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Applications of aluminium and concrete composite structures

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Abstract

The paper presents exemplary applications of aluminium and concrete composite structures. It discusses arguments for using these structures and reasons why in some cases it is advisable to replace a steel beam with an aluminium beam. Additionally, the article aims at analysing aluminium and concrete structures as a part of sustainable development. To this end, an analysis of materials used in aluminium and concrete composite structures was conducted. Moreover, the article presents a new method of joining an aluminium beam and a concrete slab, which may have a practical application.

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Keywords: aluminium and concrete composite structures

1. Introduction

Aluminium and concrete structures are a kind of composite structures. They are less known than steel and concrete composite structures. Aluminium and concrete composite structures are not a new invention, since Mromliński [1] worked on this issue as early as the previous century. He described a composite girder consisting of an aluminium beam and a reinforced concrete slab. Mazzolani and Mandara [2] presented a practical procedure for designing aluminium and concrete composite sections in bending. Aluminium and concrete structures were not commonly used because of the lack of a connector which could effectively join an aluminium beam and a concrete slab. This problem was solved by a special connector, which Szumigała and Polus [3] intend to patent. The

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lengthiness of construction was yet another problem. However, Polus and Szumigała [4] suggest using profiled steel sheeting as the shuttering of a concrete slab, which facilitates construction. Moreover, the authors analysed the resistance and stiffness of a 5.2-meter aluminium and concrete composite beam. The aluminium and concrete beam consists of a concrete slab, steel sheeting, connectors and an aluminium beam (see Fig. 1).

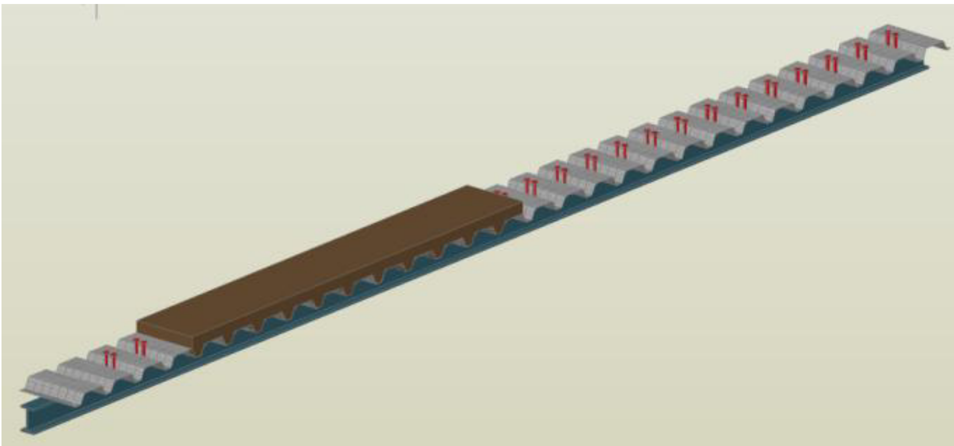

Fig. 1. An aluminium and concrete beam.

Yet another reason for the low popularity of these structures is the price of aluminium alloys, which are 5 to 6 times more expensive than steel. On the other hand, Gwóźdź [5] considered aluminium to be fully recyclable. He compared the lightness of basic construction materials, such as steel, concrete, wood and aluminium. Aluminium alloys proved to be the lightest. Mazzolani [6] pointed out that aluminium had a favourable life-cycle cost and its price gradually decreased over the years compared to the price of steel. The author compared the main properties of aluminium and steel. The specific weight of aluminium is three times lower than that of steel and aluminium alloys have a wider range of strength than steel. Pure aluminium is a very ductile material, with a ductility of 40%. However, aluminium alloys have lower ductility than steel and Young's modulus of aluminium is three times lower than that of steel. For this reason, problems related to deformation may occur. Moreover, in conditions of compression, instability phenomena are more likely to occur in aluminium than in steel, because of the small value of Young's modulus. However, in composite structures, an aluminium beam may be tensioned, while Young's modulus of aluminium is more similar to Young's modulus of concrete than Young's modulus of steel to Young's modulus of concrete. For this reason, the cooperation between aluminium and concrete may be better than cooperation between steel and concrete. Aluminium alloy structural elements may be manufactured by rolling, extrusion, casting and drawing, which makes it possible to obtain any shape. Corrosion resistance is one of the most important properties of aluminium. For this reason, aluminium may be used in structures located in corrosive or humid environments. Jasiczak and Hajkowski [7] recognized aluminium as the most corrosion-resistant material in a pH ranging from 4 to 9.

2. Aluminium and concrete structures as a part of sustainable development

When looking for new solutions, designers should focus on their resistance and on reducing the consumption of natural resources. Błaszczyński et al. [8] and Bromberek [9] believe that these requirements are connected with a new trend in designing – sustainable construction, which is a part of sustainable development. Durability of buildings is a prerequisite for sustainable construction. Brandt [10] points out that a building which is used for 50 years is more economical than a building which needs repairs. The durability of a construction determines the time of its operation. According to Brandt, the life cycle design is very important. Today, the fundamental requirement is to use materials, the durability of which is compatible with the life cycle of the building. Aluminium and concrete composite structures may be an alternative to steel and concrete composite structures. Aluminium alloys are fully recyclable and corrosion-resistant thanks to aluminium oxide. To improve the durability of steel sheeting and connectors they both should be zinc-plated. This prevents corrosion of aluminium in points of contact between aluminium and steel. To improve the durability of reinforced concrete according to EN 1992-1-1 [11], designers should use a concrete cover suited for environmental conditions. Zybura [12] suggested that the durability of a reinforced concrete slab may be increased by inhibiting admixtures, zinc- and epoxy-protection-coating or electrochemical techniques such as cathode protection, chloride extraction or carbonated concrete realkalisation.

Szczechowiak [13] claims yet another requirement of sustainable development is to minimize the use of energy. Unfortunately, Broniewicz [14] points out that aluminium has a much higher embodied energy than steel. Embodied energy is the energy used in all the processes used to obtain a given material. However, the author remarks that aluminium may be reused or recycled and embodied energy savings may be as high as 95%.

Yet another requirement of sustainable development is to limit environmental pollution. The process of electrolysis used to obtain aluminium generates fluorine. Fluorine has both a good and bad impact on human body. It participates in the mineralization of bones, however, too high concentrations of fluorine in water cause fluorosis, which decays teeth and bones, and leads to mental disorders. Rajpolt and Tomaszewska [15] analysed fluorine emissions from an aluminium smelter in Skawina. As a result of high gas and dust emissions and the storage of waste in sand pits, the smelter in Skawina was shut down in 1981. Moreover, the authors described emissions from a smelter in Konin which was more modern than the smelter in Skawina. Włodarczyk [16] pointed out that in 1980 the fluorine emissions factor was 42.52 kg/Mg Al in Skawina and only 5.6 kg/Mg Al in Konin. Płoszewski [17] noted that a lot of improvements were introduced to the smelter in Konin, which helped to reduce fluorine emissions. Improvements, however, do not always protect the environment. Accidents may be caused by a human error. On 4 October 2010 there was an industrial accident at a caustic waste reservoir in Ajka. According to the article in Wikipedia [18], after the collapse of a dam, one million cubic metres of red mud were released. Red mud is a waste product of the Bayer process.

3. Applications of aluminium and concrete composite structures

Aluminum and concrete composite structures may have a number of applications thanks to the corrosion-resistance and lightness of the aluminium beam. Such structures are used in composite bridges, but they may also be used in constructions which are difficult to access or are located in corrosive or humid environments.

3.1. Composite bridges

Mazzolani [6], Göner and Marx [19] presented various types of cross-sections used in composite bridges, in some composite bridges built in the sixties in the USA, and later in France. The first type is presented in Figure 2. It has triangular cross-section beams made of 6061-T6 alloy.

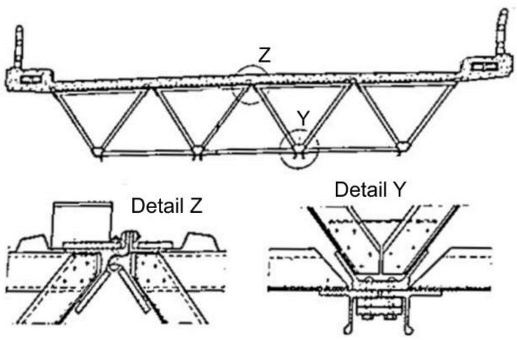

Fig. 2. "Fairchild" the composite bridge [19].

The second type has arch-like thin-walled aluminium beams, which is presented in Figure 3. The extruded profiles which are at the ends of the lower triangles reinforced the cross section. Thanks to a double chromiumzinc film the electrochemical corrosion of the aluminium components in contact with the concrete slab was prevented.

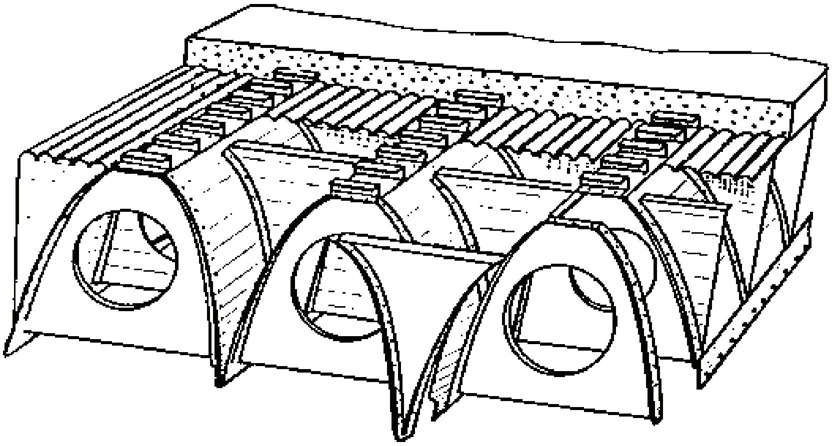

Fig. 3. A view of a composite bridge with an arch-like thin-walled aluminium beam reinforced by extruded profiles [19].

Mazzolani, Göner and Marx also presented a bridge which was made of double-T Al-Mg (5456 and 5083) aluminium alloys (see Fig. 4). This type of bridge was used in Des Moines, Iowa.

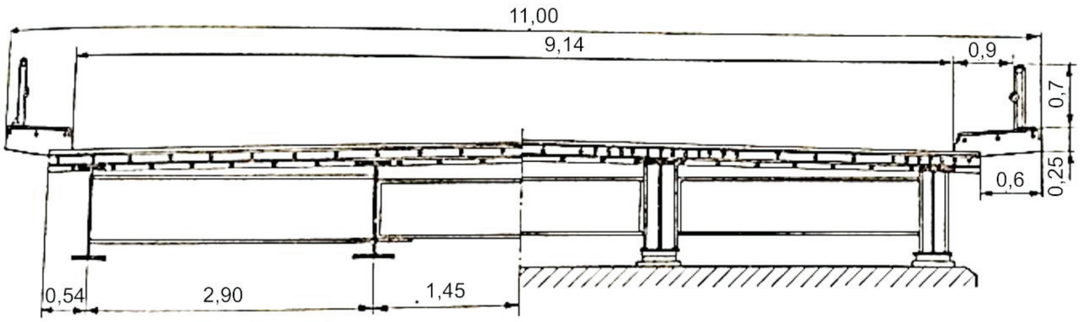

Fig. 4. A cross section of a composite bridge in Iowa, USA [19].

One of the new bridge systems was presented by Siwowski [20]. The bridge system consists of aluminium-lightweight concrete composite girders. Aluminium and concrete structures are also used in military bridges. Kamyk and Szelka [21] pointed out that light-weight bridges should be built as a result of increased mobility in the aftermath of natural disasters or on a battlefield. Hanus et al. [22] presented a prototype military bridge system which consisted of truss support components made of 7005 T53, stay-in-place-form made of pultruded glass fiber reinforced polymer and reinforcement (see Fig. 5). The system used 27.6 MPa concrete which is easy to make in-theater.

a) b)

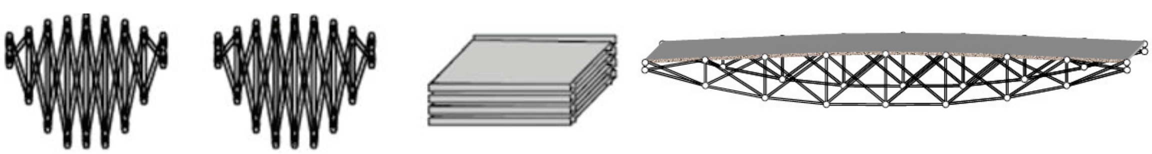

Fig. 5. (a) a truss, stay-in-place-form and reinforcement components [22] (b) completed bridge [22].

Aluminium and concrete structures may also be used in foot bridges and in deck reparation. Damaged concrete bridge decks may be replaced by aluminium and concrete structures or reinforced by pasting an aluminium beam to a concrete deck. The Groslee bridge is an example of the rehabilitated structure which is now a composite construction.

3.2. Structures situated in inaccessible places

Aluminium and concrete composite structures may be used in inaccessible places, e.g. as a roof of a gondola lift station. Aluminium beams with shear connectors and steel sheeting may be carried by a helicopter (see Fig. 6) to the top of a mountain where profiled steel sheeting may be used as shuttering of the concrete slab.

a) b)

Fig. 6. (a) a helicopter used to transport elements of the gondola lift [23]; (b) a construction site of a gondola lift station [23].

3.3. Structures located in corrosive or humid environments

Aluminium and concrete composite structures may be used in structures located in corrosive or humid environments. They may cover swimming pools, sewage treatment plants, storage vessels and warehouses for storing fertilizers or chemicals.

4. Conclusions

In some case it is advisable to replace a steel beam with an aluminium beam because of the lightness and corrosion-resistance of aluminium. Aluminium and concrete structures may be a part of sustainable development. They may be used in composite bridges, structures situated in inaccessible places and in corrosive or humid environments.

Acknowledgements

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References

[1] Mromliński R. *Aluminium structures*. Warszawa: Arkady; 1975. (in Polish)

[2] Mazzolani FM, Mandara A. Plastic Design of Aluminium – Concrete Composite Sections: a Simplified Method. *Proceedings of the International Conference on Composite Construction – Conventional and Innovative*. Innsbruck; 1997

[3] Szumigała M, Polus Ł. A numerical modelling of the load capacity of the shear connector of aluminium and concrete structures. In: Heizing T, Urbańska-Galewska E, editors. *II International Polish-Ukrainian Scientific-Technical Conference Current Problems of Metal Structures*, Gdansk: Foundation for the Development of Civil Engineering; 2014, p. 221-224.
[4] Polus Ł, Szumigała M. A numerical analysis of the resistance and stiffness of the aluminium and concrete composite beam. *CEER* 2014;15(4):99-112.
[5] Gwóźdź M. Project problems of contemporary aluminium structures. *Technical Transactions* 2007; Z4-A:281-6. (in Polish)
[6] Mazzolani FM. *Aluminium Structural Design*. Wien: Springer-Verlag GmbH; 2003.
[7] Jasiczak J, Hajkowski M. Corrosion susceptible elevations made with aluminium plates working in treatment's plant environment. *Ochrona Przed Korozją* 2008:5s/A:79-85. (in Polish)
[8] Błaszczyński T, Ksit B, Dyzman B. *Sustainable construction with elements of energy certification*. Wrocław: Dolnośląskie Educational Publisher; 2012. (in Polish)
[9] Bromberek Z. Energy efficiency and urban development. *Izolacje* 2014;1:14-8. (in Polish)
[10] Brandt A. Durability of building and civil engineering structures and sustainable development. In: Łapko A, Broniewicz M, Prusiel JA, editors. *The scientific research problems of building, Volume IV: Sustainable development in building industry*, Białystok: Technical University of Bialystok Publisher; 2008, p. 169-183. (in Polish)
[11] *EN 1992-1-1, Eurocode 2, Design of concrete structures – Part 1-1: General rules and rules for buildings*. Brussels: CEN European Committee for Standardization; 2004.
[12] Zybura A., Methods of ensuring the durability of structures on the example of concrete structures engineering, In: Łapko A, Broniewicz M, Prusiel JA, editors. *The scientific research problems of building, Volume IV: Sustainable development in building industry*, Białystok: Technical University of Bialystok Publisher; 2008, p. 235-252. (in Polish)
[13] Szczechowiak E. The role of industrialization in energy saving building. *Materiały Budowlane* 2007;9:115-19. (in Polish)
[14] Broniewicz M. Design based on sustainable development, In: Łapko A, Broniewicz M, Prusiel JA, editors. *The scientific research problems of building, Volume IV: Sustainable development in building industry*, Białystok: Technical University of Bialystok Publisher; 2008, p. 185-206. (in Polish)
[15] Rajpolt B, Tomaszewska B. *Fluorine contamination in soil and aquatic environment on the example of Aluminium Smelter in Skawina*, Kraków: The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences Publisher; 2011. (in Polish)
[16] Włodarczyk W. Electrolytic cathode carbon waste of the aluminium smelter in Skawina. *Zeszyty Naukowe AGH, Sozologia i Sozotechnika* 1987;23. (in Polish)
[17] Płoszewski K. Fluorine compounds in the atmospheric air. *Aura* 1998;5:12-5. (in Polish)
[18] Wikipedia. *Ajka alumina plant accident*. Access from the Internet (January 30, 2015): http://en.wikipedia.org/wiki/Ajka_alumina_plant_accident
[19] Göner H, Marx S. *Aluminium-handbuch*. Berlin: VEB Verlag Technik; 1969.
[20] Siwowski T. Prediction of the flexural behaviour of aluminium-leightweight concrete composite girder. In: Giżejowski MA, Kozłowski A, Ślęczka L., Ziółko J., editors. *Progress in Steel, Composite and Aluminium Structures*, London: Taylor & Francis Group; 2006, p. 236-37.
[21] Kamyk Z, Szelka J. Military composite bridges. In: Biliński T, Korentz J, editors. *X Conference Composite Structures*, Zielona Góra: University of Zielona Góra Publisher; 2014, p. 245-254. (in Polish)
[22] Hanus JP, Ray JC, Bank LC, Velazquez GI. Optimized design and testing of a prototype military bridge system for rapid in-theater construction, *25th Army Science Conference – Transformational Army Science and Technology*. Orlando: Asst. Sec. of the Army; 2006, p. 1-8.
[23] Photo gallery of Resort SKI&SUN Świeradów-Zdrój.