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Modern High-Tech Materials in Construction and Architecture: A Review of Properties, Features, and Applications

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Abstract: In the article, the author reviews modern high-tech materials that are used in construction and architecture. In the process of analyzing the typologies of each material, their properties and technological features are revealed. In order to determine the most preferable options, a comparative description of various modifications is given, and their advantages and disadvantages are identified. After fixing the scope of application of the materials in question, recommendations and methods for their practical use are offered.
Keywords: Cor-Ten steel, fiber-reinforced concrete, high-tech materials, smart windows

I. Introduction

The features of the modern stage of technical and technological progress are influenced by 3 main trends:

1. **Active development of digital and computer technologies:** Total digitalization in all spheres of modern life simplifies and accelerates the exchange of information. This contributes to the development of consistent and constructive scientific discourse globally and, as a consequence, to the elaboration of more accurate research tools and methods, to the increase in the rate and scale of engineering and technological developments up to nano- and giga-levels.

Another significant effect of digitalization is the transition from a manual way of managing and organizing system elements to an automated one. This transformation is accompanied by an increased demand for the creation of smart, autonomous system processes, particularly in design, engineering, and technology.

2. **Globalization of the market economy:** The almost global interconnection of economic processes increases the value of the competitiveness parameter, and considering the instant spread of information, economic entities have to be always "one step ahead". Playing an important part in the chain of providing benefits, the engineering and technological industry maintains a high level of internal competitiveness in a constant intensive search for innovations: improvement of existing products or creation of fundamentally new ones (besides purely scientific interest, important driving forces are grants, contracts, and orders).

Obviously, economic efficiency, pricing, and profitability remain important variables within this trend. At the same time, the market impact has a positive effect on the expertise of the industry representatives, on the quality of products, as well as on the expansion, accumulation, elaboration, and adaptation of scientific knowledge.

3. **Environmental crisis:** Potential ecological disaster hazards force humankind to reconsider the production and operation of technogenic objects, as the engineering and technology industry is substantially responsible for their creation and development. The result is a mandatory assessment of the developed and modified products in terms of sustainability, energy efficiency, and the level of harmful impact, as well as compliance with the requirements approved within this trend.

Quite obviously, a great part of engineering development is given to the search and implementation of innovative technologies in construction as it is one of the most harmful and expensive industries, which is especially challenging in process management. As for architecture, the interest in the technological improvement of materials and the creation of their more progressive modifications is driven by local (internal) trends in addition to the mentioned global ones. They are related to the solution of artistic and practical tasks: updating and expanding the expressive means, elaborating and personalization of the author's manner, style, and position, and strengthening the competitive advantage.

In line with these trends, the development and testing of high-tech materials are of particular importance as they may be capable of providing fundamentally new approaches to the implementation of architectural designs and construction solutions. Among the main tasks that high-tech materials solve in construction and architecture are the following:

- Improved performance and strength characteristics. For example, the development of materials with high durability at a reduced weight provides new structures that are optimized in terms of resource consumption and foundation load.

- Energy efficiency and thermal regulation. Modern insulation materials and coatings reflect sunlight or save heat, providing minimization of energy consumption for premises heating and cooling.
- Environmental concerns. There is a demand for materials that meet sustainability requirements and improve environmental performance. These include energy-efficient materials that save resources; materials made with the use of or containing recycled components; materials with a high degree of recyclability; and environmentally active materials with properties that improve environmental conditions.
- Adaptability and functionality. Smart materials that can change their properties in response to external conditions (temperature, humidity, light, etc.), open up new opportunities for the creation of adaptive and functional architectural space.
- Aesthetic novelty, ability to adapt to modern artistic trends. Some of modern materials have unique shapes and textures and express stylistic features of the time or the author's individuality; these are varieties of glass coatings and modified types of metals.

Starting from the most modest results at the end of the 20th century, the development of high-tech materials in its present stage is characterized by active growth, both quantitative and qualitative. However, due to the multicomponent and structural complexity of such materials under different operating conditions, their practical application is often accompanied by some kind of a challenge. A large and constantly growing number of scientific studies has been devoted to highlighting and answering these challenges, as well as developing more effective modifications. The most promising materials are in the spotlight of the scientific and professional community represented by various fields of science and art: chemistry, physics, materials science, construction, architecture, and design.

The high speed of new data acquisition in an interdisciplinary format, the thoroughness and depth of research and experiments create a significant amount of information that can be impossible to methodically assimilate in order to determine the current state of the issue. This is particularly true for practitioners who do not have enough time for a comprehensive study of the issue in their own and related industries.

This makes especially relevant the need to periodically reproduce a systematizing review study that will provide an analysis of several key variables (challenges, properties, features, characteristics) of the objects under consideration, grouped by a theme, issue, or discipline.

Based on this need, the **purpose** of the present study is also formulated, that is:

- To produce an analytical review of modern high-tech materials used in construction and architecture.

The following **objectives** are set in order to achieve the purpose:

- To determine the properties, describe the features and technological characteristics of the materials under consideration
- To provide a typology of high-tech materials, identify advantages and disadvantages for each type
- To provide scientific publications relevant to the material under consideration, dealing with any of the aspects
- To outline the area of application of the material in question and give recommendations on its use.

The main **methodologies** used were analyzing case studies and systematizing the results of these studies.

The field of scientific research covers, analyses, and problematizes a whole range of innovative building materials: from nanomaterials with unique thermal insulation and strength characteristics to biologically integrated materials capable of "self-recovery". As part of this study, the author selected the following options: fiber-reinforced concrete, Cor-Ten steel, and chromogenic windows.

II. Smart Chromogenic Windows. Actualization of the Technology

Glazing occupies one of the central places in the architectural design of buildings. Beyond the architectural and compositional potential, the window is involved in the processes of maximizing the positive effects of exposure to the external climate and minimizing the negative ones. As a transparent element of the building's exterior walls, glazing forms and maintains an optimal indoor climate, influencing such parameters as thermal protection, privacy, insolation, and ventilation.

As a consequence, glazing also retains a leading role in energy efficiency, as translucent structures account for up to 60% of total building energy loss [1].

In one of the first attempts to neutralize the heat loss and optimize the microclimate, low-emission glass was developed and set into operation. The low degree of emissivity (ability to absorb and release heat) in such windows is provided by a thin two-layer metallic coating, where the first layer is formed by silver ions and the second one by titanium oxide. The combination of these elements creates a filter that prevents the passage of long UV waves, i.e. excessive solar radiation, saving up to 78% of heat compared to conventional glass.

However, a comprehensive solution to the challenges of glazing has been achieved with the new generation of light-transmitting structures, so-called "smart" windows. The features of the smart window are based on chromogenic materials, which can change the degree of its light transmittance from completely transparent to completely dark state under the influence of various external conditions. By adjusting the level of window tint, insolation parameters (amount of light and heat) can be effectively controlled, adapting the indicators to the thermal and light comfort values inside the premises [2].

Fig. 1 – Darkening gradation of chromogenic glass

The use of chromogenic materials has also improved the energy efficiency of buildings. In summer, the infrared waves coming in through a standard window greatly increase the room temperature. Reducing the intensity of this exposure reduces the energy consumption of air conditioners used to cool rooms. In winter, solar radiation can be effectively utilized to warm up the interior space. According to some reports, 20–25% of thermal energy savings and 25–30% of energy savings in lighting are due to the reduction of loss through the window area [1]. In a detailed study of energy saving and the economic effect of electrochromic glazing calculations for a typical office building, the annual saving was 8.89% [3].

Typology of smart glass: properties and operating principle. Advantages and disadvantages of each type

Smart glass is classified according to the nature and operating principle of the underlying chromogenic material, which can be electrochromic, photochromic, liquid crystal, thermochromic, or containing suspended particles.

1. Electrochromic (EC) glass

The technology of EC materials is based on their ability to reversibly change their optical properties, changing from a transparent to a colored state, under the influence of electric current or voltage.

The EC glass design is a multilayer structure with a central layer of electrolyte, a layer of EC material to the right, and a counter electrode to the left. Further, there are transparent conductors and plain glass on both sides. The transition from one optical state to another takes place when the electric current is applied to the layers with conductors. The conductors trigger the intercalation process (reversible incorporation of ions into the interlayer space of layered materials) of lithium ions (Li^+). Moving from the side of the counter electrode through the electrolyte layer, which provides a transition of ions and a stable state of the system, the ions intercalate into the EC layer, triggering the reduction process, which results in the complete darkening of the glass. In the absence of voltage, ions are reversed, oxidizing the counter electrode and providing transparency to the glass. The amount of light transmitted and thus the degree of glass darkening is controlled by the number of ions supplied [3].

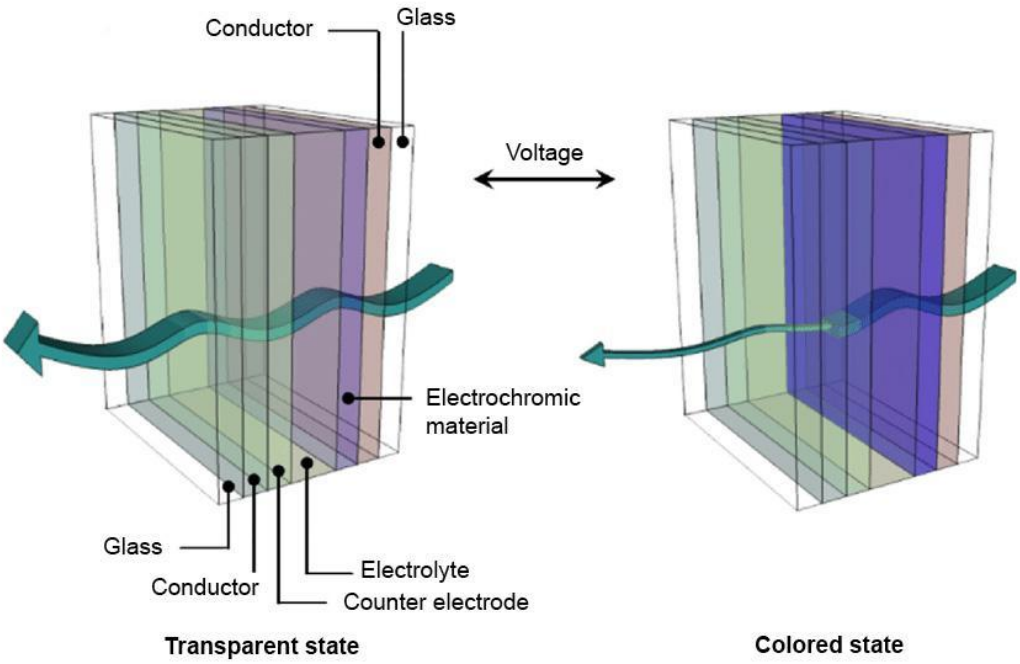


Fig. 2 – Illustration of the multilayer EC glass structure

For a conventional EC device, the maximum transparency in the visible part of the spectrum lies between 70 and 50%, while in the fully dark (colored) state, it decreases to values between 25 and 10% [2].

The inorganic EC layer responsible for coloring the glass is represented by a film or coating containing metal oxides, among which tungsten trioxide (WO3) is the most common, and the counter electrode usually contains nickel oxide (NiO). Each metal stains the EC glass with a special color that is different in reduction-oxidation states as well (Fig. 3). Electrolytes, whose main property is ionic conductivity, are represented by solutions of acids and salts, which, however, contribute to the degradation of EC glass and are nowadays replaced by solid-state electrolytes [4].

Material	Coloration	Color at		Coloration efficiency (cm^2/C)
		reduction	oxidation	
WO_3	Cathode	Colorless	Blue	42–115
TiO_2				5
MoO_3				77
V_2O_5		Yellow		15
Nb_2O_5		Colorless	Brown	12
NiO	Anode	Brown	Colorless	-36
Li*(illegible)*CoO_2		Blue	Blue	-10
$Li_{0.5}Ni_{0.5}O$		Brown	Brown	-40

Fig. 3 – Types of metal oxide coloration of the electrochromic layer [4].

Different options of the metal combinations used in EC glass layers change some properties of EC glass, i.e., transmission and absorption of waves and speed and depth of coloration/lightening. The change in the properties and characteristics of EC glass at application and combination of different EC materials has been detailed in the paper [5].

2. Polymer dispersed liquid crystal (PDLC) devices

PDLC devices use liquid crystals as the active ingredient. In the absence of voltage, they are freely distributed or dispersed (dissipated) within the liquid polymer, which then solidifies and stabilizes them. When a current is applied, the film becomes transparent as the liquid crystals form ordered structures that help to increase the level of transmitted light.

A mixture of liquid polymer and liquid crystals is usually placed between two sheets of glass or plastic coated with a layer of transparent conductive material required to energize and solidify the polymer [6].

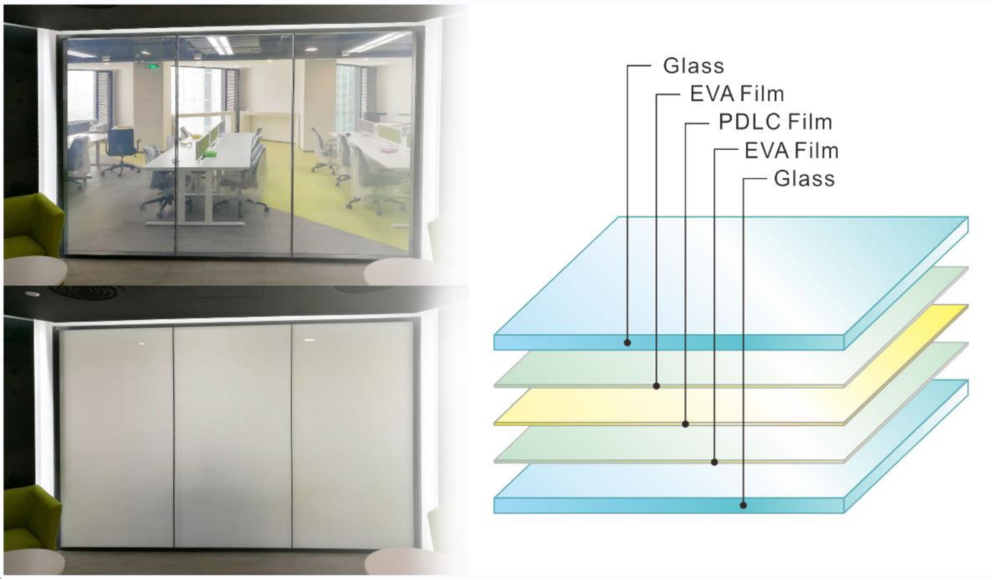


Fig. 4 – Switching modes and structure of PDLC

3. Suspended Particles Devices (SPD)

As in the case of EC glass, the SPD concept is based on the change in the behavior of elementary particles at the moment of electrical current supply. The difference lies in the EC layer itself, which is formed here by a film with microdroplets of liquid with suspended particles dispersed in the polymer. In the absence of voltage, the particles remain in a chaotic state, partially absorbing sunlight. In this phase, the glass may have shades of grey, black, or dark blue. When an electric current is applied, the suspended particles form a structure and the glass becomes transparent. The transition is instantaneous. The distinctive feature of the material is that it is optically transmissive in any state [7].

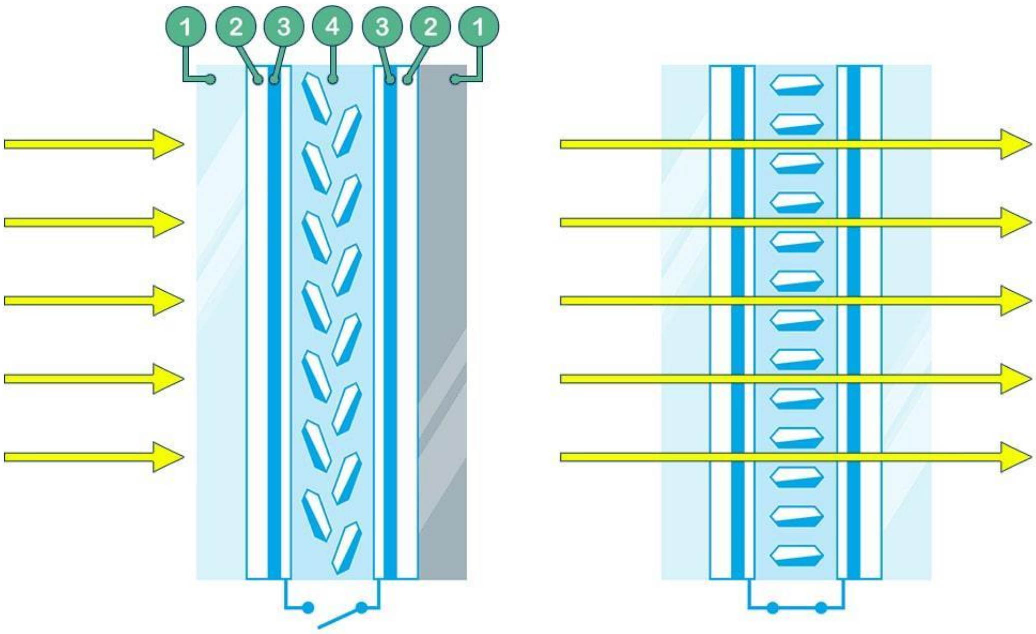


Fig. 5 – Illustration of the action of suspended particles in different phases of smart glass activity.

4. Thermochromic glass (TG)

TG refers to the passive type of light transmission control. Its activation is autonomous, without the need for an external power source or supervised control. The principle of TG operation is based on the sensitivity of its chromogenic elements to temperature changes.

TG has a complex multi-layered structure. There is a layer of a special polymer gel between the glass and plastic layers. It reacts to temperature changes caused by solar radiation: when heated, the molecules in the gel form long chains whose length exceeds the wavelength of the light hitting the glass, making it opaque. When the temperature drops, the molecules return to their original state and the glass becomes transparent again. The extent of this process depends not only on the intensity of solar radiation, but also on outdoor and indoor temperatures. In the transparent state, glass is able to transmit up to 80% of solar energy, while for the opaque state, this figure drops to 10–40% [8].

5. Photochromic glass (PG)

Just as TG, PG is a passive type of light transmission control. The change in this parameter is influenced by solar radiation. Light transmission is inversely proportional to the intensity of solar radiation. Photochromic components are able to reflect ultraviolet radiation and delay infrared radiation, which makes it possible to control not only the light in the room, but also the level of internal temperature.

Photochromic materials are mainly available in the film format, which is applied to the surface of the glass. The PG basic parameters include the ability to reflect solar radiation up to 58%, to delay infrared radiation up to 99%, to block ultraviolet up to 99%, and to transmit up to 78% of visible light [8].

Table 1 – Advantages and disadvantages of different types of smart glass

Type of smart glass	Advantages	Disadvantages
EC glass	- Does not transmit ultraviolet radiation. - Precisely controls the light and heat passing through. - Provides precise control of the degree of transparency [2].	- The device requires electric current to maintain the smart mode [2]. - The controlled reduction in the intensity of infrared radiation and visible light passing through is achieved mainly by absorption rather than reflection. The absorbed infrared radiation and visible light are converted into heat, which leads to an increase in the glass temperature, sometimes to quite high values of 60 °C. Part of this heat is transferred to the room by thermal radiation and convection [9].
PDLC	· Does not transmit ultraviolet radiation.	· No control of the darkening degree and the need for special additives and coatings to control light and heat [2].
SPD	- Instantaneous switching of states. - Precise control of transmitted light and heat [2].	- Needs special coatings to filter UV radiation. - Needs a constant supply of direct current for the transparent state [2].
TG	- Variety of optical parameter settings. The manufacturer defines the limits of certain optical properties of the glass, which makes it possible to choose the parameters based on the given conditions.	- Limited variability of use. TG changes its transparency in response to temperature exposure, but this process may not be suitable for all light conditions or outside temperatures. - The change in the properties of TG is not instantaneous and may take time to adapt to the new temperature. In a rapidly changing environment, this is highly inefficient.
PG	- Autonomous regulation of sunlight transmittance allows for more precise optimization of air conditioning and heating operation. - Reducing glare and excess light increases the level of comfort in the space.	- On very hot or very cold days, the color change may not be as effective. - PG does not change its properties instantly, it takes time to adapt to changes in light.

Application of smart glass

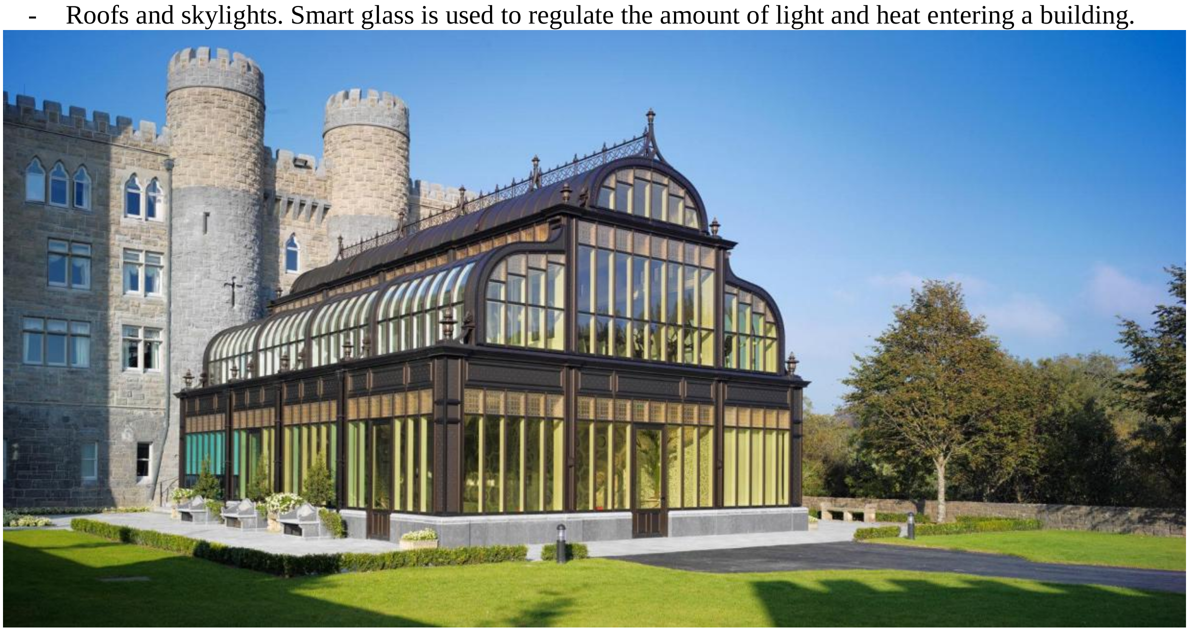
Offices and commercial property:

- Partitions and doors. Most smart glass kinds make it possible to instantly change the transparency of partitions in offices, creating private areas without losing overall light space.
- Conference and meeting rooms. Quickly switching between transparent and opaque states, one can create a confidential environment based on the situation.

Fig. 6 – An example of using smart glass in an office space

Architecture:

- Building facades. Smart glass can adjust light transmission in automatic or manual mode, which helps to efficiently manage the energy balance of buildings, reduce air conditioning and heating costs, and improve the comfort of interior spaces.
- Roofs and skylights. Smart glass is used to regulate the amount of light and heat entering a building.



Figs. 7–9 – A spa center in Ashford Castle, Ireland. The entire perimeter of the pavilion is lined with EC glass, making it possible to regulate the degree of illumination of the internal space

Transport:

- Automotive industry. Smart glass is applied in the production of windshields, door windows, and car roofs, allowing their tint level to change depending on lighting conditions.
- Aviation and marine vessels. Smart glass is applied in pilot compartments and windows of passenger airplanes, and in portholes of marine vessels for protection from excessive sunlight and privacy control. "More than 30 different aircraft models are equipped with smart glass portholes that reduce maintenance costs and block UV rays to protect the interior of the aircraft" [10].

Advertising and design:

- Storefronts and display spaces. Smart glass can serve as an effective tool for creating dynamic visual objects and attracting the attention of customers.
- Interior design. Smart glass can function as an interior element that makes it possible to quickly change the appearance of a room.

Recommendations for the application and operation of smart glass

The application and operation of different types of smart glass require special attention to their characteristics and conditions of use. Key recommendations that help to maximize the potential of smart glass and extend its life are as follows.

Before installation and use:

- **Careful selection:** It is important to ensure that the chosen smart glass is suitable for the specific application, taking into account its type, functionality (tinting, privacy, thermal insulation), and compatibility with existing room control systems.
- **Structural compatibility:** It is also advisable to pre-check the smart glass compatibility with other materials and elements of the interior and facade.
- **Expert installation**: To avoid damage to the glass and ensure its correct operation, installation by expert technicians is advisable.

In operation:

- **Regular cleaning:** Use soft cloths and specialized glass cleaners when cleaning. This will help avoid scratches and maintain clarity. Abrasive cleaners and rough sponges should be avoided.
- **Damage prevention**: Do not hit the glass with hard objects or apply excessive pressure. Doing so may damage it or cause the failure of a control mechanism.
- **Performance monitoring:** All components of the smart glass (electrical connections and control systems) should be checked for proper functioning periodically. This is necessary for the timely detection and elimination of malfunctions.
- **Overload protection:** Power supply should always be selected in accordance with the manufacturer's requirements. Never connect the glass to unstable or overloaded power grids.

III. Fiber-Reinforced Concrete. Rationale

Conventional concrete, considering its undeniable advantages, has a number of design flaws that can reduce durability and limit its use in certain conditions. While it has a relatively high compressive strength, it loses a lot in tensile strength, which makes it vulnerable to cracking when subjected to tensile loads or temperature fluctuations. The elasticity parameter of concrete at low stress maintains acceptable values, however, as the stress increases, the number of micro cracks also increases, adversely affecting the elasticity. The resulting sum of micro-cracks, under certain circumstances, grows into macro-cracks, leading to severe material degradation.

Promising developments in the field of dispersed reinforcement of the concrete matrix have become a significant advance in overcoming the structural disadvantages of conventional concrete. Various types of fibers made from different materials in the form of small discrete elements of numerous shapes and sizes have been used as disperse materials [11]. The composite material created with fibers is called fiber-reinforced concrete.

The qualitative change in the structural and operational qualities of fiber-reinforced concrete has attracted a lot of attention of the scientific community, practitioners, and business representatives. This, in turn, affected the increase and deepening of experimental and research works related to this material, the development and formulation of GOST standards, requirements and norms, as well as the emergence of the market for such materials. It seems currently that high-tech modification of conventional concrete has firmly taken its position, but the nature and prevalence of analytical, experimental, and critical scientific works devoted to fiber-reinforced concrete suggest that the process of comprehensive data acquiring on the properties and qualities of the composite has not yet passed the main phase. However, the forecast of a significant increase in fiber-reinforced concrete demand/supply is quite assertive.

Technology and general properties of fiber-reinforced concrete

The workability of fiber-reinforced concrete is formed by modifying the structural base of concrete. Thus, one of the key aspects that determine the performance of fiber-reinforced concrete is the relative stiffness of the matrix and fibers. According to available research, fiber reinforcement of concrete is based on the fact that the concrete matrix transfers loads to the fibers through tangential forces acting at the interface. When the elastic modulus of the fibers exceeds that of the matrix, the fibers take up most of the loads. Thus, the overall strength of the composition is directly related to the volume of fibers in it [11].

In addition, the character of fiber-reinforced concrete changes when the parameters of fiber materials, i.e., their quantity, shape, and geometry are varied. Fiber distribution, orientation, and density also play an important role. It is important to use a variety of fiber sizes to create a dense concrete mass. This allows the smallest particles to fill the spaces between larger particles, contributing to the strength and density of concrete [12].

The fibers used as reinforcement have certain characteristics. They can have either a round or a flat cross-section. Depending on the source material, they are divided into steel and non-steel ones, including products of acrylic, aramid, carbon, basalt, glass, polyethylene, polyester, nylon, polypropylene, and other materials [11].

Fiber-reinforced materials have good strength-to-weight ratio, high fatigue resistance, effective resistance to corrosive environments, and low thermal conductivity and are characterized by their relatively low life cycle costs, which makes them a preferred option for many applications [13].

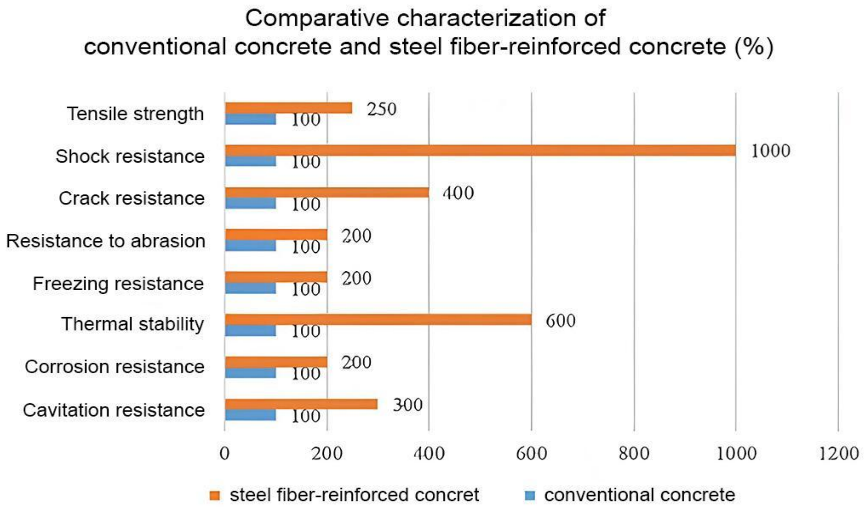


Fig. 10 – Comparative characterization of conventional concrete and steel fiber-reinforced concrete [14]

Typology of fiber-reinforced concrete according to the fiber used in the composite. Advantages and disadvantages of each type

Steel fiber-reinforced concrete: A type of composite concrete reinforced with steel fibers that are added to the concrete mix to increase its strength and performance characteristics. Fibers come in a variety of shapes and sizes including straight, wavy, and coated with copper, brass, and bronze for better adhesion to the concrete matrix.

Fig. 11. Variety of steel fibers for concrete reinforcement

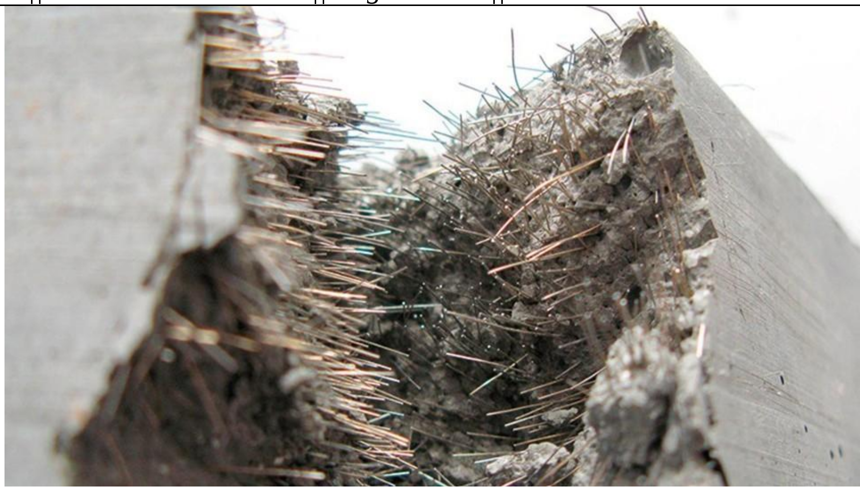


Fig. 12. Steel fiber distribution in the concrete matrix

Table 2. Advantages and disadvantages of using steel fiber in composite concrete

Advantages	Disadvantages
- The addition of steel fiber to the material helps to increase its load-bearing capacity, reduces the thickness of the structure, and increases the level of elasticity and frost resistance [11]. - Reduces the thickness of the coating by 40–50% with the same load-bearing values as conventional concrete has. - Improved compressive and tensile strength. Steel fibers effectively distribute the load within the concrete. - Improved resistance to impact and abrasion. Steel fiber-reinforced concrete has increased resistance to physical impact due to the evenly distributed steel fibers. - Increased crack resistance. The fibers redistribute stresses and prevent crack propagation. - Better resistance to freeze-thaw cycles: due to the discontinuity of concrete deformations obtained by dispersed fiber reinforcement.	- The loss of material during processing is equal to the total volume of fibers in the concrete. - When exposed to moisture, steel fibers can corrode, affecting the durability and strength of the structure in the long term. - Steel fiber-reinforced concrete is rigid and can make coating and surface forming difficult, requiring special equipment and skills. - To achieve optimum material performance, fibers need to be uniformly distributed throughout the concrete, which can be difficult to achieve in practice. - Steel fibers can cause rapid wear of concrete mixing and pumping equipment and increase the risk of corrosion.

Glass fiber-reinforced concrete (GFRC): A composite that combines the properties of concrete and glass fiber. The composition includes short glass fibers, which serve as a reinforcing component that increases the strength and performance of the concrete. The application of alkali-resistant glass fiber is most common due to its resistance to the alkaline environment of concrete.

Fig. 13. Glass fiber

Table 3. Advantages and disadvantages of using glass fiber in composite concrete

Advantages	Disadvantages
- Glass fiber concrete has high bending strength and resistance to cracking. - The material can be used to create complex shapes and textures, making it popular in architectural design. - Glass fibers are not susceptible to corrosion. - The ability of glass fiber-reinforced concrete to accurately reproduce almost any shape of the matrices used makes it possible to create products that accurately copy architectural ornaments, patterns, and reliefs [15]. - Increased crack resistance. The fibers redistribute stresses and prevent crack propagation. - Better resistance to freeze-thaw cycles: due to the discontinuity of concrete deformations obtained by dispersed fiber reinforcement. - Glass fiber-reinforced concrete has very good plasticity and can be easily dyed without losing its strength properties provided that the dye content does not exceed 3% [11].	- Low resistance to the alkaline environment that occurs in hardening cement binders, which means the medium in which the glass fiber is placed must be chemically inert [11]. - Low elastic modulus and relatively high specific gravity. - Sensitivity to abrasion during handling. - High hardness. - Relatively low fatigue resistance [16]. - Glass fiber can lose its strength properties at high temperatures. - Requires special laying techniques and experience when working, which can increase construction labor costs.

Concrete with added optical fiber: also known as ***light-transmitting concrete*** or ***transparent concrete***. It is an innovative building material that combines the basic technological properties of concrete with the ability to transmit light through optical fibers embedded in the mass.

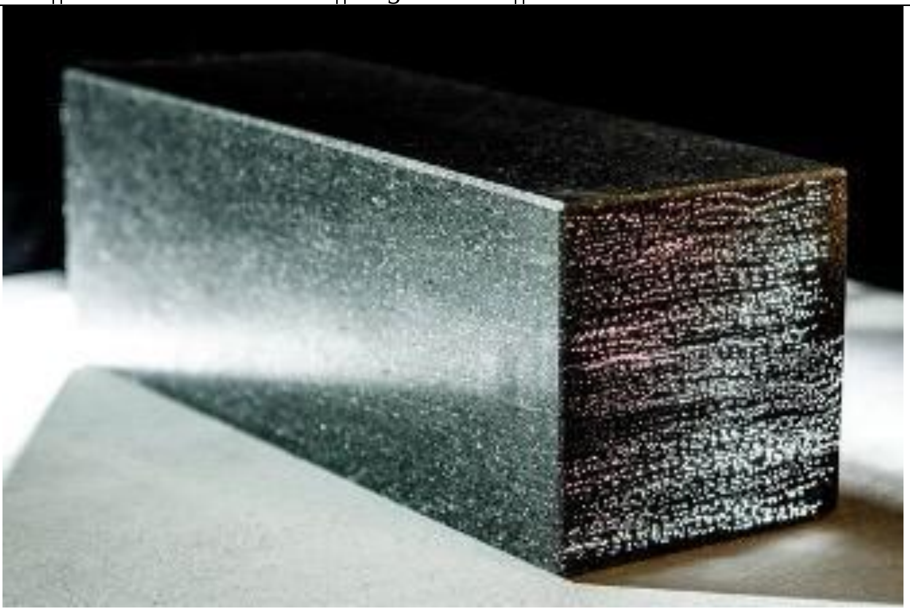


Fig. 14. Concrete with the addition of optical fibers

Table 4. Advantages and disadvantages of fiber-reinforced concrete with optical fiber addition

Advantages	Disadvantages
- Made from recycled materials. The main recyclable component is optical fiber, which is made from glass waste [17]. - Unique design opportunities. Allows creating visually appealing, internally glowing structures. - Strength and durability: it maintains the basic strength characteristics of concrete.	- Limited use. Due to the specific nature of the material, its use is limited to certain design and architectural projects. - Manufacturing complexity. Requires the precise positioning of optical fibers and the high quality of their incorporation into the concrete mass.

Fiber-reinforced concrete with carbon fiber: A high-tech composite building material that incorporates carbon fibers to act as a reinforcing component of the concrete matrix. Fibers greatly improve the mechanical properties of concrete, making it durable and lightweight. This type of fiber-reinforced concrete has high compressive and tensile strength. It is also characterized by its high resistance to corrosion, shock, vibration, and chemical impact.

Fig. 15. Carbon fiber

Table 5. Advantages and disadvantages of carbon fiber-reinforced concrete

Advantages	Disadvantages
- Durability. Due to its resistance to corrosion, the material retains its properties for a long time. - The low weight of the material reduces the load on the foundation and other parts of the building. - Allows for thinner but stronger structures. - "Carbon fiber is resistant to all aggressive environments and chemical elements. Such fibers have high thermal insulation properties and are also non-combustible" [11]. - Using simple processing techniques, it is possible to reuse carbon fiber to reinforce structural elements made of high-performance fiber-reinforced concrete [16].	- Special paving methods. Requires special knowledge and skills to handle and lay. - Limited use. Its high price and specific properties make it less available for a wide range of construction projects.

Basalt fiber-reinforced concrete: The material created with basalt fibers combines the strength qualities of concrete with the high-performance characteristics of basalt fibers. Fibers are manufactured from natural samples by melting and then drawing thin blanks. They have high levels of durability and resistance to environmental conditions.

Fig. 16. Natural basalt fiber

Table 6. Advantages and disadvantages of basalt fiber concrete

Advantages	Disadvantages
- Basalt is obtained from volcanic rocks that have hardened in the open air. From an environmental point of view, they are absolutely safe [11]. - Basalt fiber-reinforced concrete is characterized by increased durability due to its resistance to corrosive processes and chemically active media. - It is far superior to traditional types of concrete in terms of strength properties. - It provides good protection against thermal and sound effects.	- Limited availability. The capacity to manufacture basalt fibers is not available in several regions, which may limit access to the material.

Fiber-reinforced concrete with polypropylene fiber: In this type of fiber-reinforced concrete, fiber is used to prevent the formation and development of micro-cracks, both during the concrete curing process and in service.

Fig. 17. Fiber made of polypropylene

Table 7. Advantages and disadvantages of polypropylene fiber-reinforced composite concrete

Advantages	Disadvantages
- Polypropylene fibers improve concrete permeability, flexural impact, and resistance to chloride attack [18]. - The experimental study of concrete composite with polypropylene fibers demonstrated a 14% increase in compressive strength, 17% in tensile strength, and 8.5% in flexural strength [18].	- Careful mixing of concrete is necessary to ensure the uniform distribution of the fibers and to achieve the desired properties.

Application area of fiber-reinforced concrete considering different reinforcing fibers

1. **Industry and civil engineering:** Fiber-reinforced concrete is used for the construction of envelopes and load-bearing structures to increase their service life. In particular, steel fiber-reinforced concrete is widely used for road and wall covering of airfield territories, in tunnel finishing, and in strengthening and construction of coastal protection structures.

Steel fiber-reinforced shotcrete has successfully replaced welded mesh in tunnel lining. Steel fibers have performed well in applications where multi-directional reinforcement is required [16].

2. **Marine and hydrotechnical construction:** Steel fiber-reinforced concrete is often used to restore and repair offshore structures, e.g., concrete piles and caissons, demonstrating good performance when exposed to water and erosion in harsh environments. Carbon fiber-reinforced concrete is often used in hydraulic structures due to the carbon fibers' ability to resist aggressive environments, including chemical attack.
3. **Residential construction:** Steel fiber-reinforced concrete allows creating thin-walled structures used as permanent formwork, roofing materials, underground communications, monolithic shells, and hydraulic structures [11].

Recommendations for the application and use of GFRC

1. **GFRC as a material for creativity and decoration:** Unlike other common building materials imitating wood or stone, GFRC stands out for its ability to accurately recreate the texture of natural materials through external tinting or special printing. Pigments are added to the mortar to obtain the desired color stain. The introduction of fillers into the mix, such as stone chips in different colors, helps to create a unique texture.
2. **Transportation of GFRC:** GFRC requires special care during preparation, manufacture and transportation, but once installed, it is strong, durable, and repairable.
3. **Incorporation of decorative GFRC elements into the facade plane:** When designing fastening systems for the building facade, the interaction of the GFRC elements with windows or roofing should be taken into account. It is important to pre-determine the nature and order of installation works: the initial and final stages, algorithms of lifting parts, and methods of their fastening. It is also necessary to consider the thermal expansion of GFRC and leave a gap of at least 3 mm between the elements.
4. **Waterproofing:** Hydrophobization can help in providing additional protection against weather conditions and increasing the water resistance of the material, and, furthermore, sealing the material [19].

IV. Cor-Ten steel

Cor-Ten steel is one of the most popular technological materials, which are now widely used in architectural practice, construction, and design. Cor-Ten was developed by the U. S. Steel company in 1933 and was originally used primarily in industrial construction. As recently as in the 21st century, within the framework of modern ethical and aesthetic trends, it has been rediscovered not only for its structural and performance characteristics, but also for its decorative properties and environmental friendliness.

Cor-Ten Technology

Cor-Ten refers to alloy steel, which contains phosphorus, copper, chromium, nickel, silicon, and manganese in addition to carbon and iron. Depending on the steel grade, alloying elements may include silicon, molybdenum, titanium, and vanadium. These elements in certain proportions increase the performance characteristics of steel, providing high resistance to atmospheric corrosion and mechanical stress. Compared to conventional carbon steel, the corrosion rate in the Cor-Ten chemical structure is 5–7 times slower [20].

Steel grade	Corrosion rate (nm per 10 years)
Cor-Ten A	20-30
Cor-Ten B	75-100
Carbon steel	150-200

Fig. 18 – Corrosion rates in different grades of Cor-Ten steel and conventional carbon steel

Cor-Ten technology is based on oxidation and rusting processes. In the natural environment, during the wetting and drying cycles, the chemical composition of the steel triggers oxidation, which results in the surface being covered with a self-recovering dense oxide layer that closes the pores of the metal and prevents oxygen and moisture from penetrating the molecular structure of the material. A similar mechanism underlies the patination of copper and bronze products: surface oxides form a protective layer, preventing internal harmful corrosion processes [21].

The protective layer on the surface of Cor-Ten steel is different from conventional rust: its structure is denser and more homogeneous, with a characteristic velvety texture. The uniformity of the rusting process creates another feature of Cor-Ten: a gradual change in the shade of the oxide layer. Depending on environmental conditions, the color varies from light reddish to rich chocolate brown. "The rate of change and final color depends on the surrounding atmospheric conditions and the presence of contaminants in the air – sulfur will speed up the oxidation process and give the patina a darker color. Frequent changes in dry and humid conditions will also accelerate oxidation" [22].

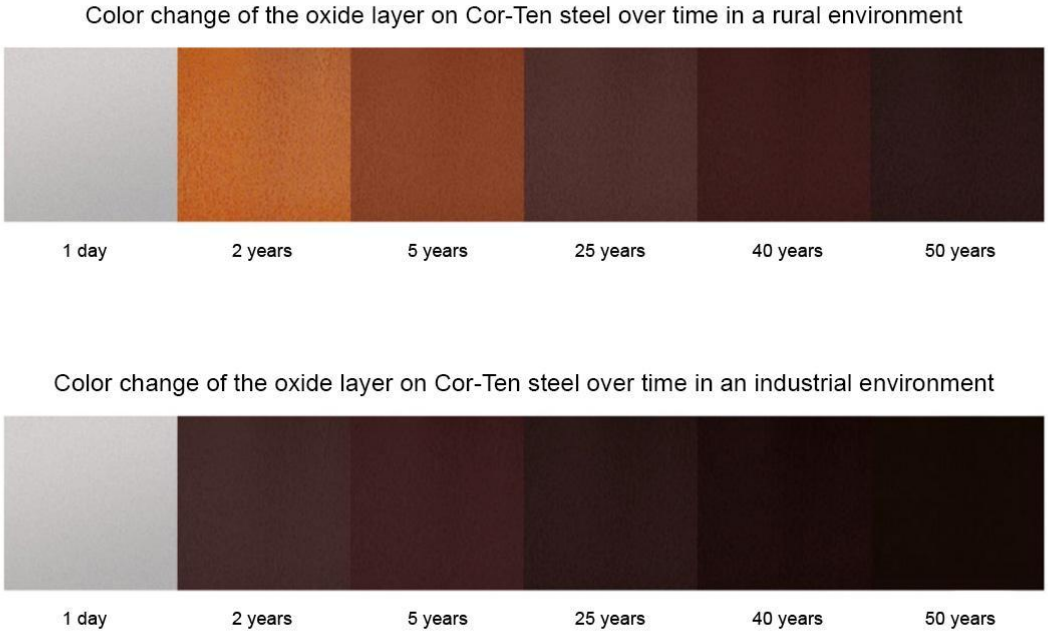


Fig. 19.Cor-Ten steel color change in industrial and rural environments

Cor-Ten steel does not need subsequent treatment with anti-corrosion compounds and coloring, which increases the environmental friendliness of the material. However, it can be painted with any paint designed for anti-corrosion treatment, as needed. "Studies have shown that the durability of an alkyd paint coating of Cor-Ten is 1.5 to 2 times longer than that of carbon steel. The figure below (on the left) shows the appearance of the painted Cor-Ten and carbon steel samples after a trial of 15 years in a marine climate. The right side of the figure shows stained samples exposed to the industrial environment for several years" [20].

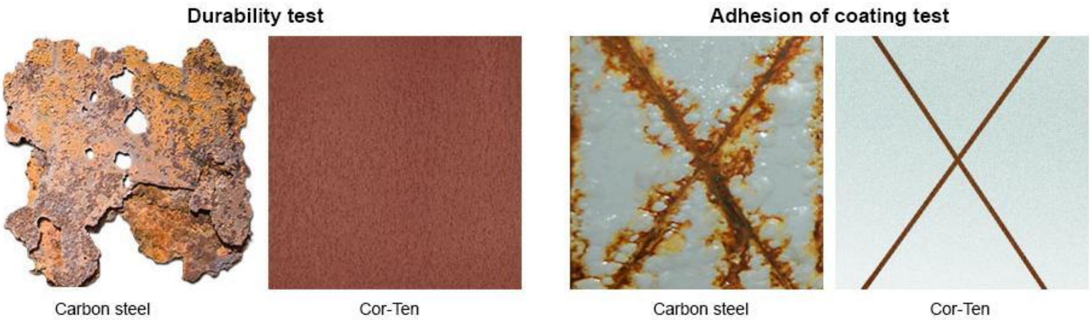


Fig. 20. Difference in coating durability for carbon steel and Cor-Ten

Application of Cor-Ten steel

As mentioned above, due to its enhanced performance characteristics, Cor-Ten steel is successfully used in the construction of civil and industrial facilities. It is used to make load-bearing structures, roof supports, fittings, road and railway bridges, platforms, overpasses, and protective screens. It is actively used in shipbuilding, in the manufacture of ships, tankers, and pontoons [23]. Atmospheric resistance and durability are maintained at elevated operating temperatures. "The maximum operating temperature of Cor-Ten A grade steel is +540 °C" [20]. This allows applying it in heat exchange industrial equipment and smoke extraction systems.

Fig. 21. Application of Cor-Ten steel in bridge construction

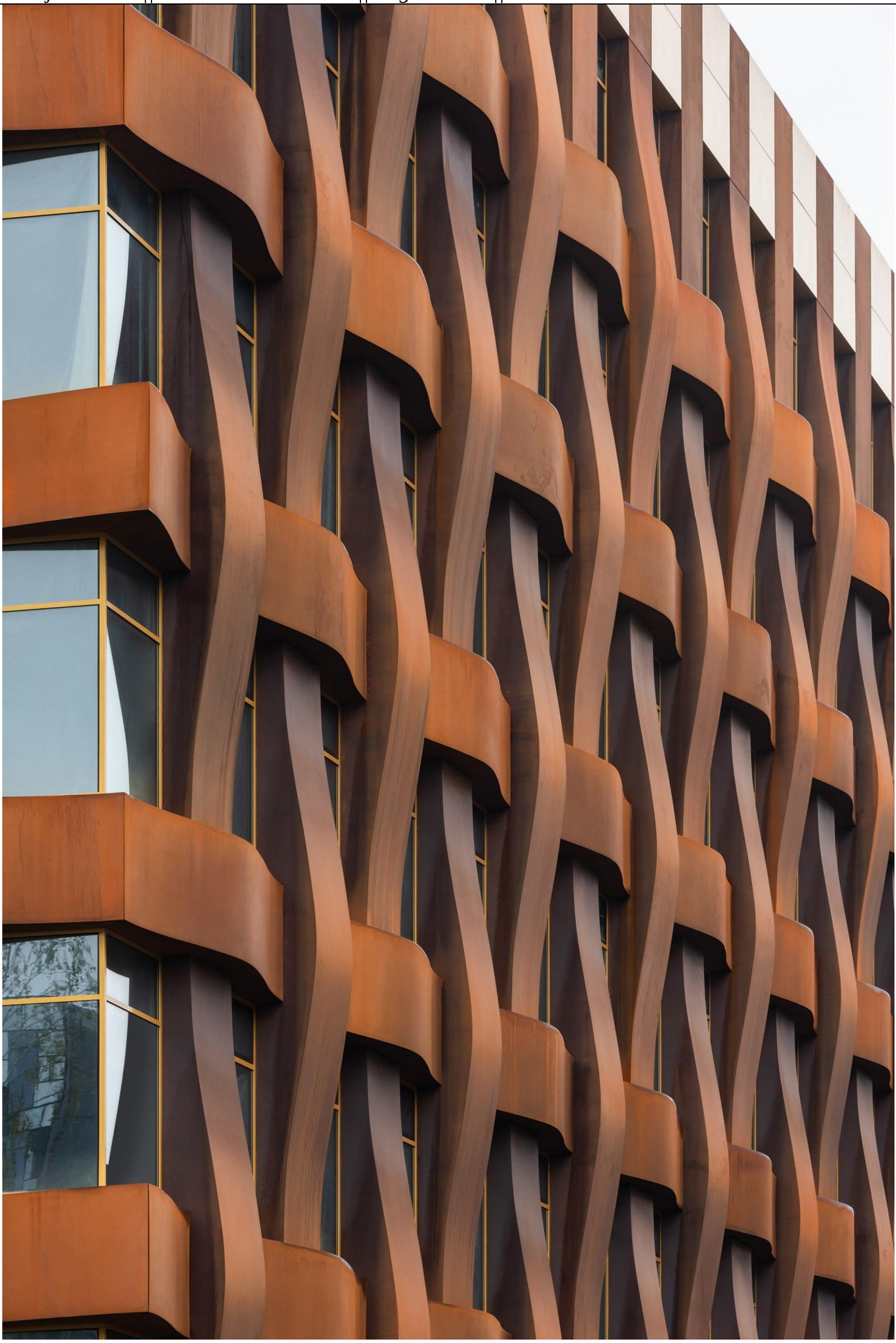
Cor-Ten steel belongs to natural materials, so it is used for construction in environmentally friendly areas: eco-parks, nature reserves, and wildlife sanctuaries. "Due to their anti-corrosion properties, the products are extremely low-maintenance, requiring virtually no anti-corrosion treatment, which dramatically reduces the life cycle operating costs and makes them environmentally friendly due to the fact that they use far less paint and solvents" [24]. In addition, the characteristic shade of Cor-Ten is combined with traditional natural materials, e.g., wood and stone.

Fig. 22.Høse pedestrian bridge, located in the eco-park

Cor-Ten's unique texture and moving, rich color tone have made it popular in architecture, sculpture, and various genres of contemporary art. The successful experience of using steel in the design of building exteriors, in particular facades, has led to the emergence of many architectural objects in the "Cor-Ten style". The Leeds Metropolitan University building can be highlighted as a landmark site. The total area of Cor-Ten steel sheets applied to the building cladding was 9200 m² [25].

Fig. 23 – Leeds Metropolitan University's Broadcasting Place building clad in Cor-Ten steel sheets

In domestic architectural practice, the use of Cor-Ten steel was very vividly realized in the project of the Ferrum business center in St. Petersburg by architect S. Choban.



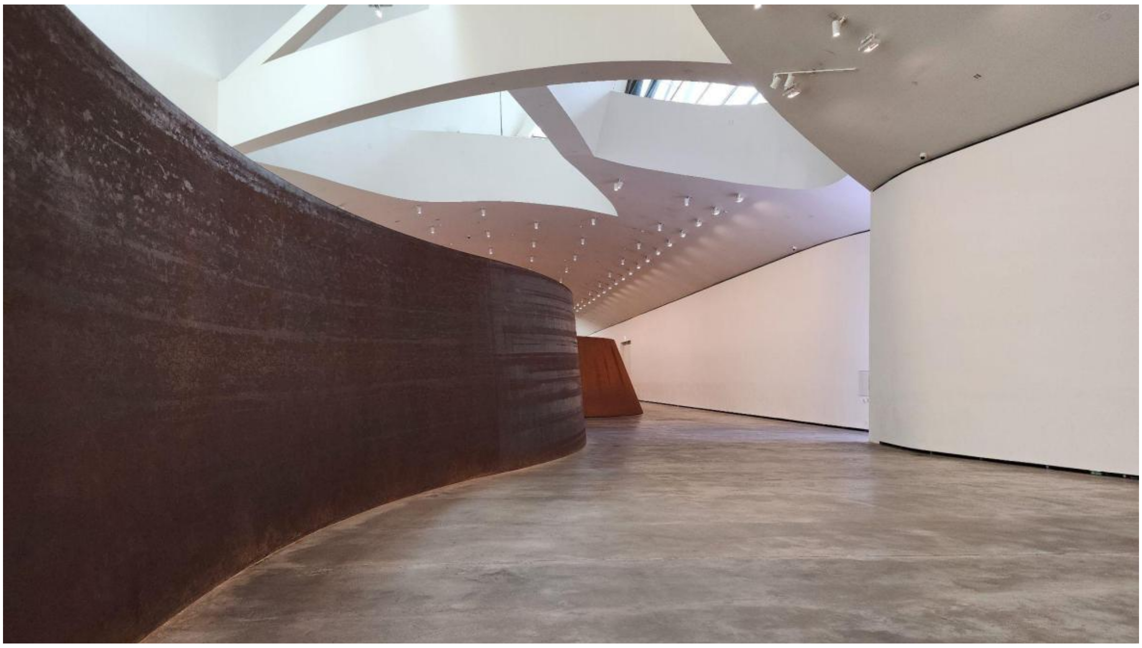
Figs. 24, 25 – Facade of the Ferrum business center in St. Petersburg, Russia

Highlighting the advantages of the material, the architect said: "Cor-Ten initially has a lively heterogeneous surface that other materials only acquire over time. Velvety and softness of tonal transitions combine well with any form of object" [26].

Cor-Ten is suitable for various types of processing: welding, laser cutting, and bending. This allows it to be used to create expressive decorative compositions in design projects. A pavilion designed by the architectural 3ndy Studio and erected during the renovation of Palazzo Campiello near Venice can serve as a good example. Around the perimeter of the half-ruined palazzo, there was created a second facade with historical outlines and a surface decorated with laser-cut quotations of Italian classics [26].

Figs. 26, 27 – Palazzo Campiello pavilion decorated with Cor-Ten steel sheets

Cor-Ten steel gained sculptural expression in Richard Serra's installation at the Guggenheim Museum.



Figs. 28–30 – Installation by R. Serra at the Guggenheim Museum in Bilbao

Cor-Ten steel operation methods

In order to maintain the structural characteristics of Cor-Ten and maximize its decorative potential, a number of recommendations should be followed during installation and use.

1. In order to form a consistent color tone of the steel, it is necessary to ensure the free flow of moisture. Also be aware that dripping water can contaminate materials and areas adjacent to the sheet. Therefore, the site should be protected with drainage. The disturbance of color uniformity is increased at the perforation points of the steel plate.
2. It should be noted that Cor-Ten acquires its color under natural conditions of weather changes. If left in a dry environment, the material will not develop a characteristic color, and too humid conditions will lead to excessive uncontrolled corrosion. If the goal is to leave the Cor-Ten steel object indoors, it is advisable to use means to create an oxide film in a controlled manner. Three formulations are used: act-COR starts the corrosion process, bp-COR stops it, and bz-COR protects the oxide layer from mechanical damage [27]. One can also fix the desired shade by coating the steel with a colorless varnish.

3. The fasteners used in the installation of Cor-Ten sheets should be made of stainless steel, and neoprene or EPDM gaskets can be used. Close contact of steel with wood, copper, and deicing salts should also be avoided.
4. When installing steel plates, a full-length ventilation gap should be provided, at least 30 mm wide. This should also be taken into account when installing using the overlapping method.
5. Steel should be stored in a dry room to ensure uniform color formation. Immediately before installation, remove dirt from the surface. For best results, it is also advisable to remove rolling scale. This can be done by sandblasting or by etching with special agents [23].

V. Conclusion

The review included some modern high-tech materials that are applied in construction and architecture. Each material responds in some way to the global and local demands, i.e., autonomy, sustainability, cost-effectiveness, and aesthetic novelty. Based on the profile literature analysis results, concerning the objects under study, with the identification of their main properties, typology, advantages, and disadvantages, the author draws the following conclusions:

- Smart glass, the concept of which is based on the specific activity of EC materials, has a high potential in creating sustainable and smart architecture. EC windows can adapt to changes in weather conditions: automatically adjusting their light transmission, they allow controlling the temperature and illumination of the room. These properties of EC windows reduce the environmental footprint and increase energy efficiency. Of all types of smart glass, EC glass is the most flexible in terms of control and adaptation to external impact.
- Analysis of the technological and operational properties of fiber-reinforced concretes, structurally based on fibers of different origins (steel, glass fiber, polymers, basalt, etc.), has shown their superior advantages over conventional types of concrete. The main advantages are improved tensile strength, high impact and frost resistance, increased crack resistance, durability, and improved water resistance. These properties allow for stronger, longer lasting, and more efficient building structures that meet today's energy efficiency and sustainability requirements.
- Cor-Ten steel has enhanced structural and performance characteristics compared to conventional carbon steel. This broadens the scope of Cor-Ten application, making its use in civil and industrial construction possible. If the operation methods of steel analyzed in this article are followed, it is appropriate to use it as an environmentally friendly, or environmentally neutral material. Furthermore, the popularity of Cor-Ten in architecture and sculpture is explained by its decorative and structural characteristics.

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