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Characteristics and properties of graphene, a revolutionary material in construction

Características y propiedades del grafeno, un material revolucionario en la construcción

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Abstract

Research concerning the potential of graphene in the construction industry, the study of its properties and its influence on traditional building materials is abundant. It was investigated that graphene contains carbon atoms located in a hexagonal structure, with which we assure a revolution and development in the construction of buildings and structures. With the objective of demonstrating its high mechanical resistance, as well as determining its durability and reinforcement in composite materials. For the research we considered points such as its high thermal and electrical conductivity that makes the material attractive, increasing energy efficiency and reducing construction costs. A qualitative methodology that collects non-numerical data was established for the research. This scientific paper emphasized the exceptional mechanical, electrical and thermal properties of graphene, material consisting of carbon atoms. The advantages of including graphene in construction materials, such as increased strength, conductivity and durability, were recorded. The implementation of graphene remains costly due to complex processes and high purity despite being a recyclable and sustainable material found in abundance in nature.

Keywords: Electrical conductivity, energy efficiency, graphene, composite materials, mechanical properties.

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Resumen

Abundan las investigaciones sobre el potencial del grafeno en la industria de la construcción, el estudio de sus propiedades y su influencia en los materiales de construcción tradicionales. Se ha investigado que el grafeno contiene átomos de carbono situados en una estructura hexagonal, con lo que se asegura una revolución y desarrollo en la construcción de edificios y estructuras. Con el objetivo de demostrar su alta resistencia mecánica, así como determinar su durabilidad y refuerzo en materiales compuestos. Para la investigación consideramos puntos como su alta conductividad térmica y eléctrica que hacen atractivo el material, aumentando la eficiencia energética y reduciendo los costes de construcción. Para la investigación se estableció una metodología cualitativa que recoge datos no numéricos. Este artículo científico hizo hincapié en las excepcionales propiedades mecánicas, eléctricas y térmicas del grafeno, material formado por átomos de carbono. Se registraron las ventajas de incluir el grafeno en los materiales de construcción, como el aumento de la resistencia, la conductividad y la durabilidad. La aplicación del grafeno sigue siendo costosa debido a la complejidad de los procesos y a su elevada pureza, a pesar de ser un material reciclable y sostenible que se encuentra en abundancia en la naturaleza.

Palabras clave: Conductividad eléctrica, eficiencia energética, grafeno, materiales compuestos, propiedades mecánicas.

Introduction

A new material has emerged as a strong candidate to transform several industries, such as construction, in recent years. Due to its extraordinary properties, graphene, a two-dimensional material made up of a single layer of carbon atoms, has attracted engineers and scientists. Its ability to change the way we build and design our cities has generated great expectations since its discovery. This article analyzes the distinctive attributes of graphene, its uses in construction, and the challenges that continue to exist in its large-scale implementation (Fonseca, 2017).

Consistent with Martínez et al. (2022) in the world of materials science, the discovery of graphene at the beginning of the 21st century was an unprecedented milestone. This nanomaterial, formed by a layer of hexagonal-shaped atoms, has extraordinary properties that make it a material with transformative potential in various industries, including construction.

The discovery of the structure of graphene was made using a technique called mechanical exfoliation. Basically, the researchers took a piece of graphite and used duct tape to separate it into increasingly thinner layers. Finally, they managed to obtain a

single layer of graphene, which they were able to study and analyze in detail (Sumdani et al., 2021).

Based on Wan et al. (2012) graphene has unparalleled lightness due to its extreme thinness, barely one atom thick, which distinguishes it from other materials. Graphene stands out for its strength, flexibility, lightness and resistance. This material is approximately 200 times stronger than steel and approximately 5 times lighter than aluminum.

Graphene is a nanomaterial formed by a group of hexagonal-shaped atoms that are joined by covalent bonds. Its basic structure is made up of a single layer one atom thick, making it extremely thin. The structure of graphene is on a nanometric scale and practically two-dimensional, forming uniform surfaces composed of between 1 and 10 atoms. The most important advantage of graphene is that it is obtained from natural graphite, which is abundant in nature. However, its large-scale manufacturing is difficult and expensive (Gómez et al., 2021).

According to Gómez et al. (2018), graphene has many properties, but the most important are its high thermal and electrical conductivity, elasticity, hardness, lightness and resistance. some characteristics that could be very useful to innovate in various sectors and represent a true revolution. Graphene is an exceptionally effective thermal insulator for construction. Its electrical conductivity offers a wide range of electronic uses in buildings. (Zumba et al., 2025)

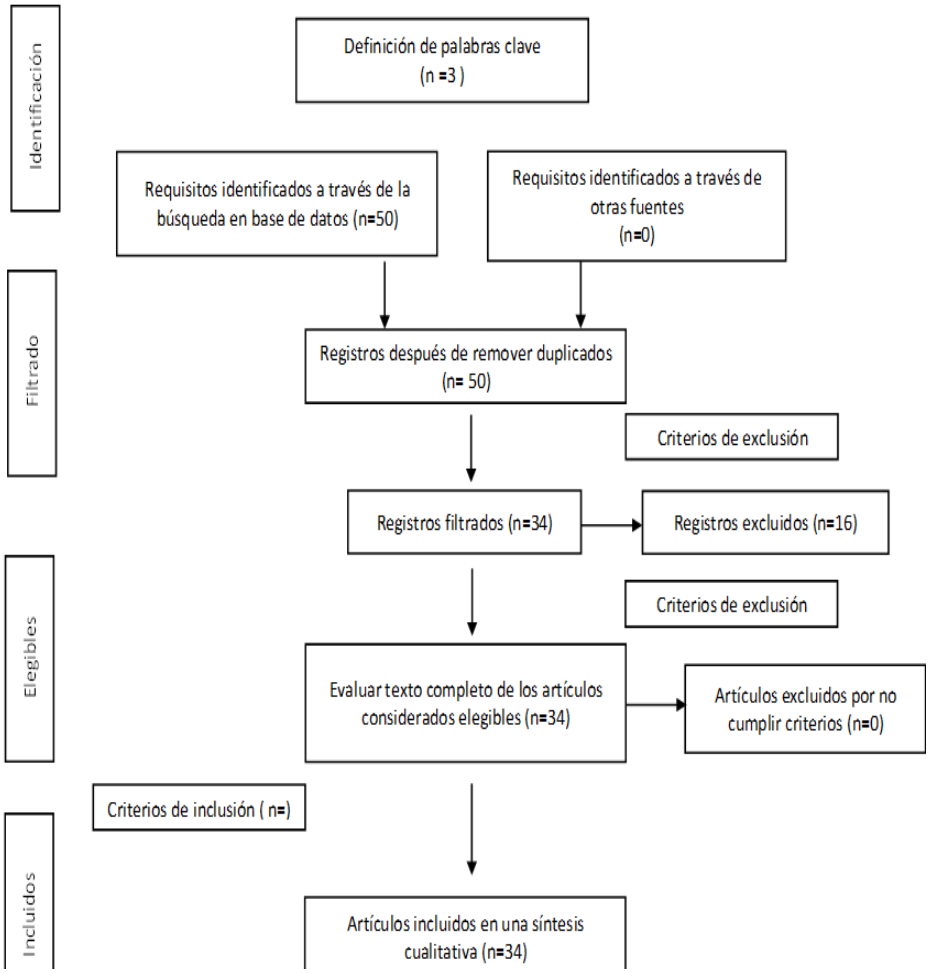
In his research Carreon (2016) states that another notable feature of graphene is its flexibility. This material is ideal for lightweight structures and panels because it can bend and deform without breaking. Its transparency, similar to that of glass, opens new perspectives for the design of windows and architectural elements (Zumba et al., 2025).

Graphene has characteristics that make it a highly sustainable material. Graphene is primarily composed of carbon, which is abundant on Earth, making it easy to obtain from a variety of sources. Graphene is recyclable and reusable, which means that its impact on the environment is minimal (Padilla et al., 2018).

Materials and methods

The research was carried out with a qualitative method, which is based on a complete review of non-numerical data. To find research examining the characteristics of graphene and its uses in construction, a systematic search was conducted in academic databases. The relevance of the research topic and the methodological quality of the studies constituted the inclusion criteria. After investigating 50 references (books, websites, articles) we selected a total of 34 references from which we analyzed important information for our study. Figure 1 illustrates the literature review process following the PRISMA method, detailing the identification, screening, eligibility and inclusion stages of the selected studies.

Figure 1. Literature review process through the PRISMA method



Keyword selection

Three main keywords were defined: "graphene", "energy efficiency" and "construction materials". These keywords were used to guide systematic searches in scientific databases.

Search and filtering of studies

The search was carried out in academic databases, initially identifying 50 records. Studies from other sources were not included. Duplicate studies were subsequently removed, maintaining a total of 50 unique records. The exclusion criteria were studies not related to construction, research with incomplete methodology or insufficient data. After applying these criteria, 34 filtered records were selected, excluding 16 studies that did not meet the study objectives.

The full text of the 34 articles considered eligible was evaluated, ensuring that they met the inclusion criteria, such as topic relevance (graphene and construction) and methodological quality. No additional articles were excluded at this stage.

Finally, the 34 selected articles were included in the qualitative synthesis, allowing the exceptional mechanical, electrical and thermal properties of graphene to be analyzed, as well as its potential impact on the construction industry. This methodological process ensured the collection of relevant and up-to-date information, providing a solid foundation to understand the revolutionary role of graphene in the development of innovative and sustainable construction materials.

Results

Through the literature review, it was found that graphene is a substance composed of pure carbon, with atoms organized in a regular hexagonal pattern, similar to graphite (Álvarez, 2018). Graphene is used in construction to create corrosion-resistant materials, improve the thermal and electrical properties of composites, and reinforce materials to make them lighter and stronger. Graphene can also eliminate static electricity generated by rubbing, making it useful in a variety of construction applications (Nguyen & Nguyen, 2016).

According to Polit (2022), the incorporation of graphene sensors and actuators in structures would allow monitoring and controlling the performance of buildings in real time to maximize their efficiency and safety. Graphene could also lead to the creation of new, more efficient and sustainable heating and cooling systems. Despite the enormous potential of graphene, its large-scale implementation in construction remains a challenge. Current production methods are expensive and complex, making them less profitable in the market. Continued research and development are essential to reduce graphene costs and optimize production processes. According to Dai (2013) graphene is also used in the manufacture of rechargeable batteries, which could significantly improve energy efficiency and allow

Graphene is an excellent option for reinforcing construction materials due to its great strength and lightness. The stacking and overlapping domains of the nanotubes improve the strength of the material, making it a better conductor than regular graphene grown by CVD (chemical vapor deposition). For applications that require lightness and strength, such as in the construction of composite materials, graphene is ideal because it is very light, like that of carbon fiber, but more flexible (Carrión, 2020).

According to Mayora et al. (2015) in his research he mentions the following "The high thermal conductivity of graphene makes it useful for improving the thermal insulation of buildings with reduced thicknesses, as well as for applications in the energy and electronics industry." He concludes: “Even with reduced material thicknesses, graphene can be used to significantly improve the thermal insulation of buildings due to its high thermal conductivity.” This property has applications in the energy and electronics industry, where it can improve thermal management and performance of systems and devices; In addition, it is advantageous for construction by allowing more energy efficient buildings.

Graphene has an even higher conductivity than copper, making it one of the best conductors of electricity. This makes it a perfect candidate for electronic applications,

such as creating rechargeable batteries and generating electricity through solar energy (Cao et al., 2019).

Graphene is ideal for applications in displays and electronic devices that require flexibility and transparency due to its low light absorption. Graphene is a revolutionary material with many applications in construction and in many sectors of daily life due to its distinctive characteristics (Ghany et al., 2017).

Based on de Abreu et al. (2017), in his research he mentions the following: "Carbon atoms are the only component of graphene, which is one of the most important and abundant natural elements. "Graphene is a highly studied material due to its natural abundance of carbon." He concludes that because nature contains a large amount of carbon graphene, which is only made up of carbon atoms, is a very valuable material. The sustainability and viability of graphene as a study and application material are highlighted thanks to the fact that its primary source is one of the most abundant elements on the planet. As a result, the sustainability and accessibility of its fundamental component, as well as its exceptional characteristics, drive graphene research.

Due to limitations in large-scale production, it is difficult to produce large quantities of graphene. However, production costs are expected to decrease in the future, which would allow greater scalability in the production of graphene compounds (Merizalde-Salas et al., 2023).

Graphene, also known as the material of the future, has a wide range of uses in a variety of industries, making it a smart and sustainable material. The material has great possibilities for innovation and revolution in various sectors due to its potential in construction, health, electronics and energy (Guacho, 2019).

In line with what is stipulated by Gómez et al. (2018), in his research he mentions that fiber concrete is an improved version of traditional concrete with better resistance to cracking, deformation, fatigue and impact. It is widely used in the production of industrial and commercial floors, tunnels, slopes, storage tanks, concrete, prefabricated materials and in some cases, it can replace electro welded meshes for floors, but not for structural columns, steel bars for loads. Unlike steel reinforcement, concrete fibers form a heterogeneous and uniform three-dimensional reinforcement in the concrete mix, giving it the same properties at all points of the structure.

The Mexican company Energía- Graphenemex, through its Graphenergy Construction division, takes advantage of the benefits of graphemic nanotechnology to improve the characteristics of conventional polypropylene fibers; Its specialized formula allows obtaining individual filaments with greater mechanical and thermal resistance, better distribution and greater adhesion within the concrete compared to common fibers (Tsioptsias et al., 2021).

Gómez et al. (2018) mentions in his research that the use of graphene in buildings improves the thermal insulation properties of buildings. Not only that, but they can also be more resistant (corrosion, moisture and fire) making them more durable and sustainable. Construction materials will be improved, and environmentally friendly

components will be used, such as "green concrete", a greener, more sustainable and durable material than existing materials.

The use of graphene in buildings is expected to improve the thermal insulation properties of buildings. Not only that, but they can also be more resistant to corrosion, moisture, and fire, making them more durable and sustainable. Construction materials will be improved, and environmentally friendly components will be used, such as "green concrete", a greener, more sustainable and durable material than existing materials (Suhendro, 2014)

Applications in construction use flexible graphene sensor technology can be used in other biomedical applications that require information from the cerebral cortex, such as neuroprosthetics for speech communication or prosthetic control. It will also pave the way for future brain-computer interfaces, an ambitious goal that will make communication between humans and artificial electronic systems more efficient. This team of scientists leads fundamental research aimed at creating innovative human applications together with the flagship Graphene and the Barcelona Institute of Science and Technology (BIST), of which ICN2 is a member (Solórzano, 2021).

The method involves high-speed collisions of graphite with a mixture of substances containing fluorine, a carbon-based polycyclic aromatic hydrocarbon, and water. The traditional way to produce graphene is by adding carbon atoms to a carbon-containing gas in a vacuum, a process that costs around 20,000 yen (154 euros/167 dollars) per unit. kilograms of the material obtained. With the new process, the Japanese gas company plans to reduce production costs to below 10,000 yen (€77/US$84) per kilogram, according to Japanese newspaper reports (Cheng et al., 2022). The company has begun trying to supply the material to about a dozen companies, including plastics and electronics manufacturers, and plans to begin mass production. Polit (2022). Camargos (2017) proposes that the value of graphene is mainly due to its incredible electrical resistance and its wide range of industrial applications. The material consists of a single layer of carbon atoms connected to each other by six chemical bonds, forming a structure similar to chicken wire. Graphene is not only very useful in scientific experiments due to its good reactivity and resistance, but it can also be added to all types of materials to increase their resistance or make them lighter, such as concrete or metal.

Explains Sabry (2022) in the global periodic table of elements, graphene, the purest form of carbon, constitutes a modern material "phenomenon" given its full potential to be transformative in all areas of human development. Graphene has a great ability to form complex networks with other elements, supporting organic chemistry and the existence of life on Earth. One of its properties is that it has high density and electrical conductivity and is harder and more resistant to wear than steel. All these characteristics made it the focus of several studies, such as the experiment carried out by scientists (Chen et al., 2017) who managed to protect it from the effects of temperature, which made it very unstable.

Graphene is the first two-dimensional material created by man and is destined to transform industries from energy to electronics, including biomedicine and aerospace, since it has several properties that make it unique in the world. The transition of its applications from research centers to large-scale industrial production represents a great challenge for the elements of innovation on which public organizations and private companies around the world are betting (Polit, 2022).

According to Weiss et al. (2012) graphene is undoubtedly a material that will revolutionize current technologies. However, almost five years after its discovery, some research groups in Mexico have been carrying out experimental and theoretical studies on it. We believe that, if we want our country not to be left out of the next technological innovation, as happened with the silicon generation, high school and university students must be interested in fundamental and applied research of this material.

Kabiri et al. (2018) describes the high elasticity and wear resistance of graphene make it the "ideal filler" for concrete and cement. The vice president of Graphenano, José Antonio Martínez, stated that the product manages to improve "all the properties that affect the resistance of concrete and compromise its good properties over time." Graphene additives significantly extend the life of concrete by improving resistance to important factors such as carbonation, chlorides and sulfates.

This characteristic is directly manifested in the optimization of natural resources and the reduction of carbon dioxide emissions into the atmosphere during the extraction, processing, production and transportation of raw materials. And according to the company, its product can reduce cement needs by up to 30% for the same application and resistance (Zapata, 2018). Graphene is also highly conductive and has unique light absorption properties. When it comes to conducting electricity, graphene rivals' copper, but surpasses all other known materials when it comes to conducting heat. At the same time, graphene is nearly transparent, making it a suitable material for touchscreen devices, as well as products such as lighting and solar panels. When mixed with plastics, graphene becomes a strong electrical conductor, making it a potentially useful product in the satellite, aerospace and automotive industries. Although still in the early stages of research and development, there are already many companies and research programs working to understand the possible applications of graphene. Due to its unique composition of properties, graphene can be used and applied in various ways, making it a valuable and cost-effective material for research, development and commercial development (Camargos, 2017).

For Ching (2023) today, graphics are gradually being introduced into architecture. Its potential is very high, but there are still problems with the full implementation and assimilation of this material. Large-scale production of high-quality graphene remains very expensive and economically challenging. Furthermore, if this were not enough, more scientific studies are still needed to ensure their long-term behavior in various combinations and that they do not harm the materials themselves or humans with degradation or other hidden negative properties. Right now, we know how perfect it is in applications, but we don't know what will happen to this material in the future.

However, the future is bright for us as we gradually explore these properties and take an approach to propagate this material in one direction. One day, graphene will be built to change agriculture and everything we know (Zapata, 2018). Zaporotskova et al. (2016) contributes to this with the following: graphene, a two-dimensional material composed of carbon atoms arranged in a hexagonal structure, emerging as a key innovation in sustainable construction. Its unique properties, including high strength, flexibility, electrical and thermal conductivity and optical transparency, offer a variety of opportunities to make the construction industry more efficient and sustainable (Zumba, 2024).

One of the most important advances in the use of graphene in construction is its ability to strengthen concrete. Research shows that adding graphene can significantly increase the tensile, flexural and compressive strength of concrete, meaning lighter and more efficient structures. The timeline provides opportunities to integrate smart systems into the infrastructure. Its use to create sensors can instantly monitor the state of the structure, detect damage and maintenance needs in time, thus contributing to the safety and durability of buildings (Nagayama & Spencer, 2007).

Conclusions

Although graphene has great potential, its large-scale manufacturing remains expensive due to complex processes and high purity. With increasing demand and optimization of production processes, however, costs are expected to decrease significantly. Due to variations in surface characteristics, homogeneous dispersion of graphene in matrices such as concrete can be complicated. To improve compatibility and ensure uniform distribution of graphene, appropriate surface treatments are required (Eisa et al., 2022). While conservative projections indicate a more gradual implementation as economic and technical obstacles are overcome, optimistic expectations foresee widespread adoption of graphene in construction in the coming decades (Li et al., 2016). The use of graphene in buildings is expected to improve the thermal insulation properties of buildings. Not only that, but they can also be more resistant to corrosion, moisture, and fire, making them more durable and sustainable. Construction materials will be improved, and environmentally friendly components will be used, such as "green concrete", a greener, more sustainable and durable material than existing materials (Dahlan, 2019).

We conclude that graphene is a substance composed of pure carbon, it is a recyclable and sustainable material that is found in abundance in nature. This feature, together with its ability to be reused, reduces its impact on the environment, making it a viable option for use in construction and other industries, contributing significantly to the circular economy and sustainability. It was deduced that graphene is about to revolutionize technology in several fields, especially in construction. As research and development continue to overcome the challenges of producing and processing it on an industrial scale, the potential applications of graphene seem almost limitless. Its impact could be as great as that of silicon in the 20th century, potentially redefining entire industries with new capabilities, efficiencies and products we can only imagine

now. As we move towards this exciting future, graphene remains a truly transformative material in today's technological era.

We determined that the role of graphene in building and construction is still in the early stages of research. However, promising graphene concepts and materials are currently being developed. There are also many research programs and institutions working on commercializing graphene. For example, the National Graphene Institute at the University of Manchester, designed by Jestico Whiles, is the world's leading research center dedicated to the development of graphene. Based in the same facility where the material was first isolated, the institute demonstrates the UK's commitment to remaining at the forefront of graphene commercialization.

Large-scale production of graphene remains expensive and technologically complicated, despite its extraordinary properties. Current production methods are complicated and not economical enough to be widely adopted. Continued research is essential to create more effective and economical methods that can lead to large-scale industrial production.

It is important to note that the conditions of each region allow the material to behave differently, so conducting experiments in different regions with extreme climates will reveal changes in graphene not only as a nano additive, but also as a composite material for the construction industry, capable of reducing the carbon footprint and investing energy and improving the performance of the materials, these materials can demonstrate important improvements that justify their development in the industry to provide better constructive solutions.

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