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VŠCHT Praha, Fakulta chemicko-inženýrská
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Zvýšení bezpečnosti zásahových žebříků pro hasiče
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Structure and Mechanical Properties of Aluminium Alloy Sampled from a Firefighter Ladder

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Anotace výsledku:

Žebříky pro hasiče jsou vyrobeny z hliníkové slitiny AA 6063. Tyto žebříky jsou široce používaným technickým nástrojem pro hašení požárů, pro zasahující hasiče a pro zachráněné osoby. Kvalita žebříků je kontrolována tzv. „Uživatelskou zkouškou", což je nedestruktivní zkouška průhybem definovaná ČSN EN 1147. Bohužel tato zkouška není z hlediska bezpečnosti dostatečně přesvědčivá. Proto je projekt nazvaný „Zvýšení bezpečnosti zásahových žebříků pro hasiče" (VI20162020021) zaměřen na komplexní posouzení stávajících hasičských žebříků a to prostřednictvím matematického modelování, materiálové analýzy a reálných zkoušek. V současné práci je představena struktura a mechanické vlastnosti vzorků (hliníková slitina AA 6063) odebraných z různých oblastí zásahových žebříků. Získaný výsledek potvrzuje vynikající mechanické vlastnosti vybraných vzorků, jako je mez kluzu v tahu a mez pevnosti v tahu, při laboratorní teplotě, ale obrovský pokles těchto vlastností po vystavení teplotám nad 200 °C i na krátkou dobu. To má za následek nutnost kontrolovat teploty v blízkosti žebříku, zejména v případě, že je žebřík umístěn v blízkosti plamene.

Řešitelský tým:

Ing. Jan Karl, Ing. Václav Vystrčil, Ing. Romana Friedrichová, Ph.D., Ing. Ondřej Suchý, Ph.D., Lukáš Kotrc, prof. Dr. Ing. Dalibor Vojtěch, Ing. Jiří Kubásek, Ph.D., Ing. Filip Průša, Ph.D., Ing. Klára Hosová, Doc. Ing. Miroslav Španiel, CSc., Ing. Karel Doubrava, Ph.D.

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Structure and Mechanical Properties of Aluminium Alloy Sampled from a Firefighter Ladder

Jiří Kubásek, Dalibor Vojtěch, Drahomír Dvorský
Department of Metals and Corrosion Engineering, University of Chemistry and Technology, Prague, Technická 5, 166 28 Prague 6, Czech Republic. E-mail: kubasekj@vscht.cz, vojtechd@vscht.cz

Firefighter ladders are manufactured of aluminium alloy AA 6063. These ladders are a widely used technical tool for firefighting, for intervening firefighters and for rescued persons. The quality of the ladders is checked by so-called "user test" which is a non-destructive deflection test defined by CSN EN 1147. Unfortunately, this test is not sufficiently conclusive in terms of safety. Therefore, the project called "Safety improvement of extension ladders for firefighters" (VI20162020021) is focused on the complex assessment of the existing firefighter ladders through mathematical modelling, material analysis and real testing. In the present work structure and mechanical properties of samples (aluminium alloy AA 6063) taken from different areas of a firefighter ladder are presented. The obtained result confirm excellent mechanical properties of selected samples, such as tensile yield strength and ultimate tensile strength, at laboratory temperature but a huge decrease in these properties after exposure to temperatures above 200 °C for even short times. This results in the necessity to control temperatures in the proximity of the ladder, especially in the case when the ladder is located near a flame.

Keywords: Aluminium alloy 6063, firefighter ladder, Electron microscopy, Mechanical characterization

1 Introduction

Aluminium alloys are widely used materials in automotive and aviation industry as well as for many specific applications which may require specific mechanical and corrosion properties [1, 2, 3]. Aluminium alloy 6063 is one of the most widely used alloys for production of various components by extrusion [4]. The extrusion is commonly used to produce complex profiles. The main alloying elements of this alloy are magnesium and silicon giving it a medium strength. The alloy has a high corrosion resistance and is suitable for various surface treatments. The chemical composition of AA 6063 is given by CSN EN 573-3 (Table 1). The values of selected mechanical properties in different states are then shown in Table 2.

Usually, the alloy is used in a thermally treated state. A T6 state is the most often one. This thermal treatment consists of two steps. The first step is a solution thermal treatment designated as T4 that is performed in the range of 560 - 580 °C. In the T4 state the alloy exerts a good formability. Then, artificial aging and extrusion processes can be performed around 180 °C and 470 °C, respectively. AA 6063 is also suitable for welding and anodizing [5, 6, 7].

***Tab. 1** Chemical composition (in wt.%) defined by ČSN EN 573-3.*

Element	Mn	Fe	Mg	Si	Zn	Ti	Cr	Cu	others (each)	others (sum)	Al
[%]	max. 0.1	max. 0.35	0.45–0.9	0.20–0.6	max. 0.1	max. 0.1	max. 0.1	max. 0.1	max. 0.05	max. 0.15	Vol.

***Tab. 2** Mechanical properties of AA 6063 alloy after different thermal treatments [5, 6, 7].*

Thermal treatment	Wall thickness [mm]	TYS [MPa]	UTS [MPa]	Elongation A [%]	Elongation A_{50mm} [%]	Brinell hardness
T4	≤ 25	65	130	14	12	45
T5	≤ 3	130	175	8	6	55
	3 - 25	110	160	7	5	50
T6	≤ 10	170	215	8	6	65
	10 - 25	160	195	8	6	60

The microstructure of the alloy may vary depending on the exact composition of the AA 6063 alloy which is often different depending on a particular material supplier. Microstructure of the as-cast ingots is characterized by cellular dendritic microstructure with large grain size. At grain boundaries segregation of secondary phases occurs. The precipitates at the grain boundaries are formed by intermetallic phases with Chinese font morphology (α-Al-Fe-Si = $Al_{13}Fe_3Si_{1-1.5}$) or needle-like morphology (β-Al_5FeSi). During thermal treatment, the original as-cast microstructure is removed. Microstructure of homogenized materials is generally composed of large grains and particles of secondary phases. During hot extrusion material is recrystallized. Microstructure of extruded products contains equiaxed grains as a consequence. In most cases, the precipitates present inside the grains correspond to the Mg_2Si phase and secondary phases distributed predominantly at the grain boundaries represent the intermetallic phase (AlFeSi) [8, 9].

2 Materials and methods

2.1 Materials

Samples of aluminium alloy 6063 were taken from a new four-part firefighter ladder (Fig. 1) from different areas specified in Fig. 2. The ladder had been manufactured by extrusion of individual parts and subsequent composition and junction of these parts using TIG welding or riveting. Individual parts such as beams and rungs and also composed ladder were thermally treated at non-specified conditions which are manufacturer's internal secret. The proper chemical composition of AA 6063 alloy of which the studied ladder was prepared is shown in Table 3.

***Fig. 1** Firefighter ladder used for study of structure and mechanical properties.*

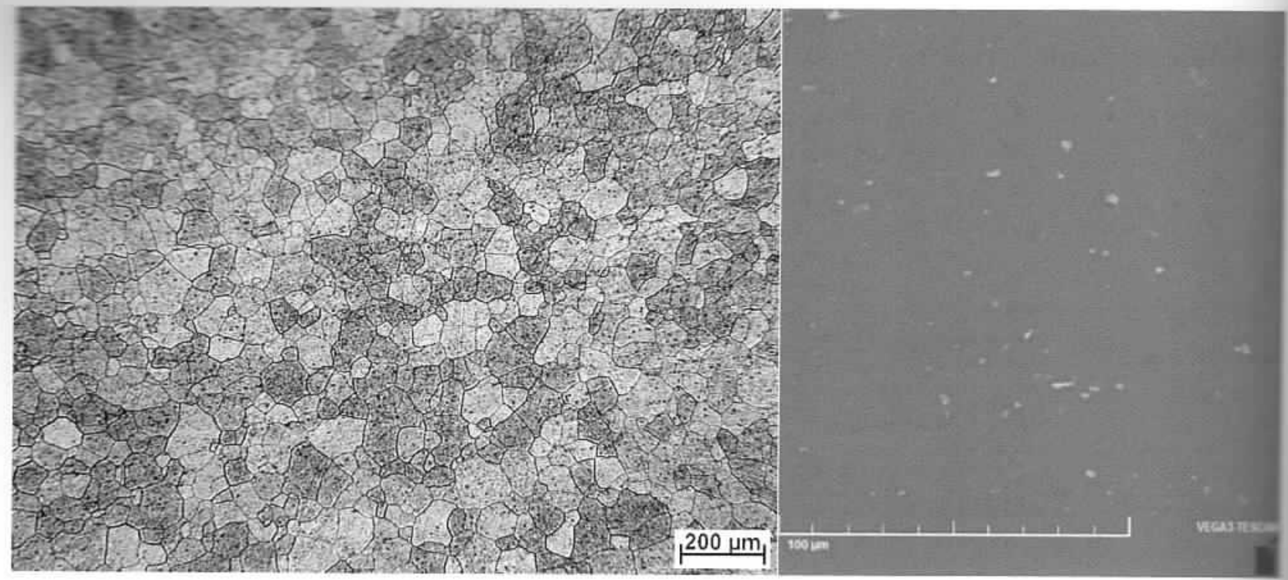

Fig. 3 Structure of a sample taken from the firefighter ladder: OM (left), SEM (right).

The Brinell hardness of the material was measured according to CSN EN ISO 6506-1 at all the sampling areas (Fig. 2) in both perpendicular and longitudinal direction. Obtained values were similar for all the measurements and correspond to 80.0 ± 1.1 HBW62.5/2.5 in the perpendicular direction and 77.8 ± 2.4 HBW62.5/2.5 in the longitudinal direction. Vickers hardness measurement according to the CSN EN ISO 6507-1 with a load of 1 kg (HV1) was performed along the whole cross section (Fig. 2) with no significant changes in the measured value. The average value and related standard deviation correspond to 92.1 ± 2.4 HV1.

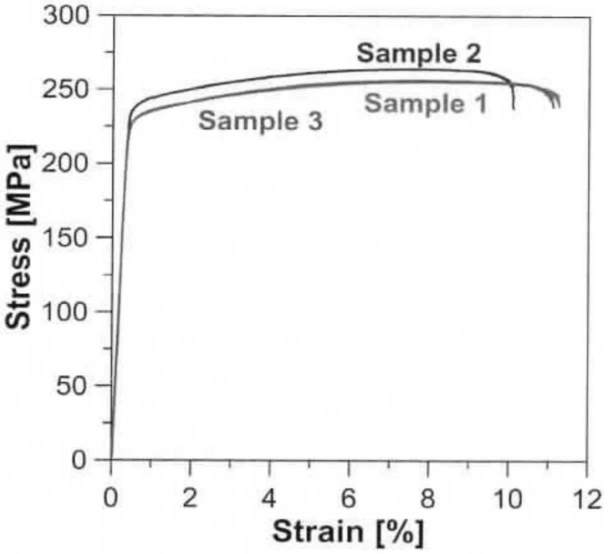

Fig. 4 Tensile stress-strain diagram reflecting similar mechanical properties of samples obtained from different areas of the ladder marked by numbers 1-3 (Fig. 2).

The samples for tensile tests were taken from the beams of the firefighter ladder according to the sampling in Fig. 2. Representative stress-strain curves of samples taken from different areas (1-3) are displayed in Fig. 4. The average values of tensile yield strength (TYS) and ultimate tensile strength (UTS) supplemented by standard deviation are summarized in Table 4. It is evident that all the samples were characterized by comparable mechanical properties. The observed differences can be attributed to the condition of the samples surface, which has not been modified in any way and was therefore identical to the real surface of the firefighter ladder. Measured mechanical properties are also slightly higher compared to EN755-2 standard. It specifies that the material in T6 state (solution annealing + artificial aging) with a wall thickness of less than 10 mm has to reach TYS and UTS of 170 MPa and 215 MPa, respectively. In addition, elongation should correspond to at least 8% according to this standard. Thus, the studied material is characterized by enhanced mechanical properties compared to the standard. It can be attributed to the applied heat treatment processes which are unfortunately not published by the manufacturer.

The main strengthening mechanisms responsible for high values of mechanical properties of the presented aluminium alloy are strengthening by grain boundaries (Hall-Petch relation), strengthening by secondary phases and especially precipitation strengthening with a strong effect [4, 10].

According to the fracture morphology (Fig. 5), material is ruptured by intercrystalline plastic fracture. The plasticity of the fracture is evidenced by the presence of specific pits (holes) on the fracture surface. On the contrary, the fracture morphology does not contain facets which are the sign of a brittle fracture mode.

Tab. 4 Tensile mechanical properties (TYS = tensile yield strength corresponding to the 0.2 proof stress, UTS = ultimate tensile strength, $A_{11.3}$ = elongation)

Sample designation*	TYS [MPa]	UTS [MPa]	$A_{11.3}$ [%]
1	221 ± 1	246 ± 2	10.6 ± [illegible]
2	232 ± 5	257 ± 5	10.9 ± [illegible]
3	229 ± 1	255 ± 2	10.7 ± [illegible]

*reflects the sampling according to Fig. 2

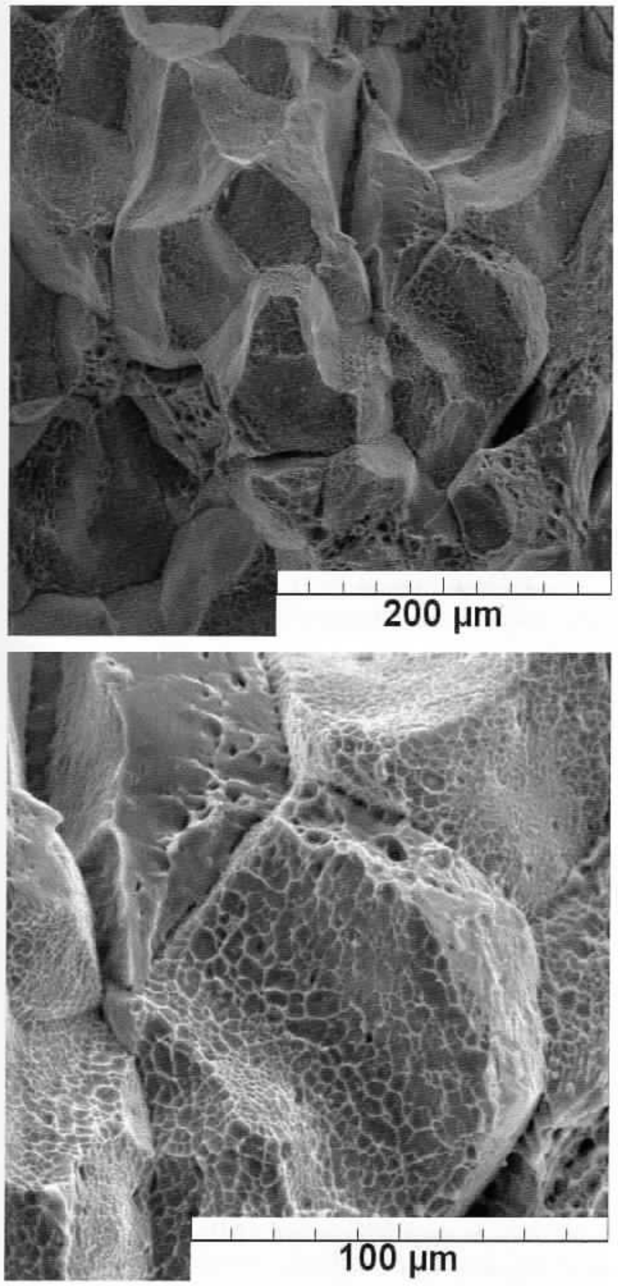

Fig. 5 Fracture area of sample 2 after tensile test (initial state).

Samples taken from area 2 (Fig. 2) were further thermally treated at different temperatures for 2 hours and subsequently stress-strain curves were measured at laboratory temperature. Representative curves are displayed in Fig. 6 and average values with standard deviation can be seen in Table 4. It is evident that short exposure of material to 200 °C has no effect on mechanical properties. However, increased temperatures cause strong decrease of both, TYS and UTS. Huge decrease is observed after exposure to 300 °C already. Elongation is improved at higher temperatures due to an increased plasticity of the material. Such behaviour can have catastrophic consequences if ladder is hit by heat near the flame, because firefighter ladders used in the Czech Republic have currently no temperature marks and the temperature close to the fire can easily exceed 300 °C.

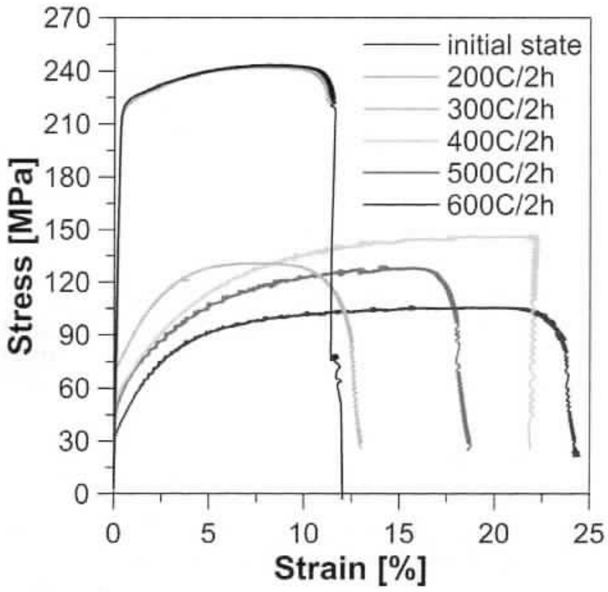

Fig. 6 Tensile stress-strain diagram reflecting mechanical properties of samples thermally treated at different temperatures for 2 hours.

Tab. 4 Tensile mechanical properties (TYS = tensile yield strength corresponding to the 0.2 proof stress, UTS = ultimate tensile strength, $A_{11.3}$ = elongation) after the exposure to elevated temperatures.

Sample designation*	TYS [MPa]	UTS [MPa]	$A_{11.3}$ [%]
200°C/2h	219 ± 3	242 ± 4	10.4 ± 0.9
300°C/2h	75 ± 3	131 ± 2	12.3 ± 1.2
400°C/2h	59 ± 2	147 ± 3	21.7 ± 1.4
500°C/2h	38 ± 2	132 ± 2	17.7 ± 1.9
600°C/2h	43 ± 3	106 ± 4	22.2 ± 1.6

4 Conclusion

Aluminium alloy 6063 is a well-known material with good mechanical properties, extrudability and corrosion resistance. Among other applications, it is also used for the manufacture of firefighter ladders which can be occasionally exposed to extreme conditions. In this study, specimens sampled from an exemplar ladder were characterized by quite high mechanical properties in tension (TYS ≈ 230 MPa, UTS ≈ 250 MPa, $A_{11.3}$ ≈ 11 %). Such properties are assumed to be the result of thermal processing, especially artificial aging. Nevertheless, the study showed that the material is not stable at elevated temperatures. Even two hours of exposure at the temperature of 300 °C caused significant decrease of mechanical properties. That can represent a great risk, because in real application, the ladder can be exposed to such or even higher temperatures shortly but repeatedly, what can lead to the final failure. Therefore, temperature indicators are considered as a good improvement of the firefighter ladders.

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The Effect of Annealing Temperature on Microstructure and Mechanical Properties of Lightweight Steel with Increased Aluminium Content

Ludmila Kučerová, Martin Bystrianský, Štěpán Jeníček
Regional Technological Institute, University of West Bohemia in Pilsen, Univerzitní 8, 30614 Plzeň. Czech Republic. E-mail: skal@rti.zcu.cz, mbyst@rti.zcu.cz, jeniceks@rti.zcu.cz

A demand for enlightening of constructions in an automotive industry resulted in an intensive development of high strength steels and in attempts to decrease the weight of the steel by intensive alloying by lighter elements. This work used chemical concept of AHSS (advanced high strength steel) TRIP (transformation induced plasticity) steel with 0.2%C and micro-alloyed by 0.06%Nb and increased manganese content to 4% and aluminium to 6.5% to produce lightweight steel, which was cast and re-forged and subsequently annealed at various temperatures in the range of 300°C – 800°C. The resulting microstructures were analysed by light microscopy, laser scanning confocal microscopy, scanning electron microscopy and X-ray diffraction phase analysis and mechanical properties were measured by a tensile test. Tensile strengths in the region of 600 MPa – 757 MPa and total elongations around 20% were obtained for annealed samples.

Keywords: aluminium alloyed steel, light-weight steel, annealing, microstructure

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