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recycling of aluminium alloys; secondary aluminium alloys; aluminium in transportation industry

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RECYCLING AND PROPERTIES OF RECYCLED ALUMINIUM ALLOYS USED IN THE TRANSPORTATION INDUSTRY

Summary. Nowadays, a transportation industry creates a lot of metal scrap because production and use of cars are on the increase worldwide. This is based on the fact that increase in the production of cars increases usage of aluminium alloys in transportation applications. Therefore, it is necessary to reduce the production of components from primary aluminium alloy and increase their replacement with secondary—recycled—aluminium alloys because the production of recycled aluminium alloys is less expensive and less energy-intensive than the creation of new aluminium alloy through the electrolysis. In addition, the recycled aluminium alloys have comparable microstructural parameters and properties as the same primary aluminium alloys.

RECYCLING UND EIGENSCHAFTEN VON SEKUNDÄRALUMINIUM LEGIERUNGEN FÜR VERKEHRSINDUSTRIE

Zusammenfassung. Dank weltweiter Produktionserhöhung und Benutzung der Fahrzeuge produziert die Verkehrsindustrie heute viel Metallabfall. Wie steigert die Fahrzeugerzeugung, so steigert auch die Benutzung von Aluminiumlegierungen. Es ist nötig, die Produktion von Aluminiumprodukten aus Primäraluminium zu reduzieren. Die Produkte müssen also durch die Produkte aus Sekundäraluminium eingesetzt werden. Während die Schmelzflusselektrolyse bei der Gewinnung von Aluminium aus Bauxit 100 Prozent Energie verbraucht, sind es beim Recycling etwa vier bis sechs Prozent. Das Aluminium-Recycling leistet deshalb einen beträchtlichen Beitrag zur Einsparung von Energie, und dient damit gleichzeitig auch dem Umweltschutz. Noch dazu, die Legierungen vom Sekundäraluminium haben vergleichbare Eigenschaften wie dieselben Legierungen von Primäraluminium.

1. INTRODUCTION

The transportation industry is one of the largest energy consuming sectors, using about 19% of the world's energy demands [1]. Car production has been increasing and it is important to reduce the energy cost, greenhouse effects, problems to the environment, etc., associated with casting from primary aluminium alloys. A survey by the Automotive Recyclers Association shows that each year the industry collects, reuses and recycles about 382 million litres of gasoline and diesel fuel, 90 million litres of motor oil, 30 million litres of engine coolant; 17 million litres of windshield washer fluid, and about 96% of all lead acid batteries [2]. These facts underline the need to search for possibilities for decreasing energy consumption of automotive producers [3-5].

The total energy consumption during the life cycle of a car can be summarised into four main stages: raw material processing, car manufacturing, car use and car recovery (Fig. 1) [3]. The great objectives of the European Union for the year 2015 was that 85% of the car weight would be re-used or recycled, 10% used to recover energy and 5% for scrap [6]. Nowadays, manufacturers currently use about 35% of secondary aluminium and about 65% of primary aluminium to meet their needs [7]. It is important to note that the production of aluminium as "secondary metal" (producing it by recycling) requires only about 2.8 kWh/kg of metal produced while primary aluminium production requires about 45 kWh/kg of metal produced. The 95% energy saving are a powerful economic incentive [8-9].

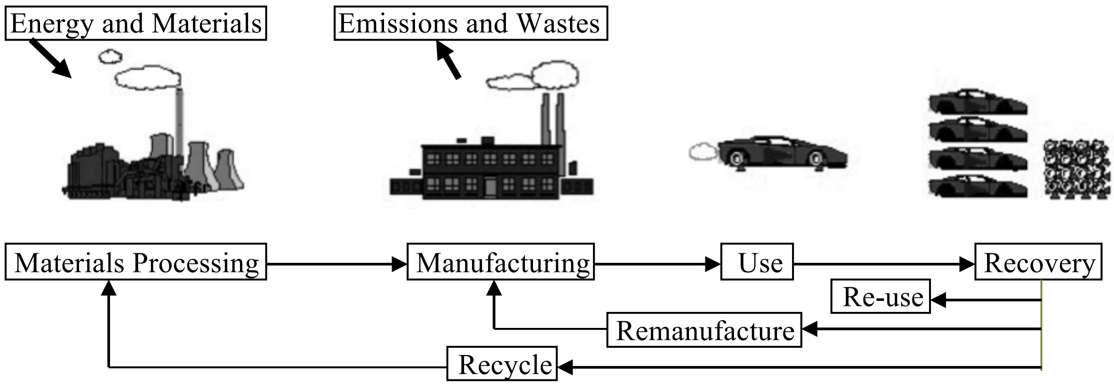

Fig. 1. Car life cycle [10]
Bild. 1. Auto-Lebenszyklus [10]

Table 1

The proportion of recycled material and their probable amount up to year 2030 [6]

Materials	The proportion of recycled material in year [%]			
	1997	2000	2005	2030
Steel	70	80	87	90
Cast iron	70	80	87	90
Wrought aluminium	85	90	93	93
Cast aluminium	85	90	90	90
Plastics	20	50	80	90

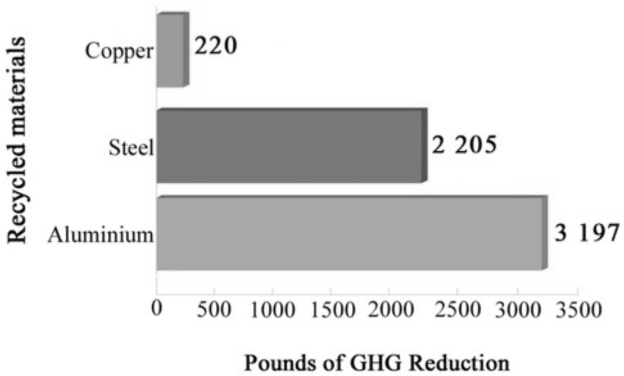

Fig. 2. Estimated GHG reductions per vehicle recycled [2]
Bild. 2. Geschätzte THG-Reduktionen pro Recycling Fahrzeug [2]

Researches show that the amount of recycled material increases over the years (Table 1). It is very important because recycling aluminium prevents more than 90 million tons of carbon dioxide from being released into the atmosphere each year [6, 7]. The automotive recycling industry reduces greenhouse gas emissions (GHG) (Fig. 2), as well as air and water pollution [2]. The amount of aluminium used per car produced in Europe almost tripled between 1990 and 2012, increasing from 50 kg to 140 kg. This amount is predicted to rise to 160 kg by 2020, and even reach as much as 180 kg if small and medium cars follow the evolution recorded in the upper segments of the automobile industry [1]. For the aluminium industry, it is appropriate to identify, develop and implement all technologies that will optimise the benefits of recycling because the automotive industry is the second-largest user of recycled aluminium [7,11].

Following these facts the research and development deal with properties and the microstructure of secondary aluminium alloys, which are used in engine construction, engine blocks, cylinder heads, carburettors, transmission housing, etc. [12,13].

2. INFLUENCE OF RECYCLING OF ALUMINIUM ALLOYS ON THEIR PROPERTIES

An example of the effect of recycling on properties and the microstructure of A226 cast aluminium alloy (AlSi9Cu3) is in this work. The A226 cast alloy has a lower corrosion resistance and is suitable for high-temperature applications (dynamic exposed casts, where the requirements of mechanical properties are not so high)—it means to max. 250°C. The chemical composition of primary A226 cast alloy obtained from standard EN 1706 [14] and secondary aluminium alloy (experimental material) according to results with using an arc spark spectroscopy are shown in Table 2.

Table 2

Chemical composition of primary and secondary A226 cast alloy (in weight %) [14]

Elements	Si	Cu	Mn	Zn	Mg	Ni	Pb	Fe	Ti	Sn	Cr	other	Al
Primary A226 (EN 1706)	8.0 ÷ 11.0	2.0 ÷ 4.0	0.55	1.20	0.15 ÷ 0.55	0.55	0.35	0.6 ÷ 1.1	0.20	0.15	0.15	0.25	rest
Secondary A226	9.4	2.4	0.24	1.0	0.28	0.05	0.09	0.9	0.04	0.03	0.04	-	rest

The secondary alloy (prepared by recycling aluminium scrap) was received in the form of 12.5 kg ingots (Fig. 3). Experimental material was molten into the permanent mould (chill casting), which were preheated to 250°C (Fig. 3). The melting temperature was maintained at 760°C ± 5°C. Molten metal was purified with salt AlCu4B6 before casting and was not modified or grain refined. The A226 castings were not heat treated, too.

a) b) c)

Fig. 3. Production of experimental material A226 cast alloy: a) aluminium scrap; b) ingot of experimental material; c) permanent mould and cast of A226

Bild. 3. Produktion von Versuchsmaterial A226-Gusslegierung, a) Aluminiumschrott; b) Gussblock von Versuchsmaterial; c) Dauerform und Guss von A226

The need for aluminium alloys having a good toughness, high strength, adequate damage tolerance capability, good fatigue resistance and good corrosion resistance for use in applications in the industries of aerospace, automotive and even commercial products led to a study of the properties and structure of these materials. Generally, the mechanical and microstructural properties of aluminium cast alloys are dependent on the composition; melt treatment conditions, solidification rate, casting process and the applied thermal treatment [15, 16]. The mechanical properties of cast component are mostly determined by the shape and distribution of Si particles and intermetallic phases in α-matrix [17]. When will there be possibilities of increasing the mechanical properties of aluminium so it will have larger application fields of complex cast aluminium components [16]? The experimental tensile and hardness specimens for an experimental procedure were made from the casting (Fig. 3c) with turning and milling operations. Mechanical properties were measured according to the standards: EN ISO 6892-1 and EN ISO 6506-1 [18, 19]. Hardness measurement for secondary aluminium alloy was performed by a Brinell hardness tester with a load of 62.5 kp, 2.5 mm diameter ball and a dwell time of 15 s. The evaluated Brinell hardness reflect average values of at least six separate measurements. Tensile strength was measured on testing machine ZDM 30. The evaluated Rm and A_5 reflect average values of at least six separate bars. The results of mechanical properties are documented in Tab. 3.

Table 3

The mechanical properties of both materials [14]

Material	Mechanical properties		
	Tensile strength R_m	Elongation A_5	Brinell hardness
Primary A226 (EN 1706)	240 ÷ 310 MPa	0.5 ÷ 3%	80 ÷ 120 HBS
Secondary A226	211 MPa	1%	98 HBS

The results of mechanical properties of secondary A226 cast alloy show that this material has lower values of mechanical properties in comparison with primary aluminium alloy. However, mechanical properties depend upon the microstructure of the material and, therefore, the evaluation of microstructure was carried out [16, 17].

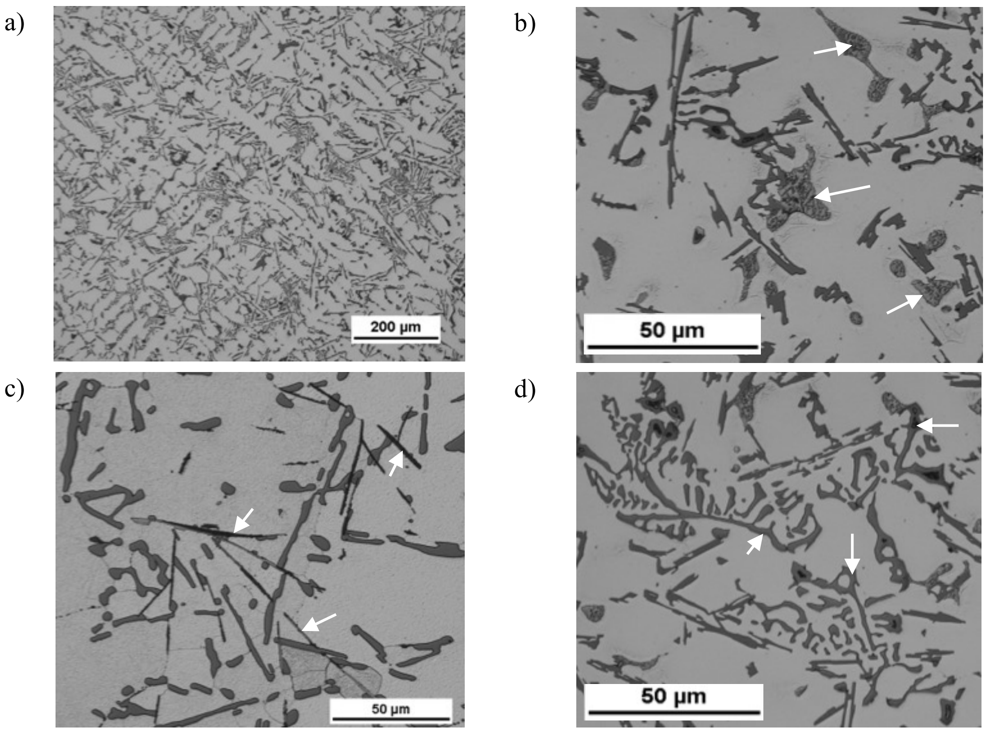

Fig. 4. The microstructure of A226 cast alloy, etch. Dix-Keller. a) α-phase (α-Al) and eutectic mixture of Al-Si; b) Al-Al_2Cu-Si phase; c) β-Al_5FeSi phase; d) α – $Al_{15}(FeMn)_3Si_2$ phase

Bild. 4. Gefüge von A226 Gusslegierung, ätzen. Dix-Keller. a) α-Phase (α-Al und eutektische Mischung von Al-Si; b) Al-Al_2Cu-Si Phase; c) β-Al_5FeSi Phase; d) α – $Al_{15}(FeMn)_3Si_2$ Phase

The microstructure of hypoeutectic A226 cast alloy is given by the binary diagram; therefore, its expected formation is α-phase (α-Al), eutectic mixture of Al-Si and various types of intermetallic phases. The amount and forms of the eutectic mixture in the microstructure of aluminium alloys depend on the level of Si. The morphology of Si-particles is plate-like when the material is beside the influence of modification, heat treatment, etc. The most common intermetallic phases in primary Al-Si-Cu alloys are, for example, Al_2Cu, Mg_2Si, α-$Al_{12}(Fe,Mn)_3Si_2$ and β-Al_5FeSi [20, 21]. These facts point out that microstructural features are products of metal chemistry and solidification conditions; therefore, the real microstructure of secondary aluminium alloys can be different.

The microstructure evaluation shows that secondary A226 cast alloy microstructure consists of α-Al dendrites mixture surrounded by the Al-Si mixture and intermetallic phases (Fig. 4). The presence of Cu, Mg and Fe in the alloy leads to a formation of various intermetallic compounds in the microstructure of the alloy [Al-Al_2Cu-Si, β-Al_5FeSi, α – $Al_{15}(FeMn)_3Si_2$] (Fig. 4). Experimental material was not modified and so eutectic Si particles are in a form of platelets, which on the metallographic sample are in a form of grey needles (Fig. 4). The Al-Al_2Cu-Si phase is observed in very fine multi-phase eutectic-like deposits (Fig. 4b – marked with an arrow). The Al_5FeSi with the monoclinic crystal structure (known as beta- or β-phase) and $Al_{15}(Mn,Fe)_3Si_2$ (known as alpha- or α-phase) with cubic crystal structure were observed in the secondary experimental material. The first phase (Al_5FeSi) precipitates in the interdendritic and intergranular regions as platelets (appearing as needles on the metallographic sample, Fig. 4c – marked with an arrow). The $Al_{15}(FeMn)_3Si_2$ were observed in form "skeleton like" or in form „Chinese script" (Fig. 4d – marked with an arrow).

3. CONCLUSION

The results present in this work show that the production of secondary aluminium alloys is much more worthy in comparison with the production of primary aluminium alloy. The production of secondary aluminium alloy is better because aluminium recycling saves energy; recycling aluminium makes use of a valuable commodity; recycling aluminium reduces your carbon footprint; recycling aluminium helps satisfy an increasing demand; etc.

The work shows that aluminium can be easily and endlessly recycled without quality loss. The chemical composition and the mechanical properties of the secondary experimental material are comparable with properties which are required from primary alloy. The evaluation of the microstructure shows that secondary material contains the some structural components as the primary alloy. The silicon particles were in form needles (plate-like) form, and in the microstructure were observed brittle and undesirable Fe-intermetallic phases and Cu-intermetallic phases which are desirable in order to obtain better mechanical properties after some technological processes (e.g. heat treatment).

In the end it is very important not to forget that most of the aluminium being produced today enters long-life products like vehicles and building products. With average lifetimes of about 15 to 20 years for vehicles and 40 to 50 years for buildings, most of the aluminium will not be available for recycling for many years. As a result, access to aluminium scrap is limited [1].

Acknowledgements

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