CONFERENCE PROCEEDINGS

5th INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

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PLACES AND TECHNOLOGIES 2018

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CONFERENCE PROCEEDINGS OF THE 5TH INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

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SUSTAINABILITY BENEFITS OF FERROCEMENT APPLICATION IN COMPOSITE BUILDING STRUCTURES

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ABSTRACT

Raising the level of sustainability in construction refers to reduction of negative environmental impact and resource consumption throughout the life cycle of built facilities, with a simultaneous increase in life quality. Ferrocement is a material that is nowadays increasingly used worldwide precisely because of the possibility to meet the numerous requirements which concern the ecological quality of buildings. Having in mind functional and design possibilitieswhich ferrocement offers as a constructive material, it is used for making of a wide range of structural elements, as well as for the strengthening of the existing structures. In addition to the above, ferrocement finds its application within the composite building structures. This paper analyzes the forms of application of ferrocement within composite building structures, as well as the benefits of its application in such systems in the context of sustainability. The analyzed systems are based on the composite action of ferrocement and conventional reinforced concrete, the composite action of ferrocement and steel load bearing elements, as well as on the composite action of ferrocement, steel load bearing elements and conventional reinforced concrete. The present analysis pointed to the key sustainability benefits of ferrocement application in composite building structures, as well as to the need for further research on possible use forms of this material within such systems, in function of raising the sustainability of the built environment.

Keywords: Sustainable building, Ferrocement, Composite building structures

Introduction

Raising the level of sustainability of building refers to the “reduction of negative environmental impact and resource consumption due to construction, use and dismantling of constructed facilities, with a simultaneous increase in life quality of and health and safety in the built environment” (Working Group for Sustainable Construction, 2001). In this process, it is necessary to strive towards achievement of an ecological quality of buildings (Nenadović, 2014), that is, towards their adequate performances. The building structure, along with other elements of architectural space, determines the performances of the building. The building structure should be designed and evaluated as a sub-system of the building, whose behaviour is directed toward the aim of system-building. Within the environmental protection criteria, this aim refers to the reduction of harmful emissions into air, water and land, as well as to the increase of resource-use efficiency. Within the criteria of social well-being, this aim refers to the realization of building performances that meet the needs and expectations of its users during the use phase of a building (Nenadović, 2014).

There are numerous examples of applications of ferrocement in architectural structures in re-

1 Corresponding author

cent times in the world, with the aim to realize efficient and economically viable solutions[2]. Ferrocement as a special form of thin-walled reinforced concrete[3], along with the economic viability, offers a wide range of functional and shaping possibilities. Compared to the conventional reinforced concrete, it is characterized by different behaviour in terms of strength and deformation, with „enhanced elasticity, fine cracks, lower permeability to water vapour and gases, higher ductility and durability" (IFS Committees 10, 2001), which places him as a special material. Various structures and their elements can be built from ferrocement, including the elements of complex geometry. Ferrocement is applied in construction of vessels, silos, reservoirs and pipes. It is also applied in architectural structures, especially in housing construction. Ferrocement can be used as the only structural material in building structure, but also as a part of the composite assembly. This paper analyzes the forms of application of ferrocement within composite building structures and analyzes the benefits of its application in such systems in the context of sustainability.

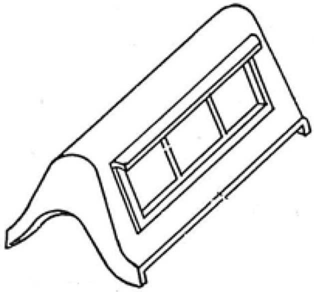
FERROCEMENT APPLICATION IN COMPOSITE BUILDING STRUCTURES

Building structures based on ferrocement and conventional reinforced concrete

Ferrocement finds its application in building structures based on his composite action with conventional reinforced concrete. The pioneer in applying ferrocement in this way is Pier Luigi Nervi, who states that ferrocement represents "a true revolution from both the construction point of view and the aesthetics as well" (Nervi, 1943). The load bearing structure of the central hall of the Turin Exhibition Complex, built in 1948 (Figure 1), is based on the composite action of ferrocement and conventional reinforced concrete (Tampone and Ruggieri, 2003). Nervi uses ferrocement for the production of prefabricated roof elements of complex geometry. These elements have a dual role: the role of load bearing elements and the role of lost formwork for the production of reinforced concrete ribs and shells on site, which eliminates the need for wooden formwork and speeds up the construction process (Huxtable, 1960). In the main part of the hall, the average thickness of the vault that spans 96 m does not exceed 8 cm, indicating the exceptional efficiency of the applied system. Corrugated ferrocement elements in this part of the hall are formed with openings, allowing natural light (Figure 2). Nervi applies the same technology to the construction of the sports hall in Rome (Figure 3). The roof structure, in form of rotational surface, is formed from prefabricated ferrocement elements of complex geometry and cast-in-place concrete, which together act as a thin ribbed concrete shell. The organic configuration of ribs enables an efficient flow of forces through the structure. The smooth finishing surfaces of ferrocement elements did not require additional layers (Chiorino, 2012). The Schlumberger Extension building, built in 1992, designed by Michael Hopkins and Partners, is another successful example of composite action of ferrocement and cast-in-place concrete (Dickson and Gregson, 1993), applied, among others, due to thermal mass. The floor structure is realized from visible white ferrocement prefabricated elements, shaped in accordance with the desired complex geometry and arrangement of primary and secondary isostatic reinforced concrete ribs (Figures 4 and 5). Ferrocement enabled avoidance of the construction problems that exist in the case ofapplication of the conventional concrete castin situ in complexly shaped wooden formwork.

2 Since recently, ferrocement is applied in Serbia for the realization of halls for different purposes (Milinković, 2009). The first technical recommendation for ferrocement in Serbia was published by Federal institution for standardization in 2002.

3 The thickness of the elements is 1-3 cm, which is practically impossible in the case of classical reinforced concrete.



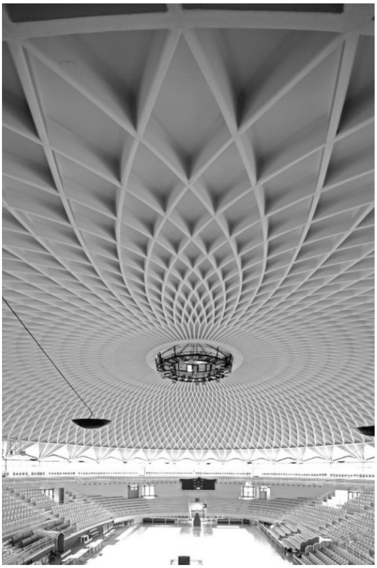


Figure 1. Pier Luigi Nervi, the Central Hall of the Turin Exhibition Complex, 1948. Interior. [Source:http://urbanthinker.com/wp-content/uploads/2012/05/4_NerviTurinExpo1948.jpg]
Figure 2. Prefabricated ferrocement element.
[Source: Rile, H. 1977. Prostornekrovnekostrukcije. Beograd: Građevinskaknjiga.]
Figure 3.Pier Luigi Nervi, the Sports Hall, Rome, 1957. Interior.
[Source: https://www.pinterest.com/pin/368098969531630025/]
Figure 4 and 5. Michael Hopkins and Partners, the Schlumberger Extension building. [Source: Walker, D., H. Edmund, and A. William. 1997. Happold: The Confidence to Build. Happold Trust Publications Limited]

Given examples indicate that using the ferrocement in a composite action with a conventional castin situ concrete, construction process and visual properties of building structure can be improved. Besides that, a better mechanical characteristic and more durable building structure can be achieved, compared to the application of pure conventional reinforced concrete. Recent research confirms Nervi's assumptions, that composite systems made of ferrocement and conventional reinforced concrete, in terms of mechanical behaviour, take advantage of each component material in the best way. The use of ferrocement in a tensile zone contributes to the greater ductility and load bearing capacity of the element, as well as to the smaller width and spacing of the tensile cracks(Al-Kubaisy and Jumatt, 2005).

Building structures based on ferrocement and steel

Ferrocement can be applied in building structures which are based on its composite action with steel elements. The architect Angus McDonald successfully uses synergy between these two materials, with the aim to build "sustainable, energy-efficient, and permanent shelter affordable to all people" (Macdonald, 2012). He developed a construction system that should overcome the limitations and disadvantages of the existing panel systems, which relate to discontinuity of the structure, weakening of the connections during time, and to sensitivity of the connections to water and moisture. The reinforcing meshes are attached to previously connectedgalvanized steel profiles. After the plastering of meshes, a continuous, seamless, highly reinforced ferrocement membrane is obtained, which together with the elements of the steel frame forms a composite ribbed monocoque shell (Figure 5). The ferrocement membrane contributes to an even distribution of forces in the system and to reduction of the effective length of the steel members, which reduces their required cross-section. The membrane functions as a diaphragm, stiffening the system horizontaly. En efficient use of materials is achieved, with a high strength-to-weight ratio.[4]The system elements are suitable for transport. The process of construction is simple, energy efficient, with minimum waste generation. The building structure is durable and requires a minimum maintenance throughout the life cycle. "Ferrocement engineering and formulas has proven to provide the optimum balance of construction speed, low cost, and building quality" (Macdonald, 2012).

Figure 5. Construction of building in Am-cor system.
[Source: http://www.am-cor.com/galleries/gallery/construction/]
Figure 6. Folded roof structure formed as composite assemblie.
[Source: http://yucatan.com.mx/multimedia/valladolid-se-une-en-un-sueno-2-galeri]

The folded roof structure that spans 22 m, created by Mendez Baeza in Yucatan, is also based on the composite action of ferrocement and steel (Figure 6). The structure is formed as composite assemblie of steel trusses and ferrocement membrane. The galvanized reinforcing meshes are attached to the skeletal reinforcement, which is previously attached to the upper side of the steel trusses. The mortar in a layer of 2 cm is applied on the reinforcing meshes.

4 The system proved to be 2-3 times stiffer than the reinforced masonry, with 80% less material used.

The agave fibers are addedin mortar, in order to achieve higher flexibility, adhesion and crack control. The layer of ferrocement monolithizes the structure, contributing to its greater structural efficiency (Baeza, 2012). The ferrocement was also applied in composite structures made of steel frames and ferrocement of 2.5-3 cm thickness, within the project for development of new technologies for residential construction in Singapore (Lau et al., 2001). These structures were 60% lighter than those made of conventional reinforced concrete. This system has been adopted for many projects in Singapore, considering the quality of finishing surfaces and the lack of joints and connections vulnerable to decay, characteristic for classical panel systems. The successful composite action of ferrocement and steel members, especially from the aspect of structure monolithization and the aspect of saving the amount of material, was also noticed by Desai (Desai, 2009). Unlike previous solutions, where ferrocement is made in situ, Desai attaches prefabricated ferrocement plates to the steel frame, by welding the reinforcement which is left out of the ferrocement panel. After the welding, the joints are fulfilled with mortar. In this way, a monolithic connection is achieved without screws. In addition, the construction process is accelerated, given the avoidance of time-consuming application of mortar on-site.

Building structures based on ferrocement, steel and conventional reinforced concrete

A system that can be interpreted as integration of the principle of formation and functioning of two previously considered composite systems, is a system based on joint work of ferrocement, steel members and conventional reinforced concrete (Figure 7). It is a system of integrated metal formwork, which can be used for realization of low-rise and high-rise buildings (Rešenja-zaenergetskuefikasnost, 2013). This system was applied within Olembe housing program, led by the Public Real Estate Company of Cameroon in the capital Yaoundé. They required quality, cost-efficient structural solution that allow fast construction. The system of stay-in-place steel formwork was the solution that answered their needs (Innovative Solutions for Construction, 2013).

Figure 7. The system of integrated metal formwork.
[Source: “Rešenja za energetsku efikasnost: Sistemi efikasne gradnje.” 2013. Beočin: Lafarge.]

In the space between double-sided metal formwork, formed of galvanized steel meshes connected to the frames of galvanized steel profiles, the standard reinforcement is embedded. After that, the concrete is poured directly into the forms (Rešenja za energetsku efikasnost, 2013). For low-rise buildings, standard reinforcement is usually not necessary. In order to prevent the leakage of cement milk through the holes of the reinforcing mesh, the concrete must have appropriate viscosity. After hardening of concrete, a layer of mortar is applied as finishing wall surface. In this way, a composite walls of two external ferrocement membranes and inner layer of conventional reinforced concrete are obtained. Thanks to the ferrocement membrane, the system has higher ductility,compared to the system with classical reinforced concrete, that is, a higher resistance to earthquakes. The system is not technologically demanding. It doesn't require special training of the labour force. It is easy to manipulate with parts of the formwork. The use of mechanization and duration of construction is reduced. A greater durability of the building structure is achieved, with simultaneous cost reduction.

SUSTAINABILITY BENEFITS OF FERROCEMENT APPLICATION IN COMPOSITE BUILDING STRUCTURES

When it comes to environmental benefits, ferrocement can be made of local resources and products, reducing the impacts of transport. The environmental benefit of building structures based on ferrocement and conventional reinforced concrete is the reduction of the amount of waste during construction phase, due to the possibility of elimination of wooden formwork, which makes up a considerable part of the generated waste. The embodied energy during the building's use phase can be reduced, because the ferrocement structural elements have long service life, with a minimum of maintenance. Ferrocement repairs are done manually, with low consumption of materials and energy. Composite assemblies based on a monolithic ferrocement shell are characterized by higher airtightness, thus minimizing air leakage. Bearing in mind quality of the final surface of ferrocement, building structure can remain visible and through the effect of thermal mass completely contribute to optimization of the heat flows in interior spaces, and thus to reduction of operational energy. In the case of application of visible ferrocement surfaces, an adequate choice of their colour may affect the level of heat absorption, optimizing the thermal performances of the building. In the case of ferrocement application, the functional integration of spatial elements can be achieved. Ferrocement structural elements, in addition to load bearing function, can also take a function of building envelope, as well as function of the finishing inner surfaces, thus eliminating the need for additional layers. The above is particularly expressed due to ferrocement resistance to aggressive environmental effects and due to possibility of free form design of ferrocement elements and the possibility of adequate treatment of finishing surfaces, that is, adequate realization of their texture and colour. In composite structures based on ferrocement, given the smaller amount of embedded materials, the amount of construction waste generated by demolition is also reduced. The reduced amount of material is primarily related to greater structural efficiency of this type of structures and to the possibility of functional integration of spatial elements.

When it comes to social benefits, ferrocement composite structures, in which ferrocement additionally monolithizes the structural assembly, have proved to be reliable, giving greater safety for people during then atural disasters. The robustness of this type ofstructuresis based ontheir continuity and ductility. Likewise, the application of ferrocement in composite structures, based on conventional reinforced concrete and/or steel, contributes to the greater resistance of the building structure to fire effects. The monolithization of the structure with the help of ferrocement, especially in composite assemblies with the steel elements, provides greater air tightness and minimize air leak, which contributes to a greater thermal comfort for building users. When it comes to the internal air quality, ferrocement can be considered as harmless material, practically with no emission of harmful gases, particles and microfibers. Building structures based on ferrocement are suitable for the realization of assemblies in accordance with the desired acoustic qualities, since they can be freely shaped. Important characteristic of ferrocement composite structures, when it comes to the space adaptability, is their durability and possibility of easy repair and maintenance, based on the application of readily available materials. Composite structures based on ferrocement enable effective maintenance over the expected service life, with a minimum investment of human, material and financial resources, provided that they are designed in accordance with specific conditions in the macro and micro environment and properly built. The ferrocement, as a composite material whose structure, texture and colour are designed and thus the degree of light reflection, as well as free domin it's shaping and in the shaping of openings, with the aim of light manipulation, can contribute to the quality of light in the interior space. Ferrocement, in the visual sense, can be experienced as a concrete with fine structure or as a rough mortar. In this context, in Europe ferrocement is associated with the mass usage of concrete or mortar within the buildings of different purposes, making it a"neutral" material, suitable for composing the spaces of different associative values. Ubiquity, standardicity, uniformity, availability, simplicity, steadiness, dynamism, freedom...ferrocement can "hide" many ideological backgrounds, i.e., take many meanings.

Conclusions

The present analysis pointed to the possible forms of ferrocement application within composite building structures, as well as to the benefits of its application in such systems in the context of sustainability. The key sustainability benefits, from the aspect of the environmental protection and from the aspect of the social well-being, are detected and emphasized. In environmental sense, these benefits primarily relate to the reduced use of resources, both in the construction phase and in theuse phase of the building, with less harmful emissions and less generated waste. In the sense of social well-being, these benefits primarily relate to the realization of more durable, more resistant and safer structural assemblies which require minimum maintenance, and which can be shaped and materialized in a way that meets the requirements of comfort and visual requirements. The paper pointed to the need for further research of possible use forms of ferrocement within composite building assemblies, in function of raising the level of sustainability of the built environment.

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