efforts was reduction of dimensions and weight of semiproducts, influencing also lower price of final products. Characteristic examples of such development are the sheet for beverage can stock, and car-body sheet with improved combination of strength and formability [4]. Reduction of costs based on the weight reduction of semiproducts at improved mechanical properties cannot be the only aim of further development of standard alloys. In the recent time, results and knowledge of physical metallurgy combined with the composition of alloys, condition of manufacturing processes, and working of material are more and more used in designing those alloys. The tendency with wrought aluminium alloys is to achieve better strength values which represents with standard alloys the greatest challenge for metallurgists. In this group, there are mainly alloys of AlCuMg and AlZnMgCu type. With the latter, the strength values of over 600 MPa at plane-strain fracture toughness of 30 MPa$\sqrt{m}$ were achieved. These alloys are used for the most demanding purposes like vehicles and aeroplanes, due to their high strength/weight ratio. There are in progress further improvements of alloys for sections, rods, tubes (AlMgSi, AlCuMg, free-cutting alloys), for deep drawing purposes, for heat exchangers, and for wrapping materials. Efforts and investigations to optimise properties of alloys and technological processes will be continued also in future, since numerous existent alloys are in fact completely suitable for general use.

Advances in the development of new alloys processed by I/M have in the fact been quit small. Aluminium materials will continue to use the classic elements as main alloying additions. Special cases like AlLiX alloys are risky and expensive to produce, and recycling requires strict separation so their use will remain confined to niches such as aviation [1].The high hopes expressed at that time concerning the alloying element scandium are not on the one hand to be regarded with some scepticism on economic grounds, but on the other hand offers prospects of success because of the major advances achieved in investigation techniques [5]. But standard aluminium alloys and their manufacturing processes are limited in comparison with other new materials which means competition for aluminium. This competitiveness is expressed mainly in the field of more demanding products. Aluminium industry reacted on this challenge with extensive research which resulted in actually new alloys and manufacturing processes. New aluminium materials in comparison with the standard ones have first of all essentially better mechanical properties which do not change at higher temperatures. These materials are made by processes of fast solidification, of powder metallurgy, and of mechanical alloying. A special group of new aluminium based alloys are the reinforced Al alloys either with particles or with fibres which are suitable for various structures because of small weight, high strength, and high elastic modulus values. At present, these materials are not yet in general use, though they have excellent properties and though there exist technical solutions of their making [6].

Further, problematic of some standard wrought alloys for rolling products which are in recent time used in the car industry and for packing will be discussed. These two regions will be in the nearest future leading areas of aluminium application. Among the newer wrought alloys, there will be discussed super plastic aluminium alloys and the AlLi alloys. These two types of alloys are interesting above all because they are made by I/M processes, and they are worked with standard equipment.

AlLi-ALLOYS

In the middle 1970s, intensive investigations on AlLi alloys took place. Those alloys should substitute standard aircraft alloys of AlCuMg and AlZnMgCu types due to some special properties. The aim of investigation was the reduction of weight, and increased elastic modulus values of engineering materials for structural components of aeroplanes with the same or with increased plasticity, increased strength properties, mainly fracture toughness, and improved corrosion properties compared to those of extent alloys. Intensive development gave important results in a relatively short time [7].

Lithium is the lightest metal, having density 540 kg/m^3. Each mass % of lithium added to aluminium reduces the alloy density for 3 % at simultaneous increase of elastic modulus for 6 %. The AlLi alloys can be age-hardened, if other alloying elements, such as copper and magnesium, are added, this property is still more pronounced. During artificial ageing of solution heat treated alloys, metastabile Al_3Li particles are precipitated in aluminium supersaturated aluminium solid solution. Presence of these precipitates in aluminium matrix increases strength values to those, comparable with standard high-strength AlCuMg alloys.

Binary AlLi alloys, which are known for a long time, are not applicable because lower plasticity and toughness values [8]. These disadvantages were improved by adding other alloying elements and by using corresponding thermo-mechanical treatments. The best properties were achieved by the combination of lithium, magnesium, copper, and zirconium, thus the AlLiMgCuZr system represented basis for all applicable alloys. Some of those alloys, containing up to 3 mass % Li, 1 to 3 mass % Cu, up to 2 mass % Mg and up to 0.2 mass % Zr, are standardised, and they are produced in great quantities. Tensile strength of those alloys is up to 500 MPa, elastic modulus 81 GPa, fracture toughness up to 40 MPaÖm, and density 2500 kg/m^3 [9]. Super plastic properties are an additional advantage of those alloys [10]. In industrial manufacturing these alloys, melting and casting are problematic due to high reactivity of lithium towards oxygen, moisture, and furnace lining. Thus closed system with argon protective atmosphere are used in melting and casting. Semi-continuous casting process is used to make extrusion bars and slab ingots for rolling [11]. Working of cast ingots by rolling, extrusion and forging is possible with usual working procedures.

Suitable strength/weight ratio, high elastic modulus, and other properties caused that the AlLiX alloys were intended for manufacturing structural aircraft parts. Such substitution would reduced aircraft weight for 15 % which represent e. g. in the Airbus A 340 aeroplane material savings of 4500 kg [11]. Advantage of AlLiX alloys in comparison with the composite materials is in fact that existent equipment can be used for their manufacturing. But the predicted new generation of high-strength alloys of AlLiX type still did not succeed to substitute standard materials of structural aircraft parts, regardless of high investments and extensive research. The main reason are too high production costs and the properties of alloys which did not reach satisfactory level in some essential fields [12]. These fields are corrosion resistence, thermal stability, and weld ability which represent basis of further investigations [13]. There still exists the possibility that the AlLiX alloys including also other materials, such as reinforced aluminium laminates in metal matrix composites, will be applied in aircraft industry.

SUPERPLASTIC ALUMINIUM ALLOYS

Super plasticity is the property of certain metallic materials that very high elongations without contraction till breakage can be achieved at suitable working conditions These elongations are from few hundred to 1000 % or even more (Figure 2.). Such a method of working occurs at low strain rates (< 1 s^{-1}), high working temperatures (> 0.5 $T_{melting\ point}$), and corresponding microstructure of material. Needed working stresses values are considerably lower than in working ordinary materials. Excellent work abilities enable wide range of applications of super plastic materials for various purposes.

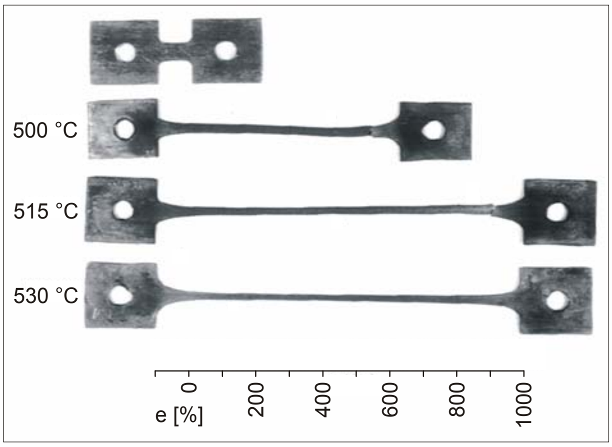

Figure 2. **Plasticity of the AlZnMgCu alloy at various working temperatures and strain rate 7.5x10^{-4}s^{-1} [20]**

Slika 2. **Plastičnost AlZnMgCu legure pri raznim radnim temperaturama i brzini deformacije od 7.5x10^{-4}s^{-1} [20]**

The first aluminium alloys with super plastic properties had eutectoidal or eutectic composition, e. g. AlCu33 alloy. They were not applied in practice due to unsuitable mechanical properties, though they possessed good plasticity. In 1970s, super plastic alloys with compositions and mechanical properties similar to those of ordinary aluminium alloys, were discovered. Since then, the development of those materials has an upward trend. Some superplastic alloys are already industrially produced and used in practice. Among the most known and useful alloys are the AlCuZr, AlZnMgCu, AlMgMn, and AlLiX (Table 1.).

Table 1. **Working conditions (working temperature T, strain rate), and the highest elongations e, for some aluminium alloys, in comparison with the ZnAl22 alloy**

Tablica 1. **Radni uvjeti (radna temperature T, brzina deformacije), i najveća produljenja e, za neke aluminijske legure, u usporedbi s legurom ZnAl22**

Alloy (designation)	T [°C]	ε [10^{-s}]	e [%]	Reference
AlCu33	500	10^{-1}to10^{-2}	2000	14
AlCu6Zr0.4 (Supral 100)	480	3.0 x 10^{-3}	>1000	14
AlZn5.7Mg2.3Cu1.5 (AA7475)	530	2.8 x 10^{-4}	1200	15
AlLi2.3Cu2Mg0.7Zr0.2 (AA8091)	500	0.6 x 10^{-3}	1137	16
AlLi2.3Cu2.5Zr0.2 (AA2090)	500	0.6 x 10^{-3}	1482	16
AlMg5Mn0.7Cu0.6	550	2.8 x 10^{-3}	700	17
AlMg3Sc0.2	400	3.3 x 10^{-3}	1560	18
ZnAl22 (Zilon)	250	10^{-1}to10^{-2}	2400	19

Basic properties which are needed for superplasic alloys, are following: (a) fine grained microstructure with an average grain size of 10 μm, (b) stability of crystal grains against growth at working temperatures, (c) stability against cavity formation during superplastic deformation, (d) low working stresses (2 to 20 MPa), and (e) high values of strain rate sensitivity exponent in the equation $s = K{\cdot}\varepsilon^m$ ($m > 0.3$).

Processes of making and working theses alloys are similar to the conventional methods used for standard aluminium alloys. Fine gained microstructure as the basic condition for superplastic working can be obtained by corresponding alloy compositions, temperatures of melt and casting, and thermo mechanical treatment. Stability of grains against growth is achieved with precipitation of fine particles on crystal grains. Superplastic alloys are mainly worked by rolling into sheet or plate strip, 0.6 to 8 mm thick. Very demanding shapes can be then made out of sheet by single working operation. Working of sheet is similar to thermoplastic moulding of plastics. The sheet being clamped in a heated chamber, is impressed by compressed gas or air into die. Shaping occurs at temperatures between 450 °C and 530 °C, at low strain rates, below 1 s^{-1}, and with gas pressures about 10 bar.

Application of superplastic materials highly reduces the manufacturing costs due to reduced consumption of energy and materials, by reducing unnecessary joining of single sections, and by using one single tool which can be made of undemanding, cheap material. Savings in tools represent up to 90 % in comparison with manufacturing equally complex products of ordinary materials.

Application of superplastic materials is suitable for making complex items in small and medium series of 50 to 10 000 pieces. Bigger series are at present not yet economic due to too long shaping times. Aluminium superplastic alloys are used for manufacturing aircraft components, components of car bodies, for housing, components of various apparatuses and musical instruments, and components in building, like linings of buildings, and for decoration purposes. High-strength AlZnMgCu, AlCuZr, and AlLiX alloys are mainly used in aircraft industry; AlMgMn alloys are more generally used for road and rail vehicles, and in civil engineering. Further development of superplastic materials will be directed towards cheaper manufacturing of those materials and to rationalisation of superplastic working. Further efforts to improve the plasticity are not needed. The plasticity, possessed by such present aluminium materials, already corresponds to the demands of superplastic working.

ALUMINIUM ALLOYS FOR CAR-BODY SHEET

Car industry is one of the most important industry. This branch is closely connected with environment in the regard of fuel consumption, exhaust gases, and recycling. Characteristic properties of aluminium alloys, such as low density, good workability, strength, and corrosion resistance, correspond to all the conditions which are demanded of materials for bodies of cars and other road vehicles. The mentioned properties also fit to always stricter environmental regulations in the regard of pollution, and simple and cheap recycling [21]. Aluminium in car represents mainly the reduction of weight, and thus the solution of environmental problems, connected to the consumption of fuel. Ten percent lighter vehicle saves 5 % of fuel. Weight reduction of any vehicle for 1 kg reduces CO_2 emission into air for 20 kg in 170 000 passed kilometres. European automobiles contain today 100 kg aluminium in average [22] while this amount in American passenger car is about 110 kg [23-24]. The main portion of this amount is represented by foundry alloys or castings, and only 10 % represent rolled and extruded components. Use of aluminium in a passenger car was in the past constantly increased, from 3 kg in 1947 to 90 kg in 1994 [25]. According to predictions, the amount of aluminium will be in cars increased at least for three times till 2010. Past, current, and predicted use of aluminium in European medium-class automobiles is presented in Figure 3.. Consumption of aluminium will jump when aluminium sheet and extruded items will be generally used in series, less prestigious cars.

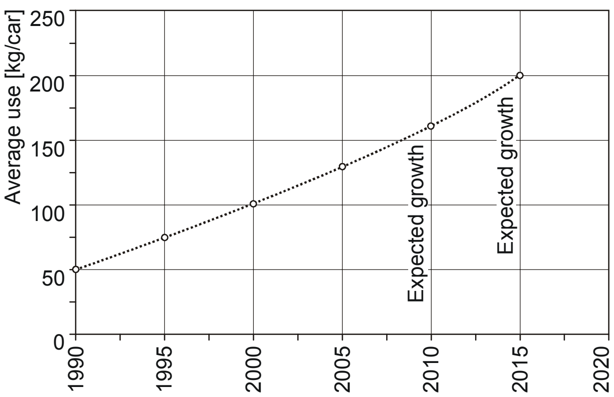

Figure 3. **Mean consumption of aluminium in kg/vehicle by European automobiles (cit. by European Aluminium Association and [22])**

Slika 3. **Prosječni utrošak aluminija europskih automobila u kg / vozilo (prema Europskoj aluminijskoj udruzi i [22])**

Replacement of steel sheet with an aluminium one means 40 to 50 % lower weight of a car body. Lower stiffness of aluminium sheet is one of rare disadvantages in comparison with steel, but it can be compensated with up to 50 % thicker sheet which simultaneously increases the safety in cars. Strength values of aluminium materials for car bodies are slightly lower than those of deep-drawing steel sheet. Regarding higher thickness of aluminium sheet to achieve stiffness and due to age-hardening which can occur during lacquering, the obtained strength values are comparable with those of steel sheet. Manufacturing aluminium alloy sheet designed for car bodies is more costly than manufacturing present steel sheet. It is expressed mainly in lower ability for deep drawing, grater number of working steps, and higher needed quality of tools. From the viewpoint of weight reduction, energy balance, and recycling, the use of aluminium has already today and with existent production possibilities a great advantage in life of cars.

Various manufacturers developed numerous alloys for car body sheet. Their origin is based on standard wrought alloys. The common guide in designing those alloys was that they must have good workability, suitable strength, good weldability, corrosion resistance, and perfect finish after lacquering. At present, there does not exist any alloy which would fulfil all these demands. All alloys have advantages and disadvantages. Measures to improve certain properties simultaneously deteriorate other ones.

Shaping of car-body sheet is a complex process. The following parameters are influencing the deep drawing process: crystallographic texture, R-values, work hardening exponent n, and strength values. The work hardening exponents of $n \geq 0.3$ are desired that contraction does not occur during the stretch forming [2]. Existent aluminium sheet has lower R-values when compared with those of steel sheet. Car-body aluminium sheet should have R-values over 0,6. Based on empirical experiences, $R_{p0.2} : R_m$ ratio should be < 0.5 for specially demanding deep-drawn sections. Sheet should not be prone to formation of stretcher strains which is especially problematic with AlMg alloys. Thus, these alloys cannot he used for visually exposed body sections. During many years, various alloys were developed for car body components. The main alloy groups for car-bodies are AlMgSi (AA6xxx), AlMg (AA5xxx), and AlCuMg (AA2xxx) alloys [26]. With the alloys of the 6xxx group being developed in Europe, the emphasis is given on the optimisation of workability. The alloys of the 5xxx group, containing also copper, were developed in Japan. Chemical compositions and properties of some alloys are given in tables 2 and 3.

Table 2. **Chemical compositions of some aluminium alloys for car- body sheet in mass % [30]**

Tablica 2. **Kemijski sastavi nekih aluminjiskih legura za automobilski karoserijski lim, u $\%_{masa}$ [30]**

Group	Design.	Si	Cu	Mn	Mg
AlMg	AA5754	0.4	0.10	0.50	2.60 - 3.6
AlMg	AA5182	0.2	0.15	0.20 - 0.50	4.00 - 5.0
AlMgSi	AA6016	1.0 - 1.5	0.20	0.20	0.25 - 0.6
AlMgSi(Cu)	AA6009	0.6 - 1.0	0.15 - 0.6	0.20 - 0.80	0.40 - 0.8
AlMgSi(Cu)	AA6111	0.7 - 1.1	0.50 - 0.9	0.15 - 0.45	0.50 - 1.0
AlMgSi(Si)	AA2036	0.5	2.20 - 3.0	0.10 - 0.40	0.30 - 0.6

Sheet made of AlMgSi (AA6xxx) alloys is used for external parts of car bodies. The work hardening exponent n, which influences the shaping of sheet, depends on the composition. Value of n increases with Si excess or increased Si : Mg ratio. With these alloys, the optimisation of the alloy composition is important since the increased work hardening exponent causes reduction of R-values. The additional alloying element in some alloy is copper. Those alloys are not susceptible to formation of deformation lines. They are very well worked in the natural ageing temper. During the lacquering process, strength values are increased because of additional artificial ageing. The addition of copper, contai-ned in the in USA developed alloys, increases strength valu-es an work hardening expo-

Table 3. **Mechanical properties of some alloys for car-body sheet [3, 30]**

Tablica 3. **Mehanička svojstva nekih legura za automobilski karoserijski lim [3, 30]**

Alloy	Temper	R_m [MPa]	$R_{p0.2}$ [MPa]	A_5[%]	n	R
AA5754	Annealed	210	100	28	0.30	0.75
AA5182	Annealed	280	140	30	0.31	0.75
AA6009	T4	230	125	27	0.23	0.70
AA6016	T4	240	120	28	0.27	0.65
AA6111	T4	275	160	28	0.26	0.56
AA2036	T4	340	195	24		

nent. Copper deteriorates alloy workability and its corrosion resistance due to precipitation of Al_2Cu intermetallic compound on the grain boundaries [27].

Alloys of the AlMg (AA5xxx) group are not-age-hardenable, and they belong to materials with medium strength values. Workability and strength values depend on the magnesium content; increased magnesium content increases strength and reduces workability. Sheet in soft temper can be better stretch formed and deep drawn in comparison to AlMgSi alloys. Most frequently the AlMg2.5, AlMg3, and AlMg5Mn alloys are used. Some alloys of the AA5xxx group contain also copper. Copper increases strength values due to age-hardening effect. Simultaneously copper reduces corrosion resistance because Al_2CuMg precipitates [27].

Alcoa Company has developed frame-space concept for manufacturing car bodies which is based on hollow sections [3, 25]. The sections are made of AlMgSi (AlMgSi0.5) alloys and manufactured at 20:1 extrusion ratio [28]. Sections are joint with nodes made of AlSi (AlSi10Mg) alloys by pressure die casting. The bearing frame has weight of 130 to 150 kg. Sheet is fixed on assembled frame by robotiesed welding. In such a way manufactured aluminium car -body consists of 20 % of castings, 25 % of extruded parts, and of 55 % sheet.

Further development of aluminium materials for car bodies will be directed towards improved workabilities and increased strength properties, among which the yield stress is in the first place. The aim of further development is to downgauge and to reduce dimensions of extruded parts which causes further reduction of weight and costs. The next aim is to increase life of new aluminium cars and to improve the yields in recycling [21, 29].

ALUMINIUM FOR BEVERAGE CAN STOCK

Consumption of aluminium for packing purposes has the highest upward trend next to existent and foreseen use for transport means, when compared with other industrial branches. In Europe approximately 40 % of aluminium rolled products are used in packing such as foil, beverage and aerosol cans [31-32]. Mean growth rate of aluminium consumption for this purpose per year is 3.8 % in the West World [33]. At the same time, it is necessary to take in account that dimensions and weights of sheet and foils are constantly reduced due to higher quality of semiproducts. Advantage of aluminium in storing food and beverages is its small weight, corrosion resistance, poisonless, impermeability for gases, liquids, greases, light, and micro-organisms, good thermal conductivity, etc, when compared with other materials. For these purposes, simple completely recyclable alloys are used [34].

Among packing items, the highest position keep beverage cans; they are becoming general purpose products manufactured in the greatest series. The portion of aluminium which was used in Europe for beverage cans is 33 % of all packing materials in the past decade [33]. Deliveries of empty beverage cans in Western and Central/Eastern Europe continued to increase from 33.8 billion cans in 1999 to 35.4 in 2000 representing 4.9 % growth [32]. This upward trend is not yet completed, since the consumption of beverage can stock in Europe is lower than that in USA. Also in this field, the development of aluminium materials and manufacturing processes is further very intensive, regardless of apparently simple products. The main object in the development of cans is the reduction of their weight which can be achieved by thinner sheet at corresponding increased strength values. The weight of 0.33 l can was reduced from 18.6 g in 1983 to 13.4 in 1995 which is approximately 30 % (Figure 4.). Sheet thickness was in approximately the same time reduced from 0.4 to 0.25 - 0.30 mm [35].

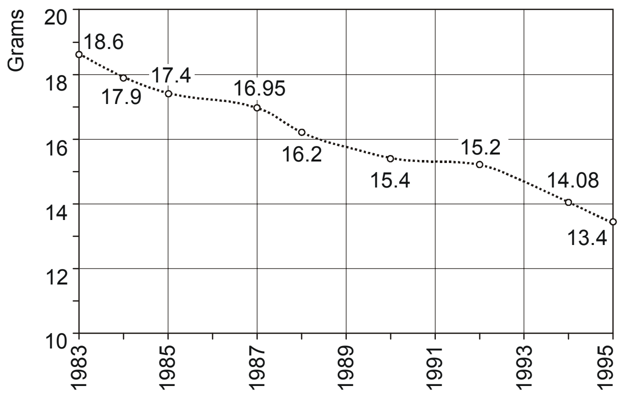

Figure 4. **Weight reduction of 0.33 l aluminium beverage can (cit. by European Aluminium Association and [35, 36])**

Slika 4. **Težinsko smanjenje aluminijske limenke za piće od 0.33 l (prema: Europskoj aluminijskoj udruzi i [35, 36])**

Non-heat-treatable alloys of AA3xxx, and AA5xxx types are used for beverage cans: AA3004 (AlMg1Mn1), and AA3104 alloys for can bodies, AA5182 (4.0-5.0 mass % Mg, 0.20-0.50 mass % Mn) for cabs and tabs. These alloys quite satisfactorily fulfil the demanded properties, and there is no need at the moment for their replacement. Among material properties, the main problem is the texture as a function of mechanical forming and heat treatment during the sheet manufacturing process. Sheet is made by standard technology, consisting of slab homogenising, hot rolling, intermediate annealing, and cold rolling. Each of technological steps of manufacturing can sheet have critical influence on the sheet properties during further operations. Can sheet must have corresponding strength and good deep drawing ability. It must have low anisotropy which cause earing during the deep-drawing process. Unsuitable earing means rejection. The main reason for earing effect is the texture which appears during final cold rolling. Materials not to be susceptible to earing during the deep-drawing process must have cubic texture. Cubic texture must be present already in the hot rolled sheet. Texture control is important problem in further development of aluminium sheet for beverage cans. This problem can be solved by the optimisation of alloy composition and thermomechanical treatment. Materials for such sheet should not contain coarse intermetallic compounds or other inclusions. Sheet must have suitable mechanical properties which are achieved by deformation hardening during cold rolling. In such a way, the yield strength of order 300 MPa is achieved. The temperature of the materials which can rise for more than 100 °C during rolling with high strain rates can reduce strength values due to recovery effect.

Alternative for manufacturing sheet for beverage can stock are the cast-rolling processes. These methods are interesting mainly from the economic point of view if equipment investments are neglected. The disadvantage of cast-rolling process is that texture cannot be influenced since some technological steps, like homogenising, and hot rolling are absent. Also surface quality is problematic since there is no mechanical surface chipping like in standard working of slabs.

Development of aluminium alloys for beverage can stock will include further sheet downgaugeing to reduce weights of products, at simultaneous improvement of strength properties and workability in the regard to earing effect, to simplify and unify recycling, and probably new designs of can stock can be expected too.

REFERENCES

1. I. Gyöngyös, B. Rüttmann: The future of the aluminium industry, Aluminium, 76 (2000) 4, 239-258
2. D. G. Altenpohl, P. Furrer: Knowledge management - the key to lasting success, Aluminium, 76 (2000) 6, 446-450
3. D. G. Altenpohl: Aluminium von Innen, 5. Auflage, Aluminium-Verlag Düsseldorf, 1994
4. Aluminium 97 (1997), Aluminium 98 (1998), Internationale Messe und Kongress, Essen
5. ICAA 7, Aluminium in the next 100 years, Aluminium, 76 (2000) 11, 960-961
6. P. Furrer: Aluminium alloy development today, Aluminium, 73 (1997) 4, 262-265
7. 4th International Aluminium-Lithium Conference, Journal de Phisique, 48, Coloque C3, (1987), Paris
8. H. F. de Jong: A survey of the development, properties and applications of aluminium - lithium alloys, Aluminium, 60 (1984) 9, 673-679
9. G. Schart, G. Winkhaus: Technical perspectives of aluminium materials, Aluminium, 63 (1987) 7/8, 788-808
10. J. Wadsworth, C. A. Henshall, T. G. Neeh: Superplastic aluminium-lithium alloys, Aluminium-Lithium Alloys III: Proceedings of the Third International Aluminium-Lithium Conference, The Institute of Metals, (1986), London, 100-212
11. K. H. Rendigs: Aluminium-Lithium-Werkstoffe vor dem Einsatz im Airbus (I), Aluminium, 67 (1991) 4, 357-359
12. J. Jupp, H. J. Price: Transport aircraft - a challenge for aluminium alloys for the 21st century, Proceedings of the Aluminium 97 Conference, Paper 4, (1997), Essen
13. B. Lenczowski, T. Pfannenmüller, U. Koch: Neue Aluminiumlegierungen für die Luftfhart, Auminium, 73 (1997) 5, 350-356
14. R. Grimes, M. J. Stowell, B. M. Watts: Superplastic-aluminium based alloys, Metals Technology, (1976), 154/160
15. D. H. Shin, S. C. Meang: Superplastic behaviour of 7475 aluminium alloy, Journal of the Materials Science Letters, 8 (1989), 1380-1382
16. T. J. Watson, J. I. Benetsh: The effect of microstructure in the SPF behaviour of Al-Li-X alloys, Superplasticity in Aerospace, H. C. Heikenen and T. R. Nelly, eds, The Metallurgical Society, Warrendale, (1988), 261-297
17. O. D. Sherby. Advances in superplasticty and in superplastic materials, ISIJ International, 29 (1989) 8, 698-716
18. P. B. Berbon, S. Komura, A. Utsunomiya, Z. Horitu, M. Furukava, M. Nemoto, T. G. Langdon: An evaluation of superplasticity in aluminium-scandium alloys processed by equal-channel angular pressing, Materials Transactions, JIM, 40, (1999) 8, 772-778
19. I. I. Novikov, K. K. Portnoj: Superplastizität von Legierungen, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, (1984)
20. A. Smolej, M. Gnamuš, E. Slaček: The influence of the thermomechanical processing and forming parameters on superplastic behaviour of the 7475 aluminium alloy, Journal of materials processing technology, 118 (2001) 1-3, 397-402
21. R. L. Klimisch, J. C. Benedyk: Automotive aluminium - protecting what's important, Light Metal Age, 59, (2001) 1-2, 72-80
22. M. D. Röhrle: Alcan promotes the use of alternative materials for established a designs, Aluminium, 77 (2001) 10, 740-746
23. R. A. Schultz, W. J. Haupricht: Trends in aluminium use for passenger cars and light trucks in North America, Light Metal Age, 57, (1999) 1-2, 108-113
24. J. C. Benedyk: Light metals in automotive applications, Light Metal Age, 58, (2000) 9-10, 34-35
25. I. J. Palmer: Light Alloys, Arnold, London, 1994
26. D. G. Altenpohl, P. Furrer: Innovative aluminium applications for automotive use in Europe, Light Metal Age, 57, (1999) 9-10, 24-33
27. P. Furrer: Opportunities for rolled products in the automotive industry-body sheet applications, Proceedings of the Aluminium 97 Conference, Essen, (1997), paper 10
28. F. Wehner, P. Furrer: Innovative Strangpressprofilanwendungen im Automobilbau, Aluminium, 73 (1997) 9, 592-595
29. M. Nagler, S. Hummel, M. Kaiser, K. H. V. Zenger: The aluminium Audi A8, Proceeding of the Aluminium 97 Conference, Essen, (1997)
30. Aluminium and aluminium alloys, ASM, Metals Park, 1994
31. P. Johne: Growth in aluminium rolled products-how steep will the increase be?, Aluminium, 77 (2001) 10, 735
32. N. N. Aluminium for future generations, News - press information, The year 2000 -"a good vintage" for aluminium can and its recycling, European Aluminium Association, (2002)
33. N. N-: Aluminiumverpackung in Europa, Aluminium, 72 (1996) 12, 876-881
34. A. H. Wirtz: Aluminium packing - a contribution to sustainable development, Aluminium, 76 (2000) 1/2, 39-41
35. A. Karlsson: Some product developments in rolling industry, Proceeding of the Aluminium 97 Conference, Essen, 1997, Paper 9
36. N. N.: Aluminium for future generations, The industry at a glance, European Aluminium Association, (2002)