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SOME AEROSPACE APPLICATIONS OF 7075 (B95) ALUMINIUM ALLOY

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Abstract

Nowadays, aluminium alloys are of growing interest to scientists and are widely used in aerospace and allied industries due to their inherent lightness, high strength to weight ratio, excellent thermal and electrical conductance, good reflectivity and low working cost. Among the conventional structural materials used in aerospace applications aluminium alloys are frontrunners. This is due to the ability of modern aluminium alloys to achieve unique combination of properties, through alloying and heat treatment, tailored to particular applications. Aluminium alloy 7075 (B95) is a high-strength alloy that works in extreme conditions and is used in modern construction of aircraft, spacecraft and satellites.

In this mini-review, we will briefly focus on some of the existing and growing applications of some 7xxx aluminium alloys, in particular 7075 (B95), in the aerospace industry. Possible options for continuing work in this area are considered, and some Bulgarian developments are presented.

Introduction

The application of aluminium in our life began about 100 years ago. But today aluminium, aluminium (Al) alloys and aluminium-based (Al-based) composites are the most important structural engineering materials and are widely used in aerospace and terrestrial industries, because of their inherent lightness, high strength-to-weight ratio, excellent thermal and electrical conductivity, good reflectivity, low operating costs and to a certain extent good corrosion resistance [1–16]. The use of aluminium alloys in these areas leads to a decrease in the mass of the structure, which leads to an increase in the payload and a greater mass of fuel and, consequently, to an increase in the service life of the spacecraft. The application of lighter aluminium alloys and Al-based composites, instead of the (dominating since 1920s) special steels, reduces the weight of the vehicles and hence fuel and energy savings, reducing exhaust emissions, and improving safety. Among the common structural materials used in aerospace, aircraft, transport and related industries aluminium alloys are in the lead. One of the proofs of this is the huge amount of available literature on aluminium alloys.

The purpose of this mini-review is to define some general concepts of Al alloys and Al-based composites related to the aerospace industry. The most important Al alloys and some of their applications are mentioned, with emphasis on Al alloys 7xxx, 7075 (B95) in the aerospace sector, and finally some of the Bulgarian contributions to the investigation of Al 7075 (B95) alloy are mentioned.

Al alloys for aerospace and aircraft structures – some history and classification

The aerospace industry covers the production of aircraft and spacecraft; includes the production of both non-space articles (passenger and military aircraft, helicopters, gliders, balloons, etc.) and space articles (including spacecraft, spacecraft launch vehicles, satellites, planetary probes, orbital stations and shuttles); also includes the manufacture of their parts and accessories used in civil and military applications, as well as in terrestrial space complexes, such as aircraft instruments, navigation and control systems, ignition parts and other electrical parts for internal combustion engines, space radio and telemetry systems and others [17].

The aerospace industry has a long history of using aluminium and aluminium alloys in many applications both civil and military. It is of prime importance to lower the weight of air- and spacecraft, as well as projectiles, to aid in decreasing emissions and increasing fuel efficiency. These changes will result in a lower operational cost as well. Aluminium is an ideal material for use in these applications.

In this article we do not present data on the structure of aluminium and its alloys, as these data are presented in virtually all textbooks, reference books and monographs on metals and materials. Pure aluminium is used little (for electrical conductors and for domestic products) or is not used, due to its insufficient strength and heat resistance. For serious structural/construction use it has to be strengthened by alloying. The chief characteristic of Al and Al-based alloys is their low density, which is why they are so valuable for aerospace and terrestrial industries.

As for the classification and designation systems of Al alloys, it should be noted that currently there is no universal one. Different classifications and designation systems are used in different countries, as well as in Bulgaria [1, 2, 11]. According to Bulgarian State Standard, Al alloys are conditionally denoted by chemical signs of the base metal and the components of the alloy and by the numerical values of the respective composition. But despite the different designation systems for Al alloys, it is not difficult for a specialist to understand what kind of alloy it is (there is enough literature on the subject). To improve the physical, mechanical and technological properties (to obtain Al alloys with different and desired properties), aluminium is alloyed with various elements (copper, magnesium, manganese, silicon, zinc, lithium). In addition to these six basic ones, about 20 other alloying additives are known. Today, the industry mainly uses about 55 grades of aluminium alloys.

The various types of aluminium may be divided into two general classes: (1) casting alloys (those suitable for casting in sand, permanent mould, or die castings) and (2) wrought alloys (those which may be shaped by rolling, drawing, or forging). From these two, the wrought alloys are the most widely used in aircraft and spacecraft construction, being used for stringers, bulkheads, skin, rivets, and extruded sections. The most recently developed of the Al-alloys are Al-Li alloys. Lithium is presented in several Al-alloys, but since it is not necessarily the main alloying element, forged Li-containing Al-alloys can be found in different groups of alloys: 1xxx, 2xxx and finally 8xxx, which are the alloys of this last group, with higher Li concentrations.

The first appearance of Al in aerospace was in 1901, when Wilhelm Kreiss used aluminium for the floats of his triplane, in which he failed to get into the air from a tank in Austria. But the first successful aviation appearance of Al was in the engine of the world’s first successfully powered aircraft (operated by the Wright brothers in 1903), whose cylinder block and crankcase were manufactured by Al [2–4].

The development of stronger Al alloys, suitable as structural metals, was accelerated in 1903 by the German metallurgist Alfred Wilm, who discovered age hardening, a phenomenon in which some aluminium alloys, although they remain weak immediately after heat treatment (quenching), slowly harden when left for several days at room temperature. Further work led to the creation of stronger Al alloys, and in 1909 he produced an alloy with properties almost as good as the low-carbon steel, Al-CuMgMn, which he called “duralumin” (from the name of the city Duren — the city where its industrial production was started in 1909). This was the beginning of what we now call the 2xxx series of Al alloys.

About 1920 a second kind of age-hardening alloy emerged, namely the Al-Mg-Si type. This alloy group (the present day 6xxx series) has a tensile strength in its strongest version of some 300 N/mm^2, and is thus generally weaker than the 2xxx series. But it has other characteristics that have since led it to become aluminium “low carbon steel”.

Then Al-Mg alloys emerged, our current 5xxx series. These are non-heat treatable roll-hardened alloys developed in the UK in the late 1920s and marketed under the name “Birmabright”. These alloys have very good corrosion resistance and were successfully used in shipbuilding in the 1930s.

In the 30s of the last century, both of the strongest types of alloys appeared, both of which are heat-treatable alloys and react to artificial aging, i.e. increased aging at elevated temperatures. The first, another alloy of the 2xxx series, was the development of Wilm's duralumin and was named "superdural". It has a tensile strength of over 450 N/mm^2 when fully heat treated and high yield strength. The second appeared in 1936, turned out to be even stronger. It was a new type of Al-Zn Mg alloy, the first in today's 7xxx series, with a tensile strength of over 500 N/mm^2 and still the strongest form of aluminium commonly used.

By 1939, all of today's major Al alloy series had arrived this way, except for one, namely the weldable 7xxx series alloy. This series was actively developing after the Second World War [4–6, 8–11].

The application that put aluminium on the map as a structural metal was its use in airplanes, first in airships and later in airplanes [4–6]. In 1919, the first duralumin aircraft appeared. A huge step forward for aluminium was its use for military aircraft during the Second World War. But the ubiquitous distribution and use of aluminium in the world, and not only in military aviation, began after the Second World War.

The main areas of application of aluminium and its alloys are aviation, space technology, electrical engineering, and construction. Aluminium alloys make up from 2/3 to 3/4 of the dry weight of the aircraft and from 1/10 to 1/2 of the dry weight of the missiles.

In recent decades there has been a considerable effort to develop Al alloys, possessing improved and/or new desirable properties for new aerospace applications. The structure of these alloys, and therefore their properties, can be modified by changing the concentration of the main components or adding new ones [18, 19], or by application of new/modified technologies [20]. For example, rapidly solidified nano-microcrystalline Al alloys are designed to replace titanium alloys for high temperature applications [20].

The Space Age began October 4, 1957 with the launch of *Sputnik-1* by the USSR. This satellite operated until January 3, 1958. It consisted of an aluminium sphere with a 58 centimetre diameter, two radio transmitters, four antenna and total weight of 83.6 kg.

Today, space systems are available in all sizes and shapes; they work in orbits near the Earth, in geosynchronous orbit and around other planets in our solar system. Some space systems explore the outer limits of the solar system itself. Some large systems, such as the International Space Station (ISS), are the product of multiple launches. And in all these systems, the most common material for aircraft construction is aluminium. Aluminium is rightly called a winged metal. Here is one of many examples: the structural skins of all the modules of the International Space Station are constructed from either AA7075 or AA2219. These have been delivered by US, European and Japanese companies (Source: European Space Agency) [6].

Examples of some Al alloy applications used in aerospace

In the literature there are sufficient data for Al alloy applications. The famous dural or duraluminium (it is most often denoted by2024 or sometimes by 2017, or by D16) is an alloy of Al, the main alloying metals of which are copper (4.4% of mass), magnesium (1.5%) and manganese (0.5%). Dural is durable, high-strength and lightweight, resistant to corrosion, deformation and environmental influences, aesthetic and easy to maintain, therefore it is one of the most demanded alloys in modern industry. Light alloy duraluminium is used in various fields such as: aviation, space, technology, electrical engineering, shipbuilding, construction, motor transport, at home. The first application of duraluminium is the manufacture of the skeleton of airships of rigid construction. The new alloy has become one of the main structural materials in the aircraft industry, space technology, nuclear engineering, defence industry, and, of course, for the production of high-speed trains. Despite competition from other materials, Al alloys still make up > 70% of structure of modern commercial airliner.

Design requirements for application of aluminium alloys in aerospace mainly include careful balance of material properties. Components must be lightweight, damage tolerant, durable (corrosion resistant) and cost effective. More specifically, the alloy property requirements vary depending on the application. Severe operating conditions in air and space often limit the possibility of using some of these Al alloys directly and for a long time. These are many harsh factors – gravity, vacuum, neutral particles, plasma, micrometeorites, space debris, radiation etc. in our space environment. Therefore, in order to reduce the impact of unfavourable environmental and space conditions, for successful use in the space industry and transport, aluminium alloys and their products require special surface treatment by coating. Nowadays there is a tremendous interest in extremely stable in space environment Al alloys and Al alloys coatings materials. The evidence is the space programs and enormous space budgets, which almost every country has. Therefore, in order to reduce the impact of severe space conditions and prevent from them, we must study and know how outer space conditions influence the properties of Al alloys together with their coatings.

Typical materials used for the fuselage and wings of civil aircraft are:

- 2000 series aluminium alloys based on the aluminium – copper system;
- 7000 series aluminium alloys based on the aluminium – zinc – copper – magnesium system;
- aluminium – lithium alloys.

The 2xxx series (Al-Cu alloys) are heat-treatable, and possess in individual alloys good combinations of high strength (especially at elevated temperatures), toughness, and in specific cases, weldability; they are not resistant to atmospheric corrosion, and so are usually painted or clad in such exposures. The higher strength 2xxx alloys are primarily used for aircraft (2024) and truck body (2014) applications; these are usually used in bolted or riveted construction. Specific members of the series (e.g. 2219 and 2048) are readily welded, and so are used for aerospace applications where that is the preferred joining method. Booster rockets of the Space Shuttle are 2xxx alloys, originally 2219 and 2419, now sometimes Al-Li "Weldalite" alloy 2195 [4].

Heat treatment plays an important role in aircraft and spacecraft industry. Different heat treatment manufacturing processes are employed in the production of Al alloys in order to change and improve certain properties. For example (see Table 1), you might use heat treatment to make alloy stronger, harder, more durable, or more ductile, depending on what the material needs in order to perform properly.

Table 1. Heat treatment designations for aluminium and aluminium alloys

Term	Description
T1	Cooled from an elevated temperature shaping process and naturally aged
T2	Cooled from an elevated temperature shaping process cold worked and naturally aged
T3	Solution heat-treated cold worked and naturally aged to a substantially
T4	Solution heat-treated and naturally aged to a substantially stable condition
T5	Cooled from an elevated temperature shaping process and then artificially aged
T6	Solution heat-treated and then artificially aged
T7	Solution heat-treated and overaged/stabilised

The 7xxx (Al-Zn alloys) alloys are heat treatable and among the Al-Zn-Mg-Cu versions provide the highest strengths of all Al alloys. There are several alloys in the series that are produced especially for their high toughness, notably 7150 and 7475, both with controlled impurity level to maximize the combination of strength and fracture toughness. The widest application of the 7xxx alloys is in the aircraft industry. The most common aluminium alloy used in aerospace is 7075, which has zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other aluminium alloys. The atmospheric corrosion resistance of the 7xxx alloys is not high, so in such service they are usually coated or, for sheet and plate, used in an alclad version. The use of special tempers, such as the T73-types, is required in place of T6-type tempers whenever stress corrosion cracking (SCC) may be a problem.

All Al alloys of the Al-Zn-Mg-Cu system (7xxx) exhibit the highest strength. Table 2 shows some mechanical properties of selected aluminium alloys.

The following alloys have the highest tensile strength values that aluminium alloys can have: 7075, 7079 and 7178. In many countries around the world, metallurgical plants produce these alloys due to their properties and high demand.

There are no satellites or spaceships that do not use at least one element made of some aluminium alloy. We will give an example with Ten-Koh (satellite from the Kyushu Institute of Technology in Japan — https://www.n2yo.com/satellite/?s = 43677), which is a 23.5 kg, low-cost satellite developed to conduct space environmental effects research in low-Earth orbit (LEO). The satellite carries a double Langmuir probe, CMOS-based particle detectors and a Liulin spectrometer (designed and developed in Bulgaria, at SRTI — BAS) as main payloads. The main structure of Ten-Koh is composed of a CFRP composite shell with a rigid internal load-bearing structure made of aluminium alloy (Al 6061-T6). The DLP (double Langmuir probe) system is composed of two spherical, 10 µm gold-plated electrodes, made of solid aluminium. Control electronics circuits of DLP are housed in the internal structure of the satellite shielded in a 3 mm-thick aluminium box.

Table 2. Mechanical properties of selected aluminium alloys

Alloy	Temper	Proof Stress 0.20% (MPa)	Tensile Strength (MPa)	Shear Strength (MPa)	Hardness Brinell HB	Hardness Vickers HV
AA2011	0	35	80	50	21	20
	T4	270	350	210	90	95
	T6	300	395	235	110	115
	T8	315	420	250	115	120
AA6082	0	60	130	85	35	35
	T5	275	325	195	90	95
	T6	310	340	210	95	100
AA7075	0	105	225	150	60	65
	T6	505	570	350	150	160
	T7	435	505	305	140	150
AA7075-R			645			
AA7075-S			167			

7075 or B95 aluminium alloy

Al alloy 7075 — Al-Zn-Mg-Cu-Cr alloy — has the widest and longest use of all alloys of the 7xxx series. It was introduced in Japan in 1943, was a big secret and was used to make Japanese military aircraft. Alloy 7075 was originally used for parts and components with a thin cross section, mainly in the form of sheets and extruded profiles. For these products, the quenching rate is usually very high and tensile stresses do not occur in the short transverse direction. Therefore, stress corrosion cracking is not is a problem for such materials with a high-strength T6 state.

Al alloy B95 alloy was developed independently in the former USSR in the middle of the last century for the production of the Tu-16 strategic bomber and other aviation equipment.

Foreign companies produce Al alloy 7075 or B95 under different names, but all are analogues:

- USA – AA7075 (AA = American Association);
- Germany – 3.4365;
- Japan – 7075;
- European Union – ENAW AlZnMgCu;
- former USSR and Russian Federation – B95.

Alloy types 7075/B95 includes:

- zinc — 5÷7 %;
- magnesium – 0.2÷0.6 %;
- copper – 1.4÷2 % and some others.

Usually, Al alloys 7075 and B95 are considered analogous and identical. The same applies to alloys 2024 and D16. They are very similar in composition and properties.

Aluminium alloys used in aircraft construction around the world have approximately the same composition and characteristics (Table 3). Thus, practically the same alloys were used for passenger and transport aircraft in the USA and Russia: in the USA — for the bottom of the wing and fuselage — alloys of the 2xxx series; for the top — alloys of the 7xxx series. In Russia, for the bottom of the wing — alloys D16, 1161, 1163, for the top, alloy B95pch (B95пч); for the fuselage — alloys D16, 1163, D19, 1420.

Table 3. Chemical composition (weight %) of some American and Russian Al alloys for aviation equipment

alloy grade	**Zn**	**Mg**	**Cu**	**Mn**	**Cr**	**Fe**	**Si**	**Ti**	**Ni**	**other impurities**
2024	-	1.5	4.4	0.6	-	0.5	0.5	-	-	-
D16	0.3	1.5	4.35	0.6	-	0.5	0.5	0.1	0.1	0.1
7075	5.6	2.5	1.6	-	0.23	0.4	0.4	-	-	-
B95	6.0	2.3	1.7	0.4	0.17	0.5	0.5	-	0.1	0.1

However, when alloy 7075 is used in products and parts of large size and thickness, it becomes clear that such products and parts, thermally hardened to T6 states, often do not meet the specified requirements. Products obtained by large machining from large forgings, extruded profiles or slabs were then subjected to prolonged tensile stresses in unfavourable orientation. Under such operating conditions, stress corrosion cracking (stress corrosion) occurred quite often.

The solution to this problem was the introduction of the T73 condition for thick and massive products from alloy 7075. The heat treatment that is used to obtain this condition requires a two-stage artificial aging. The second stage is performed at a higher temperature than that used to reach the T6 state. This additional heat treatment reduces the strength to a level below that which the 7075 alloy reaches in the T6 temper.

The T7 state is achieved by overaging, which means that the aging of the alloy continues after reaching the peak of its hardness and strength, in contrast to the T6 states. Numerous experiments and long-term operating experience have confirmed that alloy 7075-T73 has significantly higher stress corrosion resistance compared to alloy 7075-T6. Interestingly, the wheels of the famous Curiosity rover are made of 7075-T7351 alloy by machining from a one-piece forged ring. Hence new alloys with improved properties for use in the aerospace industry were obtained from the Al 7075 alloy by changing the composition and/or applying a special heat treatment (tempering).

B95 (Al 7075 alloy) alloy is used for the manufacture of power components for civil aviation and military equipment, in particular, frames, spars and other parts and assemblies operating under constant compression pressure. The keels of some large aircraft are made of this alloy. B95 is used to produce various blanks and semi-finished products — profiles, bars, etc. B95 is used for the production of rivets and related wires of various sizes.

Fuselage/pressure cabin stringers and frames, upper wing stringers, Airbus A380 floor, beams and seat rails, Upper wing covers, Frames, brackets, stringers, Upper and lower wings skins, bulkheads, door rails — are some of the main applications of Al 7075 alloy. Main features of Al 7075 alloy are: the highest strength; the highest tensile strengths that aluminium alloys can have; a fairly high corrosion resistance, controlled by proper heat treatment and the addition of some alloying materials. Main products and status of Al 7075 alloy are: T6 T73 T76 sheet plate, T651 T7651 T7351 thick plate, T6 T73 T7352 casting and T6511 T3511 extrusion [8]. Many new and superior alloys from the 7xxx series are based on the 7075 (B95) grade [2–6, 8–11]. For example, "Boeing" manufactures the upper wing of the "B777" airplane from 7075-T77 alloy plates, which is an exact copy of the B96-C3 alloy.

In Table 4 are listed several conventional wrought Al 7075 alloys used for commercial aircraft parts.

Conventional (non-lithium-containing) aerospace alloys always require some form of corrosion protection. This can be cladding with (nearly) pure aluminium and anodizing for sheet alloys; anodizing or ion vapour deposition for other types of products; and primer and paint systems [3].

The surface condition has a significant effect on the durability of high strength aluminium alloys. Severe operating conditions in air and space often limit the possibility of using some of these Al alloys directly and for a long time. Therefore, in order to reduce the impact of unfavourable environmental and space conditions, for successful use in the space industry and transport, aluminium alloys and their products require special surface treatment by coating. Nowadays there is a tremendous interest in extremely stable in space environment Al alloys coatings materials [2, 7].

Table 4. Al 7075 alloys used for commercial aircraft parts

Alloy	**Temper**	**Application**
7075	T6	Fuselage skin Empennage (tail), Wing lower panels, Wing lower stringers, Wing upper skin, Wing upper stringers
7075	T6 and T73	Fuselage stringers
7075	T6, T73 and T76	Aircraft structures

More than a decade composites have started to be used more widely in large commercial jet airliners for the fuselage, wing as well as other structural components in place of aluminium alloys due their high specific properties, reduced weight, fatigue performance and corrosion resistance. Composite materials based on aluminium, reinforced with fibres of boron, charcoal, SiC, etc. are promising for use in aircraft construction.

In the composite materials (CM) Al alloys + SiC, Al alloys from the systems Al-Cu-Mg, Al-Mg-Si, Al-Cu and others are used as a matrix material. As reinforcing filler, both whiskers and SiC powders with a dispersion of 1 to 20 microns are used. The volume fraction of the reinforcing filler can vary from 5 to 40%. The technology provides a high degree of uniformity of SiC distribution in the matrix material.

A promising material for the cladding of aircraft is a laminated CM, consisting of alternating thin aluminium sheets and interlayers of adhesive prepreg with glass fibres — SIAL (S — glass, A — aluminium) — an analogue of GLARE. SIAL is distinguished by high specific strength and rigidity, satisfactory corrosion resistance, good workability, high resistance to fatigue crack growth [2].

In our Space Materials Science department at SRTI-BAS was synthesized a new type of composite based on aluminium Al-based alloy, namely aluminium alloy 7075 (B95) strengthened with nanoparticles of nanodiamond powder and tungsten (W). Table 5 shows the composition of the thus obtained Al alloy. Several samples of the so modified, with nanodiamonds and W, aluminium alloy 7075 (AA7075+W+ND), were a part of the DP-PM module of the international space experiment "Obstanovka" (carried out in the Russian sector of the International Space Station). The aim of this international space experiment was to study the influence of the space environment on the properties of the new composite (AA7075 + W + ND), after a stay of 28 months in outer space. After this exposure to space, the samples were returned to Earth (space samples AA7075-S) for research and compared with samples of the same material stored in terrestrial conditions (AA7075-R) for the same period. Today, a comparative analysis of the properties of the samples (one of the samples was stored in terrestrial conditions (reference sample) and the other sample was installed on the outside of the International Space Station for the same period (space sample)) has already been done [12–14]. The results obtained will be repeated to see if the data has changed over time.

Table 5. Chemical composition of AA 7075 (in wt. %)

Al	**Cu**	**Mg**	**Zn**	**Fe**	**Si**	**Mn**	**Cr**	**Ti**	**UDDP + W**
86.2 ÷ 91.5	1.4 ÷ 2.0	1.8 ÷ 2.8	5.0 ÷ 7.0	0.0 ÷ 0.5	0.0 ÷ 0.5	0.2 ÷ 0.6	0.10 ÷ 0.25	0.00 ÷ 0.05	0.1

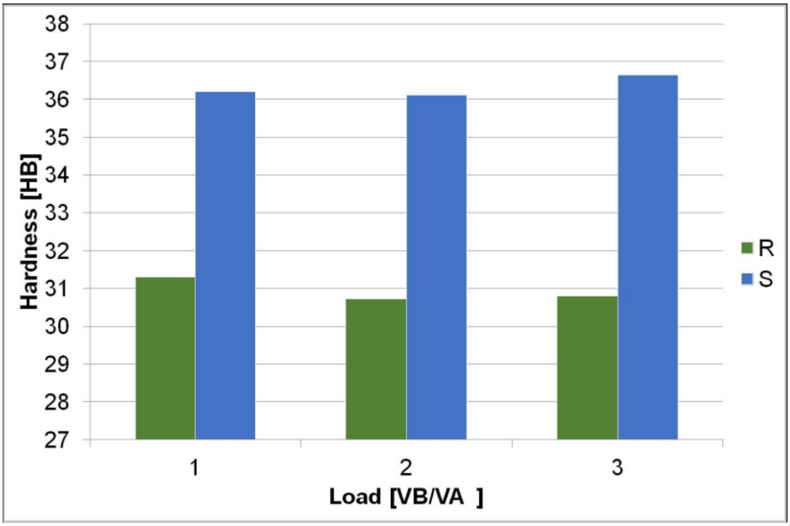

Fig. 2. Leeb hardness measurement results for three "reference" (R) and three "space" samples (S)

Fig. 2 shows the average hardness values of three of the two types of samples. Seven measurements were made for each sample. Hardness was measured with a universal digital hardness tester according to Leeb/Al-150A. This is necessary because the studied "space" samples are very small.

The obtained average hardness value for the reference samples is: R1-31.3; R2-30.72 HB and R3-30.8 HB. The same for space samples is: S1-36.2HB; S2-36.11 HB and S3-36.64 HB (Fig. 2). The hardness of space samples is greater than that of reference samples. Based on the results obtained, it can be concluded that the introduced radiation defects and temperature cycles within ~300 °C, leading to the refinement of the material structure on the surface and periphery, are the reason for the higher hardness of the space sample S-36.31 HB compared to the reference R-30.94 HB (see also Table 2).

In our Space Materials Science department at SRTI-BAS we also work on the production of new FGM (functionally graded materials) based on aluminium with high hardness, high density and high thermal stability for different applications. Such materials will be of significant interest for their application in space technology and in particular for aerospace instruments [15, 16].

Future of aluminium in aerospace industry and conclusions

The rapid development of the aviation industry contributes to the progress of new materials. Aluminium alloys and aluminium-based composites are very important structural engineering materials widely employed in the aerospace industry. The production and widespread use of Al alloys continues to increase, largely due to the excellent combination of their properties.

7xxx series aluminium alloys (Al 7xxx alloys) are widely used in bearing components, such as aircraft frame, spars and stringers, for their high specific strength, high specific stiffness, high toughness, excellent processing, and welding performance. Therefore, Al 7xxx alloys are the most important structural materials in aviation and aerospace.

Due to the broad and rapidly developing field of Al 7xxx alloys, all their properties and aerospace applications cannot be encompassed in this paper. Nevertheless, here are some of the observations of the authors based on the published research and their own analysis of the subject.

The next generation of Al 7xxx alloys should be higher strength, higher toughness, higher damage tolerance, higher hardenability, and better corrosion resistance. It is urgent requirements to develop or invent new heat treatment regime.

In order for aluminium alloys to remain attractive in the airframe construction and compete with and/or be compatible with currently used polymer composites and titanium alloys, research activities on the improvement of structural performance, weight and cost reductions are needed.

There have been important recent advances in aluminium aircraft alloys that can effectively compete with modern composite materials. It is believed that developments of advanced hybrid materials, like fibre metal laminates could provide additional opportunities for aluminium alloys and new material options for the airframe industry.

As the main part of high strength aluminium alloy, Al 7xxx alloys have been successfully used as the main materials of aircraft structural components. With the application of titanium alloys and composite materials in the fuselage design, the proportion of aluminium alloy has been reduced. In order for aluminium alloys to remain attractive in the airframe construction, research should be necessarily carried out in terms of structural properties, weight reduction, and cost reduction. Therefore, current studies for Al 7xxx alloys contain improvements on mechanical properties; reduction of manufacturing, maintenance, and repair costs; prevention of corrosion and fatigue; and ability to perform reliably throughout its service life.

In recent years, Al 7xxx alloys have successfully improved static strength, fracture toughness, fatigue and corrosion resistance through composition design and control of chemical composition, as well as via the exploitation of more efficient heat treatment methods. It can be seen from this review that the main improvement of Al 7xxx alloys is to optimize the solute content and solute ratio to achieve better balance for the performances. Therefore, for the design of the alloy, the content of Zn will be increased to more than 10%, while the content of Mg and Cu will be reduced. Also, the content of impurity elements such as Fe and Si will be even lower. On the other hand, the addition of trace transition elements like Zr and Er will be more reasonable.

The attractiveness of aluminium is that it is a relatively low cost, lightweight metal that can be heat treated to fairly high-strength levels; and it is one of the most easily fabricated of the high-performance materials, which usually correlates directly with lower costs. Disadvantages of aluminium alloys include a low modulus of elasticity, rather low elevated-temperature capability (≤ 130 °C), and in high-strength alloys the susceptibility to corrosion [1].

Improvements in aluminium manufacturing technology include high-speed machining and friction stir welding (FSR):

- Although higher metal removal rates are an immediate benefit of high-speed machining, an additional cost saving is the ability to machine extremely thin walls and webs. This allows the design of weight competitive high-speed machined assemblies, in which sheet metal parts that were formally assembled with mechanical fasteners can now be machined from a single or several blocks of aluminium plate.
- FSR is a solid state joining process that has the ability to weld the 2xxx and 7xxx alloys, which are not suited to conventional fusion welding. FSR also allows the design of weight competitive assemblies with a minimum number of mechanical fasteners.

There are still more to be done in terms of research to improve the performance of manufacturing processes of Al 7xxx alloys in order to make them more cost effective. Emphasis should be placed on modelling for the design of new Al alloys and coatings that have specific and desirable properties.

There is no doubt that high-strength aluminium alloys are, and will remain, important and indispensable airframe materials in the aerospace industry.

References

1. Luts, A. R., A. A. Suslina. *Aluminium and Its Alloys*. Samara, Samara state tech. un, 2013, p. 81 (in Russian).
2. Beletskiy, V. M., G. A. Krivov. *Aluminium alloys (composition, properties, technology, application): reference book*. Kiev: Komintech, 2005, p. 365 (in Russian).
3. Rambabu, P., N. Eswara Prasad, V. Kutumbarao, R. Wanhill, J. H. Chapter 2. Aluminium Alloys for Aerospace Applications. Springer Science+Business Media Singapore, N. Eswara Prasad and R. J. H. Wanhill (eds.), Aerospace Materials and Material Technologies, Indian Institute of Metals Series, 2017, p. 595, DOI: 10.1007/978-981-10-2134-3_2.
4. Dwight, J. *Aluminium design and construction*. CRC Press, 1999, p. 301, ISBN 0-419-15710-7 (Print Edition).
5. Weisshaar, T. A. *Aerospace Structures-an Introduction to Fundamental Problems*. Purdue University, USA, 2011, 197 p.
6. Dong, H. (Ed.). *Surface engineering of light alloys: Aluminium, magnesium and titanium alloys*. Cambridge, Woodhead Publishing Limited, 2010, 680 p.
7. Karaguiozova, Z., A. Miteva, A. Ciski, G. Cieślak. Some aerospace applications of aluminium alloys. *Proceedings SES 2017*, 2017, 327–332, ISSN: 1313-3888.
8. Zhou, B., B. Liu, S. Zhang. The Advancement of 7XXX Series Aluminium Alloys for Aircraft Structures: A Review. *Metals*, 2021, 11(5), 718. DOI: https://doi.org/10.3390/met11050718.
9. Gialanella, S., A. Malandruccolo. *Aerospace alloys*. Springer, 2020, 583 p.
10. Davis, J. R. (Ed.). Metals Handbook Desk Edition. Ohio, CRC Press, 1998, 2571 p.
11. Zhang, X., Y. Chen, J. Hu. Recent advances in the development of aerospace materials. *Progress in Aerospace Sciences*, 2018, 97, 22–34. DOI: https://doi.org/10.1016/j.paerosci.2018.01.001.
12. Bouzekova-Penkova, A. Investigations of the mechanical properties of a dispersion-reinforced aluminum alloy intended for outer space. *Proceedings SES 2013*, Sofia, Bulgaria, 2013, 492–496.
13. Bouzekova-Penkova, A., K. Grigorov, M. Datcheva, C. A. Cunha. Influence of the outer space on Nanohardness properties of Al- based alloy. *C. R. Acad. Bulg. Sci.*, 2016, 69 (10), 1351–1354.
14. Bouzekova-Penkova, A., M. Datcheva, R. Iankov. Mechanical properties of the enhanced with nanodiamond and tungsten strengthened aluminium alloy being exposed in the Outer space. *International Journal "NDT Days"*, 2019, II (4), pp. 396–401.
15. Bouzekova-Penkova, A., A. Miteva. Aluminium-Based Functionally Graded Materials. In Bulgarian Academy of Sciences, 2014, 10.

16. Miteva, A., A. Bouzekova-Penkova. Some aerospace applications of functionally graded materials. ibid. *Aerospace Research in Bulgaria*, 2021, 33, 79–86. DOI: https://doi.org/10.3897/arb.v33.e14.
17. Mardirossian, G. *Fundamentals of remote aerospace technology*, Chapters 3 and 4. NBU, Sofia, 2015. ISBN: 978-954-535-882-1 (In Bulgarian)
18. Vencl, A., I. Bobić, M. Stanković, *et al.* Influence of secondary phases in A356 MMCs on their mechanical properties at macro- and nanoscale. *J Braz. Soc. Mech. Sci. Eng.*, 2020, 42, 115. DOI: https://doi.org/10.1007/s40430-020-2197-6.
19. Dyakova, V., Y. Kostova. Influence of TiN and TiCN nanosized modifying compositions on the corrosion behaviour of AlSi7Mg alloy. *Engineering Sciences*, 2019, 3, 72–80, DOI: 10.7546/EngSci.LVI.19.03.07.
20. Lavernia, E. J., T. S. Srivatsan. The rapid solidification processing of materials: science, principles, technology, advances, and applications. *J. Mater. Sci.*, 2010, 45(2), pp. 287–325. DOI: https://doi.org/10.1007/s10853-009-3995-5.

НЯКОИ АЕРОКОСМИЧЕСКИ ПРИЛОЖЕНИЯ НА 7075 (В95) АЛУМИНИЕВА СПЛАВ

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Резюме

В днешно време алуминиевите сплави представляват все по-голям интерес за учените и намират широко приложение в аерокосмическата и свързаните с нея индустрии поради присъщата си лекота, високо съотношение на якост към тегло, отличната топлинна и електрическа проводимост, добра отразяваща способност и ниски експлоатационни разходи. Сред конвенционалните конструктивни материали, използвани за аерокосмически приложения, лидират алуминиевите сплави. Това се дължи на способността на съвременните алуминиеви сплави да постигат уникална комбинация от свойства, чрез легиране и термична обработка, адаптирани към конкретни приложения. Алуминиевата сплав 7075 (В95) е високояка сплав, която работи в екстремни условия и се използва в съвременните конструкции на самолети, космически кораби и сателити.

В този кратък обзор се съсредоточаваме накратко върху някои от съществуващите и перспективни приложения на някои алуминиеви сплави 7xxx, по-специално 7075 (В95) в аерокосмическата промишленост. Разгледани са възможни варианти за продължаване на работата в тази област и са представени някои български разработки.