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Ecological Properties of Glass Fibre Reinforced Materials Based On Architecture of Zaha Hadid

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Abstract. Since 1977 – the year of inventing a glass fibre reinforced gypsum – the progressive popularity of materials strengthened with glass fibre is noticed. Light, high strength resistant, manufactured in complex geometries at high tolerances, made from post-consumer recycled material makes it a perfect component of each dream, architectural project. Zaha Hadid was an exceptional author of GFRG and glass fibre reinforced concrete (GFRC) breathtaking objects. Her astonishing Heydar Aliyev Center in Baku (The Republic of Azerbaijan) owes its fluid form to GFR materials. Glass Fibre Reinforced Concrete (GFRC) and Glass Fibre Reinforced Polyester (GFRP) were chosen as ideal cladding materials, as they allow for the powerful plasticity of the building's design while responding to very different functional demands related to a variety of situations: plaza, transitional zones and envelope. These panels generate a single curving surface that appears to emerge from the topography. It rises, undulates, and wraps inward at its base to completely envelop the building's various volumes. Another magnificent project created by Zaha Hadid studio is a King Abdullah Petroleum Studies and Research Centre - a non-profit institution for independent research into policies that contribute to the most effective use of energy to provide social wellbeing across the globe. Adding an eco-friendly advantage gives this material a full right to be announced a superb brick of the future. Glass Fibre Reinforced Concrete (GFRC) contains materials that, taken from the soil, have no adverse effect on the environment. Concrete's components include Fly Ash, Silica Sand, Portland cement and aggregate. Providing cheaper substitute than concrete and bricks for construction and reducing the duration of overall construction and hence saving labour cost makes it a more and more popular building material in developing countries which suffers from low increase of housing estates. Throughout a thorough scientific research the author tries to confirm this thesis, although some disadvantages of GFRC, such as lateral stiffness have been found. The architecture of Zaha Hadid represents a beauty and complexity of material reinforced with fibre glass, whereas its popularity in impoverished and developing countries such as India makes it a new kind of low-cost building element.

1. Introduction

The invention of Glass Fibre Reinforced materials in late 50's was an indisputable breakthrough in the world of building components. Russia and China were the first countries, which initiated tests on adding E Glass and C Glass reinforcements to various materials, such as cement. For almost 50 years of ongoing development GFR concrete and polyester, it became one of the most popular and versatile building material available to architects and engineers. Its astonishing properties and thereby a large number of usage methods inspired, among others, one of the greatest architects – Zaha Hadid. It would not be an overstatement to describe her the utmost creator of buildings based on GRFC materials.

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Heydar Aliyev Centre in Baku (Azerbaijan), Capital Hill Residence in Moscow, The One Thousand Museum residential tower in Miami are just few of the projects she has designed with the use of GFRC structures. As a great popularizer of the mentioned material, she has worked on projects with a number of the Members of the International Glassfibre Reinforced Concrete Association (GRCA) on GRC clad projects all over the world. Zaha was a great supporter of the GRC Association and user of GRC, attending and speaking at the GRCA's Congresses.

Throughout a deep research of bibliography focused on properties of GFRC and its use in Zaha Hadid architecture, a list of high-quality features and ecological attributes has been prepared in the paragraphs below. Despite acknowledging the material as a brick of our future, the summary conclusions also present disadvantages of GFRC usage. Nevertheless, materials reinforced with glass fibre dominated the world of architecture and still remain unmatched.

2. GFRC – Glass Fibre Reinforced Concrete

2.1. History of material

In the late 50’s and early 60’s E glass and C glass were being proposed as reinforcements for concrete in Russia and China. It was thought that due to its very high tensile strength and elastic modulus glassfibre would be a good reinforcement for concrete, which is inherently brittle. However, what occurred within the next years was, that E glass and C glass fibres were not stable in concrete due to the high alkalinity of the matrix. Scientists focused on the use of low alkali cement and acrylic polymers to overcome this, but after a failure, the projects were abandoned.

It seemed to be crucial to make the glass itself alkali resistant, and at the end of the 1960’s a suitable glass formulation was identified containing zirconia (ZrO_2). After numerous trials the zirconia content was optimised at approximately 17%. In the 1970’s the technology was developed to produce AR-glassfibres from this glass formulation, and the Glassfibre Reinforced Concrete industry was born.

For almost 50 years of ongoing development, the industry now presents better quality glass fibres with a wider variety of sizing, new pozzolans to enhance the overall GFRC properties, low alkali cement to reduce the attack on the fibres, improved and diversified equipment, and more manufacturing methods. During this time, the market has witnessed continual growth in the volumes and the range of products manufactured. Today GFRC has become one of the most versatile building material available to architects and engineers.

2.2. GFRC components

GFRC is a composite material, which combines the high compressive strength of cement mortars with significantly increased impact, flexural and tensile strengths obtained by the glass fibre reinforcement. According to the particular product and the engineering design, GFRC formulation materials are normally involved with the following:

Alkali Resistant (AR) Glass Fibre Products

AR glassfibre is specially formulated to have a high degree of resistance to alkali attack and high durability in cement. Laboratory testing shows that at least 16% zirconia content is required for adequate alkali resistance. AR glassfibres are available in roving, chopped strand, net and mat forms. The use of roving for hand spray including auto spray and chopped strands for premix are most common, with scrim being used in areas of high stress concentrations and mat for the similar application although more successful in floor screeding.

Cement

Ordinary Portland Cement (OPC), Rapid hardening Portland Cement (RHPC), Calcium Sulphoaluminate Cement (CSA) and White Portland Cement are the most commonly used cements. They should conform to the relevant National or International Standards. CSA cement is widely used in the Far East due to its low alkalinity and rapid hardening properties, which consequently reduces the corrosion of fibres and speeds up the mould turnover. White Portland Cement is used in GFRC where a white or light coloured finish is required.

Sand
Properly graded silica sand is recommended. The particle shape is preferably round or irregular but having a smooth surface without honeycombing. For spray GFRC, the maximum particle size is generally limited to 1.2 mm; for premix GFRC, the maximum particle size may be 2.4 mm. Sand other than silica sands may be used but the producer should provide evidence of their suitability.

Water
Water should be clean and free from deleterious matter and should meet relevant standards for water to be used to mix concrete. Potable water is normally suitable.

Pozzolanic materials
PFA, GGBS, Metakaolin, Microsilica and ground glass powder are a range of pozzolanic materials that can be used to partially replace cement either to have a beneficial effect on the properties of GFRC or for the environmental concerns. They work by reacting with the free lime produced during the hydration process to form further hydration products.

Sand and aggregating for facing
When a facing mix is used to produce an architectural finish special aggregates and sand may be required. They should be clean, hard, strong, durable and inert, and free of staining or deleterious material. Crushed and graded hard rocks like limestone, granite, spar, calcite or marble are particularly suitable.

Admixtures
Admixtures such as water reducers, accelerators, retarders and air entraining agents may be used to impart specific properties to GFRC. They can be standard concrete admixtures or those specially formulated for GFRC manufacture.

Polymer
Acrylic thermoplastic polymer is added to the GFRC mix to allow for a subsequent dry cure and for property enhancement, particularly the reduction of surface crazing. It is particularly favoured, when white cement is used, to avoid the possible water stain from wet cure.

Pigments
Powder pigments or dispersions may be used to achieve specific colour effect. They are normally iron oxide based and should be harmless to concrete strength and set, temperature stable, non-fading and alkali resistant. The dosage should not exceed 10% of amount of cement.

Paints and sealers
Paints and sealers may be applied to GFRC. Latex masonry paints and water resistant stains in a methylemethacrylate base offer a wide range of colour choices. A clear coating of silane or siloxane may be applied to the face and back surfaces of a panel to reduce moisture movement and efflorescence. [1]

2.3. Use of GFRC – environmental properties
The world of design nowadays is faced with numerous choices when it comes to ecological design and construction. “Green” materials and techniques are ubiquitous, presented in every phase of design,

what is no longer a novelty. Designers are aware of the fact, that everyday decisions concerning materials and methods will impact our future generations.

The GFRC components are environmental friendly. The glass elements are from reclaimed or recycled materials, and the cement mix includes fly ash, which is the waste produced by industrial smokestacks. The finishes are ecologically friendly water-based materials that give off no pollutants or toxins when produced. Using GRC is friendly on the environment and goes hand-in-hand with the current "green building" push. [2] GRC contains materials that, taken from the soil, have no adverse effect on the environment. Concrete's components include Fly Ash, Silica Sand, Portland cement and aggregate. In GRC we introduce the component of fibreglass as well as other natural chemicals in order to produce a super strong and flexible material. The process of producing the water based material produces no chemical off-gas or byproducts. GRC is a green material in many ways. Primarily, the use of recycled aggregates such as recycled glass, metals and other recycled materials give GRC a modern look. The aspects of GRC which make it a green material include its composition of natural materials such as sand, and other aggregates. [3]

Fibre glass is made from an abundant and rapidly renewable resource (Sand) and recycled postconsumer glass. Slag wool insulation is made from recycled blast furnace slag - a by-product of other industries.

Although GFRC has a myriad number of advantages and is slowly called a brick of the future, it also has some flaws, which seems to be a main topic of many worldwide scientific projects. There is a number of defects, that are highly connected with the environmental impact. Here is a list of just selected ones:

- The cost of GFRC is higher than traditional concrete. Due to the fibreglass being inside the concrete and the addition of additives and acrylic co-polymer the price is steeper.
- When produced as cladding panels, should only be used in nonload-bearing applications.
- A separate anchorage system in required to support the panels. Large panels require a metal reinforcement or other construction system.
- The integral color of GRFC will lighten as a result of weathering – especially wetting and drying.
- Proper detailing of the joints, including the material used and the dimensions and location of joints, is essential to the water tightness and long-term service ability of the panel system.
- The expansion and contraction characteristics of GFRC change with moisture content and thermal changes.
- Unknown history of GFRC use in domes. Can only be used in vertical planes. [4]

2.4. Ecological properties of GFRC materials.

Within numerous, eco-friendly advantages of GFRC products, it's proper to mention a certain ranking called LEED. The LEED rating system has become the basis for evaluating the claims for Green Architecture. LEED (Leadership in Energy and Environmental Design) Green Building Rating System® is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings.

LEED was created to define "green building" by establishing a common standard of measurement, promote integrated, whole-building design practices recognize environmental leadership in the building industry, stimulate green competition raise consumer awareness of green building benefits transform the building market Members of the U.S. Green Building Council representing all segments of the building industry developed LEED and continue to contribute to its evolution. LEED standards are currently available or under development for, New commercial construction and major renovation projects as well as many other project typologies.

The aspects of GFRC which make it a green material include its composition of natural materials such as sand, and other aggregates. Also, the inclusion of recycled content gives the design team to specify this material and garner LEED points for their projects.

Advantages of GFRC for Green Building:

- GFRC has low toxicity raw materials: Cement, sand, glass fibres and water
- Durable, long lasting materials reduce replacement, maintenance and repair
- *GFRC* can be supplied prefinished to eliminate VOC's during painting
- *GFRC* is non-combustible and meets ASTM E136
- Can meet hurricane resistance of Miami Dade Large Missile Impact and Small Missile Impact
- Lightweight *GFRC* panels use 80% less material than precast
- Lightweight *GFRC* panels reduces fuel and costs of transportation

2.5. Zaha Hadid's architecture based on GFRC materials.

Zaha Hadid is considered one of the architects, who successfully followed Frank Lloyd Wright's postulates of 'organic architecture' philosophy. Her works evolved from fragmented distorted explosive forms with flying beams and anti-gravitational masses towards more smooth, curvy lines that twist in complexity and give the feeling of fluidity. By the time of GRFC materials expansion and its development, Zaha was aware of the opportunities this certain component offers and started to use it on many fields in her projects.

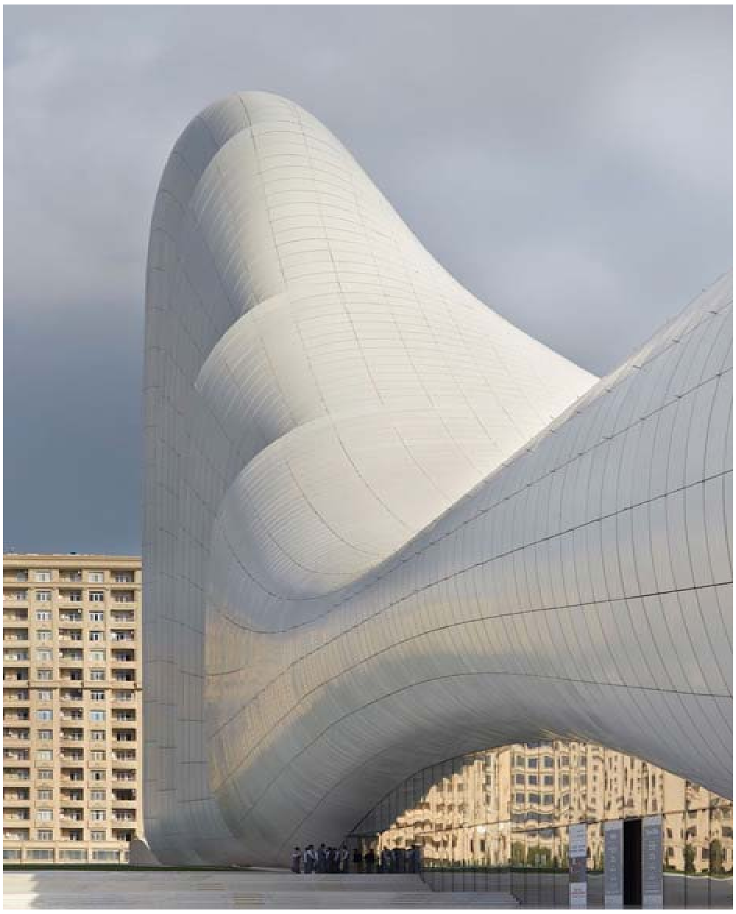

Figure 1. Heydar Aliyev Center, main entrance, Hufton & Crow [6]

Organic architecture is characterized by several main features, which at the same time are possible to be fulfilled only by the use of GFRC materials:

- Complex Curvilinearity – the effect of fluidity is achievable by the use of curves. It's crucial to express the impression of sketch or drawing and keep the complexity and randomness in the project.
- Dynamic Fluidity – buildings are intended to be in relation with humans and should have the sense of motion.
- Coherent Integration – could be monitored between the concept and mass, between the building and the site and between the exterior and interior. The landscape is an essential part of the design of the building. It is an extension of the interior lines and complements with the masses. [5]
- Parametricism
- Elegance and Balance
- Taking analogies from nature – the architecture should be connected with nature, whether in the form of imitation or inspiration.
- Following sustainability measures

Heydar Aliyev Center in Baku (Azerbaijan)

Completed in 2012 is considered one of the most important projects of Zaha Hadid. Its shell is made out of a steel space frame and glass-fibre-reinforced concrete panels, concealing the vertical supports within the walls. The building reflects the fluidity of traditional Azeri architecture and represents traditional floral patterns. Ornamentation runs from the flooring to the walls and to the dome. In this project parametric software was heavily used to develop the skin to make it more rational and efficient and, what's more important, allowed the creators to form an internalised urban space formed by undulated ground panels.

Façade of the complex consist of 18,000 panels, approximately 1 m by 2 m. Fibre Reinforced Polymer (FRP) and Glass Fibre Reinforced Concrete (GFRC).The main structure of the Heydar Aliyev Cultural Centre is a mix of reinforced concrete, steel frame structures, and composite beams and decks. The space frame is composed of a special steel tube-and-nodes system (a product of MERO-TSK International). For aesthetic purposes, the cladding needed to give the building a monolithic appearance, not only to make it read as a continuous volume but also to accomplish the transition to the plaza surface. All visible seams needed to run parallel to one another, reinforcing the building's wavelike design. The cladding material had to meet various practical considerations, such as UV resistance and light reflectivity.

Capital Hill Private Residency in Moscow (Russia)

It was the first and only project of Zaha Hadid made for a private investor. Vladislav Doronin wished to wake up every day right under the blue sky, what was achievable only by lifting the bedroom level above the trees of Barvikha forest. Curvy lines of this spaceship building could be made only by the use of GFRC panels. During the design stage, the architectural team was contemplating natural stone, GFRC and GFRP for the façade, or pre-cast concrete usable in external façade. During the summer of 2008, after seeing the first mock-up made by Fibrobeton, the architect decided that the best alternative to put the project into practice was GFRC. Contract was signed in the beginning of 2010. Primarily, all the elements were designed in accordance with their transport, assembly and production requirements. Wind, earthquake and snow loads had a great effect on design criteria. The most important load in the project located in Moscow was the snow load. Because of this, the dimensions of production had to be calculated and adjusted, and unique solutions were developed by increasing the thickness of the material. 1.100 molds were made in order to produce a total of 1.100 individual panels. All panels were manufactured in a unique manner, and according to their own CAD details. Special GFRC gutter elements, with very sharp edges were produced for the Banya building. 3D, digitally designed panels, which are all different respectively were produced only after being checked countless times with wind, snow and fire. [7]

3. Conclusions

Glass fibre reinforced concrete (GFRC) is being used in many different applications, such as structural applications as thin plated staircases and cantilevering terraces, but more widespread in decorative applications, as ornaments on buildings, and more recently as cladding for complex geometry buildings. The popularity of this material is strictly based on its high, ecological standards and the fact that it's recyclable. Over the years, fibre glass has been rigorously studied by government and independent research organizations. Their conclusions show that fibre glass is safe as a finished product or as a product component, and it is safe for workers who make or install the product when they follow simple work practices to avoid temporary mechanical irritation.

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