STRUCTURAL ALUMINIUM AND SUSTAINABILITY

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1. SUMMARY

Civil engineers have recently adopted criteria of sustainability regarding the choice of structural materials and the application of building activities complementing functionality and structural stability, as the role of environmental parameters regarding the design and construction of the structures is becoming more and more significant. In the present paper the most important features of structural aluminium regarding sustainability are briefly presented. In particular, certain characteristics of aluminium structural elements such as durability and recyclability and their role into the life cycle analysis (LCA) are analysed, whereas the relation between energy efficiency of buildings and aluminium applications is discussed. Special emphasis has been given on aluminium-based building applications such as curtain-walls, window frames and facade sheets which are presented with regard to environmental and economic aspects, whereas specific innovative construction techniques where aluminium elements collaborate with other systems in order to produce renewable energy, e.g. solar panels and photovoltaics are being introduced.

2. INTRODUCTION

The ‘*green building perception*’ has recently started to become a nowadays trend, whereas the necessity to adopt an approach in assessing the impact of building

activities on the environment, economy and society is recognized by all the contributors to the construction process. The concept of '*sustainable construction*' has been developed, which involves minimization of the building costs, materials and waste, minimization of the energy use and improvement of the energy efficiency of the structure. Furthermore, it includes also the choice of recyclable construction materials and products since saving energy is a major objective and the removal or not of materials at the end of their life cycle is dependent on such a choice. Generally, sustainable building is the building where the principles of sustainable development in the construction industry are implemented, namely the optimization of structures at ecological, economic and socio-cultural levels simultaneously [1].
The scope of the present research effort is to focus on environmental perception and to investigate the relationship between sustainability and aluminum alloys material. Aluminum alloys are new construction materials comparable to steel or concrete and can contribute to the sustainability of structures. Their physical and mechanical properties can provide buildings a green performance in terms of ecology and economy besides functionality and structural stability. This paper aims at presenting all special aluminium features that contribute to sustainability and some of the most commonly used aluminium systems in building activities.

2. STRUCTURAL ALUMINIUM ALLOYS AND PROPERTIES

Aluminum alloys are classified in various categories regarding their chemical composition and their further process they are subjected to, whereas every alloy is characterized by unique properties and exhibits different structural behavior. There are wrought alloys, which are worked to shape and cast alloys, which are poured in a molten state into a mold that determines their shape [2]. While strength and other properties for both products are dependent on their ingredients or the selective addition of alloying elements, further variations on these properties can be achieved by tempering, a process that refers to the alteration of the mechanical properties of a metal by means of either mechanical or thermal treatment. Temper can be produced in wrought products by the strain hardening that results from cold working. Thermal treatments may be used to obtain temper in cast products, as well as in those wrought products identified as heat-treatable. Conversely, the wrought alloys that can only be strengthened by cold work are designated non-heat-treatable. Regarding wrought aluminum alloys, the basic types that are used in industry and construction are summarized in *Table 1*.

Series number	Primary alloying element
1xxx	None- Pure Aluminum
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc and Magnesium

Table 1: Series of aluminum wrought alloys

Aluminum alloys represent a wide family of constructional materials, whose mechanical properties make them very popular in civil engineering works and cover an extended range of application fields. In spite of their higher initial cost compared with structural mild steel, such materials are finding increased application in the structural field due to their peculiar features, which generally offer several benefits when the whole lifetime of the project is considered, as they exhibit high mechanical behavior and good ductility as steel [3]. In addition, their physical properties, such as the light weight give advantages as erection phases can be simplified, as the loads transmitted to foundations can be reduced and as the physical labor can be reduced. Another characteristic of aluminum alloys is their corrosion resistance, which results in reducing the maintenance costs and adopting a good performance in highly corrosive environments [4]. It is noteworthy that the functionality of aluminum alloys regarding geometrical shapes can make them really competitive as the geometrical properties can be improved through the design of sections, as stiffened shapes can be obtained without using built up systems and as simplifying connecting systems among different structural members, thus improving joint details [5].

3. ALUMINIUM AND ITS SUSTAINABLE CHARACTERISTICS

Aluminium can justifiably be described as the "green metal", namely it is non-toxic and recyclable, easily formed yet strong, durable yet modern. From the sustainability point of view, aluminium alloy structures provide great credibility when a long term approach is being adopted. Despite the initial high cost and the great amounts of energy consumption during production, the special features of alloyed aluminium enable sustainable performance when the consideration refers to the whole service lifetime of the structure [7].

To begin with, building aluminium material has a very long life cycle, ranging from 30 to 50 years and due to durability, the maintenance costs are very low over the lifetime of the structure. In addition, the majority of alloys used in construction are weather-proof and corrosion resistant, thus a long serviceable lifetime is assured. Another important characteristic of the material is its high reflectivity, which can be exploited in several building techniques and systems. An example of this is when aluminium solar collectors are installed to lower energy consumption regarding heating in winter and artificial lighting, while there is the case of aluminium shading devices reducing the need for air-conditioning in the summer. Furthermore, aluminium alloys exhibit excellent recyclability. Used aluminium products and scrap can be recycled and at the same time the environmental impact related to recycle processes is reduced. As almost all aluminium material used in construction can be recycled, the considerable energy invested in the production of primary aluminium can be reinvested into other aluminium products. Scrap may not necessarily be recycled back into its original product or even reused in the country in which it was first manufactured, but the original energy investment will not be lost.

Concerning structural applications and aluminium alloys, their strength, weight and versatility make them ideal building and cladding materials. Since they are corrosion resistant, they are mostly used in maintenance-free applications such as siding, windows, skylights, doors, screens, gutters, down spouts, hardware, canopies and shingles, etc. Regarding aluminium siding, systems are also available with insulation and reflective foil backing, so walls can be made weatherproof and energy-efficient.

A layer of insulated aluminium siding is four times more effective than uninsulated wood siding, four inches of brick or ten inches of stone masonry.
In addition, the relatively low melting point of aluminium alloys (660°C) means they will "vent" early during a severe fire, releasing heat and thereby saving lives and property. Regarding recycling, aluminium not only has important economic implications but also contributes to environmental production, whereas depositing or incineration does not have harmful side-effects even if inadvertently dispersed in the environment.

4. ALUMINIUM BASED APPLICATIONS

Aluminum applications can be both structural and non structural. Regarding structural applications, aluminum alloys are usually used in large span roof systems, where live loads are small compared to dead loads. In addition they are used in structures located in inaccessible places far from the fabrication shop, thus they can provide transport economy and ease of erection. In structures like swimming pool roofs, marines, river bridges, which are characterized be humid environments, the aluminum alloys is preferable [8].

In the building sector popularity of aluminum alloys in load carrying structures as well as in secondary or decorative elements has increased significantly over the past 50 years. Currently, a total of 26% of all aluminum products is used in building applications, whereas with 51% they represent the biggest customer of the extrusion market and cover 11% of the rolled products market. All kinds of aluminum products are used both in new home construction and in rehabilitation and renovation of existing structures. The range of building applications of aluminum is extensive: it is commonly used in the building envelope for facades, glazed and roofing systems, curtain walling, window frames and doors. It is also applied for railings, balconies, staircases, heating/ air conditioning and solar elements, see *Fig. 1* [9].

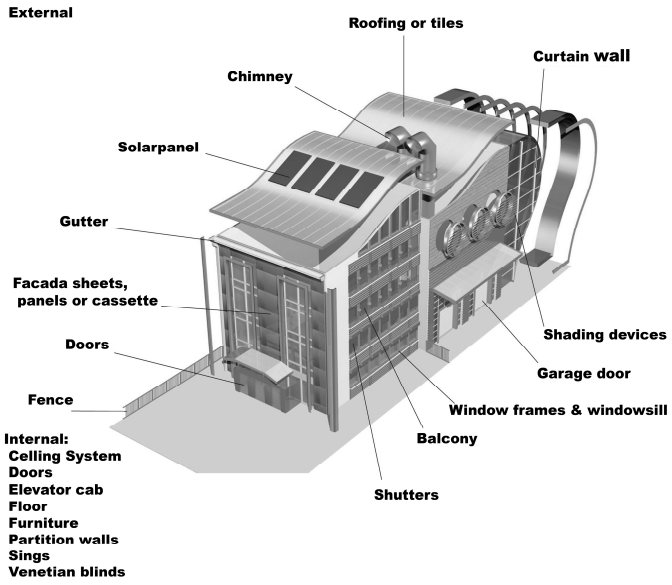

Fig. 1. Aluminum in building applications

Regarding aluminum alloys series and their use in building applications, non heat treatable alloys of 3xxx series as AW 3103, which are characterized by rising strength and big corrosion resistance are mostly used in cladding systems, in facade engineering. Furthermore, alloys of series 5xxx are very corrosion resistant, are suitable for welding, and some of them like AW 5083, AW 5454 are used in special works, i.e. chemical plants and road tankers. The most commonly used series in construction is that of 6xxx series, where alloys like AW 6063, AW 6061, AW 6082 are used in architectural extrusion window frames and roof trusses.

The use of aluminum cladding on building facades is a promising construction alternative for building or the renovation of non-insulated buildings [10]. Aluminum cladding is placed at a proper distance from the external wall, ranging from 5−10 cm for alignment purposes. The air gap that is created between the building's wall surface and the aluminum cladding, acts as a thermal buffer zone. In particular, curtain walling or roofing can use aluminum with glazing or other transparent and semitransparent materials, creating uninterrupted large surfaces and atriums, see *Fig. 2*. Large curtain walling is usually recommended in climates with heating loads.

Fig. 2. Aluminum based curtain-wall applications

There are also facade and roof systems where aluminum is used in window and glazing frames and glazing spacers.
The function of these systems is to provide daylight, visual contact between the exterior and the interior, provide protection against the weather (rain and wind), provide passive solar heating gains, help keep interior thermal comfort and keep the energy use for operation at its minimum.

Regarding shading systems, there are window blinds, screens, overhangs, sidefins and others. Aluminum is used in lamellas, screens and fins. The function of these systems is to prevent glare and overheating and thereby minimize the energy use for space cooling. There are also aluminium systems that enhance the daylight penetration and distribution into the room, e.g. light shelves, light-reflecting lamellas, etc. Better daylight availability and distribution in the space makes it possible to save electricity for artificial lighting, by turning the lights off when there is sufficient daylight. This may also, in turn, reduce the needs for cooling. Aluminum may be used as light directing devices.

Aluminum is used also in window frames where it provides flexible and popular window geometry and operation. Since aluminum is a good heat conductor, it is

necessary to use proper thermal breaks for enhanced thermal performance. Regarding insulation, it offers high levels of heat and noise insulation and the flexible design of systems used in doors and windows enables you to choose from among traditional or modern structures. Aluminum is a material that does not wear out in time, thus ensuring the long life of the respective frames. It is also appropriate for areas with high temperatures and intense sunlight. The maintenance and care of frames is quite easy, and they can be cleaned periodically. Aluminum is of natural origin, and there is plenty of it in nature. As it is environmental friendly and 100% recyclable, it does not have a negative effect on human health and the environment.

In places like Mediterranean where the ample sunlight and wind potential offer plenty of solar and wind power the exploitation of renewable energy sources is the main objective. The maximum energy from sunlight is produced at peak consumption times and solar energy is converted to a usable form of energy (electricity) through the photovoltaic effect. Photovoltaic systems in developing countries and isolated areas (e.g. the Greek islands) can offer energy solutions and improve the standard of living. These thermal systems are most commonly used as auxiliary energy systems to provide energy for domestic hot water heating and/or space heating in order to reduce the use of conventional energy. They can also produce electricity that can be used directly for running lights and equipment in the building or fed into the electric utility grid. In this case, aluminum is used for absorbers, frames and casings for thermal collectors and for frames and support structures for photovoltaic modules, see *Fig. 3.*

Fig. 3: Photovoltaic systems – Heliodomi

5. CONCLUSIONS

Aluminium alloys can make a valuable contribution towards achieving these environmentally friendly goals, when used appropriately. Increasing demand for adequate and sustainable performance with high quality materials in structures offers an opportunity for aluminium alloys since they possess properties such as formability, functionality, flexibility, light weight, excellent recyclability and corrosion resistance. Despite the fact that aluminium alloys are characterized by high energy consumption during their production and initial costs, they perform in a sustainable way with the consideration of the building in the full service lifetime.

Nowadays, new building systems and innovative design concepts regarding aluminium alloys cooperating with building elements are adopted in order to provide more sustainable solutions and to meet future ecological demands. In particular intelligent facades incorporating aluminium systems that can decrease energy consumption in buildings up to 50% have just started to appear in European construction era. They are characterized by constructive interaction with the exterior, markedly reducing heating, cooling, ventilation and lighting energy demands. New technologies mean solar power captors can be inserted in aluminium frames, thus saving considerable amounts of energy and protecting the environment. Numerous techniques are being adopted and processes including photovoltaics, optimised ventilation mechanisms and appropriate light and shade management are applicated in order to ensure long term sustainability and at the same time static stability and fitness. By means of these innovative systems, where aluminium is the basic structural element the environmental performance of constructions can be improved, ~~and~~ thus providing more sustainable solutions.

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ΠΕΡΙΛΗΨΗ

Το αλουμίνιο και τα κράματά του αντιπροσωπεύουν νέα σχετικά δομικά υλικά σε εφαρμογές Πολιτικού Μηχανικού και χαρακτηρίζονται από ιδιότητες που επιδεικνύουν έναν φιλικό προς το περιβάλλον χαρακτήρα. Στο παρόν άρθρο παρουσιάζονται τα πιο σημαντικά χαρακτηριστικά του δομικού αλουμινίου αναφορικά με τη βιωσιμότητα. Συγκεκριμένα, αναλύονται χαρακτηριστικά των δομικών στοιχείων αλουμινίου όπως ανθεκτικότητα, ανακυκλωσιμότητα ενώ περιγράφεται η σχέση μεταξύ της αποδοτικότητας ενέργεια των κτιρίων και των εφαρμογών αλουμινίου. Ο σκοπός της παρούσας ερευνητικής εργασίας είναι να αναδείξει τη βιώσιμη λειτουργία του δομικού αλουμινίου και των κραμάτων του και να προσεγγίσει την επίδρασή των εφαρμογών αλουμινίου στη βιωσιμότητα των κατασκευών.
Στο άρθρο αυτό, παρουσιάζονται κτιριακές εφαρμογές αλουμινίου όπως υαλοπετάσματα, κουφώματα και φύλλα προσόψεων όσον αφορά τις βασικές αρχές βιωσιμότητας, ενώ περιγράφονται τεχνικές και συστήματα όπου τα στοιχεία αλουμινίου συνεργάζονται με άλλα συστήματα και τεχνολογίες προκειμένου να παραχθεί ενέργεια. Επιπρόσθετα, γίνεται αναφορά σε μηχανισμούς βελτιστοποίησης αερισμού και σε συστήματα φωτισμού και ρυθμιζόμενης σκίασης που βασίζονται σε στοιχεία αλουμινίου ή που προσαρτώνται σε μέλη αλουμινίου με σκοπό να συνεισφέρουν στην αποτελεσματικότερη διαχείριση των φυσικών πόρων.