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Production of C-SiO_2 Composite from Waste Plant Raw Materials and Its Use as a Filler of Structural Carbon Materials

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Abstract: The purpose of this study is to investigate the processes of obtaining and characteristics of the C-SiO_2 composite obtained from plant waste and to assess its potential as a reinforcing component in structural carbon materials. The methods used include analytical method, classification, functional method, statistical method, synthesis. In the course of the study, a C-SiO_2 composite was obtained from lignin extracted from rice straw after hydrolysis in an autoclave at a temperature of 200°C using a 1% solution of H_2SO_4. The resulting composite contains 70% of the material and has morphology characterised by fibres and dendrites of carbon particles of various sizes. X-ray diffraction analysis revealed the presence of graphite-like, naphthenic and hydrocarbon phases with their corresponding content, which makes it potentially effective filler for structural carbon materials. The use of this new carbon material containing 30% C-SiO_2 composite in the manufacture of products using standard technology has demonstrated improved wear resistance and long service life in abrasive conditions, which makes it promising for various industries.

Keywords: rice straw, lignin, environmentally friendly technologies, X-ray diffraction, hydrolysis

1. Introduction

The study of the topic of obtaining silicon dioxide (C-SiO2) composite from plant waste and its application in structural carbon materials is an integral part of modern research in the context of striving for sustainable and environmentally friendly development. In the modern world, reducing dependence on fossil resources, such as oil, and creating more efficient and durable structural materials are becoming priorities.[1] The use of plant waste and its transformation into C-SiO_2 composite represents a promising way to create environmentally sustainable and highly efficient materials for construction and engineering applications. This research not only contributes to the development of new production technologies, but can also contribute to reducing the impact on the environment, which is relevant in the modern context of climate change and the desire for sustainable exploitation of natural resources.[2],[3]

The problem of this study is the need to find innovative and sustainable ways to produce structural materials that combine high productivity and environmental safety. Plant waste is an extensive and potentially recyclable source of raw materials, but its maximum use and conversion into a C-SiO_2 composite is a difficult task. This includes optimisation of hydrolysis and heat treatment processes, and analysis of the structure and characteristics of the resulting composite. Moreover, it is necessary to evaluate its applicability and high performance in structural materials and consider environmental aspects associated with the transition to sustainable technologies. Thus, the scope of the study includes not only scientific and technical aspects, but also issues of sustainable development and innovative application of the obtained materials in modern industry.

According to N. Appazov et al.[4], extraction of lignin from rice straw and its subsequent use as a raw material for the C-SiO_2 composite may represent a promising path to the creation of more environmentally friendly structural materials. However, aspects related to the economic efficiency and cost of the composite production process were not considered, which is also an important factor in its widespread introduction to the market. A. Ibrayeva[5] emphasises that the relevance of this issue is increasing in light of the growing interest in sustainable technologies and environmental sustainability in the production of building materials. The study did not include an analysis of the impact of the composite on energy consumption and the efficiency of production processes in the construction industry, which is also an essential aspect for assessing its sustainability and prospects. According to B. Kaidar et al.[6] the C-SiO_2 composite obtained from plant waste may have unique characteristics, making it a promising material for use in various industries. However, the long-term consequences of the material in various industrial applications and its environmental impact have not been investigated, which is an important aspect of assessing its sustainability and potential risks.

Researchers M. Temirbekova et al.[7] note that the processes of hydrolysis and heat treatment of lignin from plant waste are key stages in the production of the C-SiO_2 composite and require in-depth scientific analysis. The study did not consider the analysis of the influence of various conditions and parameters of hydrolysis and heat treatment processes on the quality and structure of the resulting C-SiO_2 composite, which may be important for optimising production methods. A study conducted by M. Umerzakova et al.[8] emphasises the need to consider the morphology and structure of the composite when developing it and evaluating its potential in structural materials. However, the study did not cover the analysis of the influence of the physical and chemical properties of the composite on its mechanical characteristics and long-term durability under operating conditions, which may be important for its practical application. Y. Ilyin et al.[9] raised an important question about the applicability of a new carbon material containing a C-SiO_2 composite in engineering applications and about its competitiveness in the construction materials market. However, the researchers did not cover the analysis of the economic efficiency and cost of producing a new material, which is an essential aspect for its successful commercialisation and application in engineering applications.

The purpose of this study is to identify and achieve new characteristics in the C-SiO_2 composite and its important function in improving the physical and mechanical properties of the carbon antifriction material.

2. Materials and Methods

A scientific study on C-SiO_2 composites from plant waste was conducted using methods that reveal the content of the object. The analytical method helped in a more comprehensive investigation of the physicochemical properties of the resulting C-SiO_2 composite, determining its structure and morphology at the micro and nanoscale, and evaluating its mechanical, thermal, and electrical characteristics. These data are key for further optimisation of the production process and the development of structural materials with improved properties for a wide range of applications. Using the statistical method, important dependencies between the composition of raw materials, process parameters, and properties of the C-SiO_2 composite were revealed. These conclusions allow optimising production conditions, reducing material losses, and improving its quality, which made it possible to use this composite more efficiently in various industrial and technical fields.

Applying the functional method, new ways of modifying the C-SiO_2 composite were developed, adjusting its properties to specific needs. These innovations open up prospects for creating more highly efficient and adaptive materials capable of solving a variety of technical tasks, from strengthening structures to improving energy efficiency, and the environment. The structural and functional methods helped in the creation of C-SiO_2 composites with optimal microstructure and unique functional characteristics. These composites demonstrate outstanding properties in the field of mechanical strength, heat resistance, and electrical conductivity, making them an ideal choice for use in structural materials with increased performance and durability requirements.

The deduction method helped to identify common patterns in the process of obtaining C-SiO_2 composites from plant waste. This analytical approach allowed optimising each stage of production, reducing costs, and increasing the efficiency of the process, which eventually led to a more sustainable and cost-effective methodology for the production of these innovative materials. By applying the synthesis, more efficient and improved processes for the production of C-SiO_2 composites have been successfully developed. These innovative synthesis methods have allowed for achieving higher purity and stability of the product, which has made C-SiO_2 a more affordable and competitive material for a wide range of applications, including construction, electronics, aviation, and many other industries.

The study was conducted with the disclosure of some aspects, including theoretical and practical components. The theoretical component included an in-depth analysis of the chemical and physical processes underlying the synthesis of C-SiO_2 composites, and the study of the structural and morphological characteristics of the materials obtained. The practical part of the study included conducting experiments on the synthesis and modification of C-SiO_2 composites using the developed methods. Various raw material options, temperature conditions, reaction conditions, and other parameters were investigated to optimise the process. New ways have been identified to improve the production of C-SiO_2 composites and their application in various fields, which can play an important role in the development of innovative technologies and the sustainable use of natural resources.

The Sigeta Forward LCD electron microscope was used to study the microstructure of materials such as lignin in rice straw. Xpert3 Powder X-ray diffractometer was used to perform microdiffraction, study the crystal structure, and analyse diffraction patterns. Based on the results obtained, recommendations were developed for industrial enterprises and research laboratories seeking to introduce the production of C-SiO2 composites from plant waste. These recommendations include optimal synthesis processes, processing parameters, and tips on choosing suitable starting materials.

3. Results

Among the many residues after the processing of vegetable raw materials, special attention is drawn to the materials obtained as a result of rice processing, such as rice husks and straw. They are of interest not only because of their extensive formation and insufficient use, but also due to their unique chemical composition, including a high content of C-SiO_2 and organic carbon. As a result, they represent a valuable source of raw materials for the creation of a variety of materials containing silicon and carbon, which can replace traditional fillers made from petroleum products and other non-renewable natural resources, both with respect to their application.

Research in the field of replacing hydrocarbon sources with plant materials, including rice husks, for the production of carbon materials has been conducted for more than a century, and there are an extensive number of research papers in this field.[4)-9)] There are many methods of processing rice husks, which involve its use as a fuel, a component of building materials and fillers, and for the production of sorbents, silicon carbide, silicon materials, and other products.[10)] However, to date, industrial production has not been created anywhere in the world to produce silicon-carbon and silicon-carbide fillers of composite materials (elastomers and carbon friction and antifriction products) from rice husks and straw. The importance and relevance of such studies are explained by the accumulation of significant reserves of resources, such as rice husks and straw, which are used sparingly, both in Kazakhstan and globally.[11)]

To improve the properties of carbon materials and improve their performance in various products, new fillers with a finer structure are being investigated.[12)] Grain size plays a key role in determining characteristics such as density and thermal expansion of graphite. It is known that traditional carbon materials, such as artificial graphite, coke and coal pitch, are limited in their resistance to wear in abrasive conditions, especially at elevated temperatures.[13)] To increase the service life of friction elements in antifriction materials, especially under conditions of variable load, boundary conditions and in the presence of abrasive particles, a C-SiO_2 composite can be used, which is obtained from rice husk and straw processing products.[14)]

Products made of carbon material enriched with such fillers can be successfully used in friction units, especially as components of sealing elements of mechanical seals. These applications require not only high gas permeability, but also reliable long-term performance, especially in the chemical and petrochemical industries. The inclusion of such materials in the composition of antifriction carbon composites contributes to the formation of graphite with a finer structure, which increases its quality and value. Studies related to the process of creating a C-SiO_2 composite from rice straw lignin and its characteristics as a filler for structural carbon materials have practically not been conducted, which is an important scientific direction. Lignin was obtained by thermal hydrolysis of rice straw in an autoclave using a 1% solution of H_2SO_4 at a temperature of 200°C. During the hydrolysis process, the ratio of liquid to solid parts was 1:8, and the procedure lasted for one hour. After cooling, filtration of sediment and subsequent drying, the resulting volume of lignin was 37.4% of the total weight of rice straw. In addition, under similar production conditions, the yield of lignin from rice husks was 24.7%.

In the process of autoclave synthesis of lignin, C-SiO2 present in rice straw remains in the structure of lignin and makes up 32%. This process allowed obtaining 3.8 kg of lignin in the form of a brown powder with a bulk density of 0.2 g/cm^3.[15)] The morphology of the obtained lignin depends on the conditions of its synthesis.[16),17)] In this case, lignin has a fibrous structure with dendritic formations and rounded particles with a size of 20-30 nm (Fig. 1a, b, c), while SiO_2 particles are represented by point reflexes with a diameter of 0.45 nm (Fig. 1d).

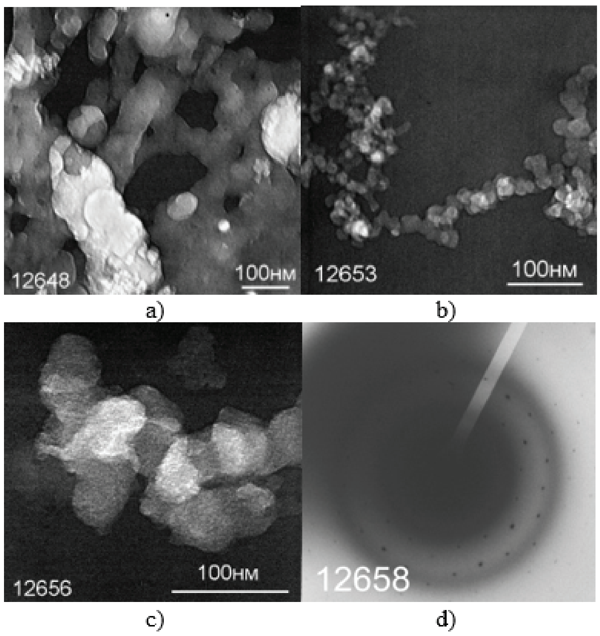

Fig. 1: Micrographs and microdifraction pattern of rice straw lignin.

A characteristic set of bands is observed in the lignin spectrum, which is explained by fluctuations of various functional groups, including hydroxyl (3416 cm^{-1}), aliphatic (2925 cm^{-1}) and methylene (1450 cm^{-1}) (Fig. 2). In addition, absorption bands (468, 792, and 1100 cm^{-1}) are present on the spectrum, which are associated with the presence of amorphous C-SiO2.[18)]

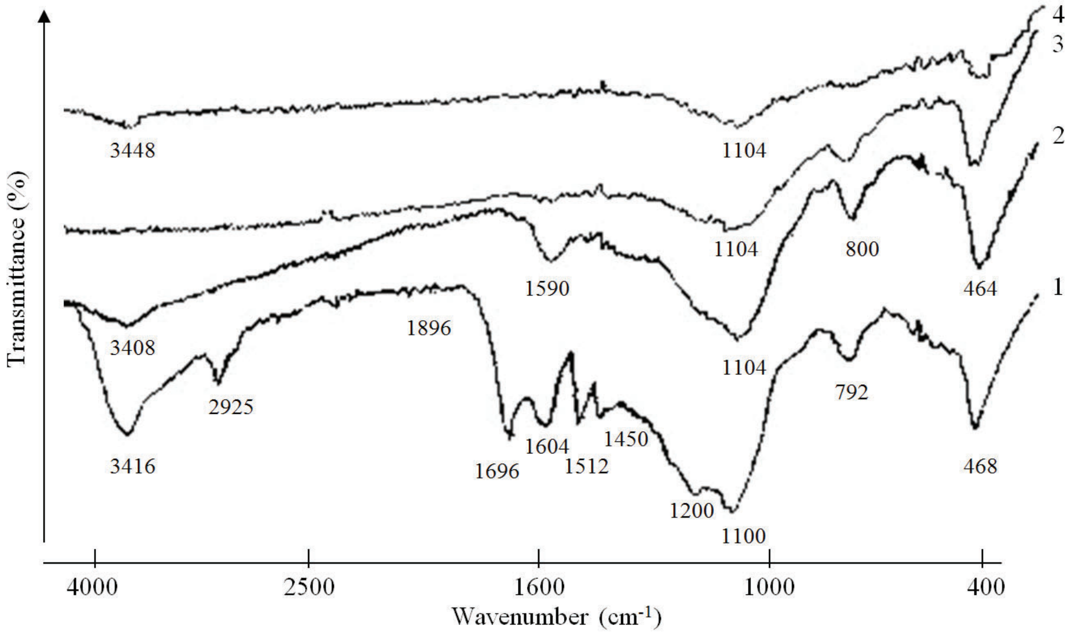

Fig. 2: Infrared spectra are presented for the following samples: 1 – lignin; 2, 3, 4 – $C\text{-}SiO_2$ composite at different processing temperatures: 500°C, 650°C, and 800°C.

Pyrolysis of rice straw and extraction of lignin from it were carried out in stationary conditions using a vertical shaft furnace and the atmosphere of outgoing steam gases. During the experiment, the temperatures at which pyrolysis was carried out varied, and the holding time at the final temperature was 30 minutes. Table 1 provides information on the composition and characteristics of the obtained $C\text{-}SiO_2$ composites after pyrolysis at 600°C.

Table 1. Composition and characteristics of the $C\text{-}SiO_2$ composite

Material	Content, %		Specific surface area, m^2/g	Iodine activity, %	Composition of the carbon-containing phase, %		
	C	SiO_2			G_p	N_p	H_p
$C\text{-}SiO_2$ composite made from rice straw	58	26	150	10	50	35	14
$C\text{-}SiO_2$ composite made from straw lignin	50	36	445	35	45	38	13

Note: G_p – graphite phase; N_p – naphthenic phase; H_p – hydrocarbon phase.
Source: compiled by the authors.

In order to improve the chemical purity and uniformity of lignin, it was treated with a 72% solution of H_2SO_4. In Figure 3a, the amorphous phase is designated as “A”. The X-ray of purified lignin shown in Fig. 3b is characteristic of amorphous organic compounds containing hydrocarbon components.[19)]

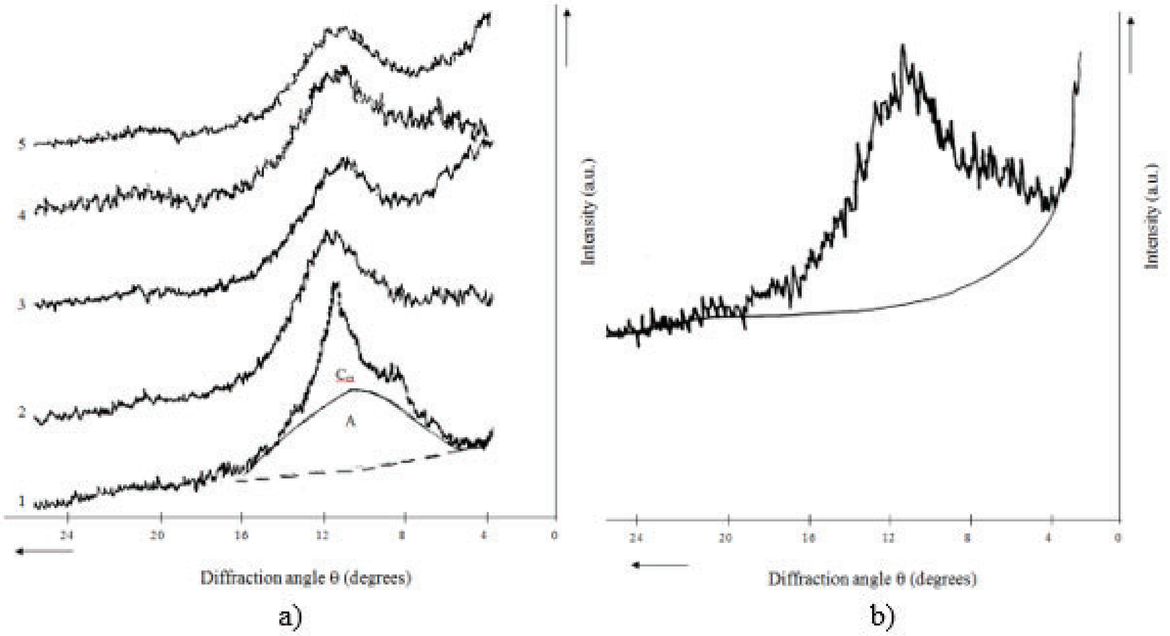

Fig. 3: Radiographs are images of lignin from rice straw (1) and its carbonation products (2, 3, 4, 5) in the form of C-SiO_2 composites at different temperatures (500°C, 650°C, 800°C, 1000°C).

X-ray images of the materials under study were obtained using a computerised DRON-2 diffractometer with upgraded collimation. Filtered CuKα radiation and reflected rays were used for the study, and the samples were in a metal cell measuring 17×17×1.5 mm.[20),21)] X-ray images of C-SiO_2 composites obtained from lignin showed a wide range of reflections in the area of the angle θ from 5 to 16 degrees (Fig. 3a). This is typical for carbon materials, which are multicomponent systems. By decomposing X-ray diffraction samples into components using an interactive method, it was possible to detect the presence of a carbon phase (graphite-like Gp) and two hydrocarbon phases (poly-naphthenic Np and, probably, oxygen-containing Hp).[22)] The characteristics of these phases are given in Table 2.

Table 2. Phase composition and characteristics of X-ray diffraction associated with a phase similar to graphite

Sample	Composition of the carbon-containing component, %			G parameters	
	G	N	H	d_{002}, nm	L_c, nm
L-500	44	41	15	0.380	2.1
L-600	43	35	22	0.381	4
L-800	44	38	18	0.375	4.6

Source: compiled by the authors.

The morphology of carbon particles in the C-SiO_2 composite obtained from lignin revealed the following characteristic features: the presence of carbon fibres with a size of 20 to 100 nm (Fig. 4a, 4b), spherical structures with a diameter of 230-260 nm, dendrites with a size of 30-50 nm (Fig. 4c), and diffuse rings with dimensions of 0.2-0.4 nm.

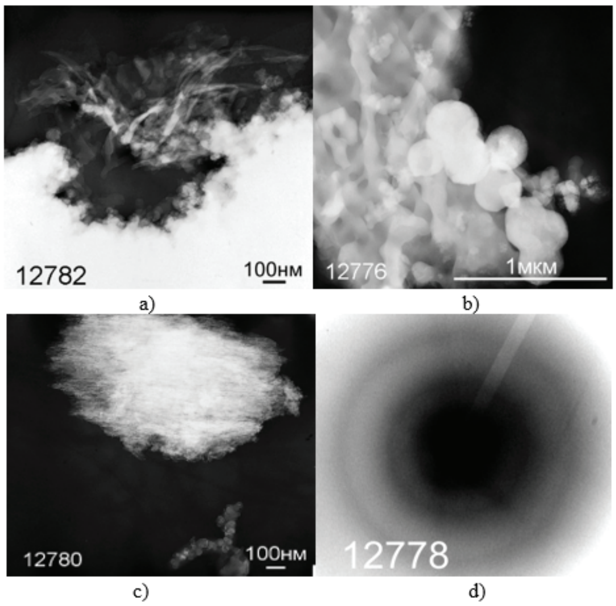

Fig. 4: Micrographs and microdifraction pattern of rice straw lignin using radiation.

2.6 kg of C-SiO_2 composite obtained from lignin were developed for the production of products made of antifriction carbon material. This composite contained 49% carbon and 37% C-SiO2, had particles less than 0.1 mm in size, a bulk density of 380 kg/m^3, and a specific surface area of 160-170 m^2/g.

The most promising is the use of a C-SiO_2 composite obtained from lignin, which has a finer particle structure (1-20 nm), which is one of its advantages.[23] This filler is offered as an alternative to calcined coke to improve the quality of manufactured products and reduce their cost. The composition of the antifriction material (1 proposed, 2 standard) is presented in Table 3.

Table 3. Composition of carbon material.

Components	Mass, %	
	Composition 1	Composition 2
1. Coal pitch coke	7	7
2. Dry lubricant (boron nitride)	12	12
3. α-furylcarbinol polymer	8	8
4. Furfurolacetone oligomer	3	3
5. Boric acid	4	4
6. $C\text{-}SiO_2$ composite from lignin	30	0
7. Calcined coke	0	30
8. Artificial graphite	Remainder	Remainder

Source: compiled by the authors.

The mixtures were thoroughly mixed and placed in a mould, which was lined with refractory electrical insulation material. Then each of the mixtures was kept in a mould for one hour. After that, the hot pressing process began, in which an electric current passed through the mixture, and it lasted for 1.5 hours. The whole pressing and firing process was carried out at a pressure of 350 kg/cm^2 and at a temperature of 1000°C. After completion of this process, the resulting workpiece was cooled to 300°C under pressure, then it was pressed and cooled to room temperature in air. After mechanical processing, the resulting products (bushings) were placed in an autoclave and a vacuum was created at a residual pressure of 5 mm of mercury for one hour. Then a special impregnating solution was fed into the autoclave, which consisted of a mixture of furyl carbinol and furfurolacetone mixed with a 60% aqueous solution of citric acid, and kept at a pressure of 12 atmospheres for 2 hours.

Further, the obtained workpieces were subjected to heat treatment until a temperature of 350°C was reached with an average temperature rise rate of 5-7°C/h. As a result of this sequential technological operation, the gas permeability of the material decreases by two orders of magnitude and reaches the level of 1-5·10-5 cm^2/s. Further, the resulting products were tested on a friction testing facility under boundary friction conditions and in a liquid medium (water) with the addition of abrasive particles ranging in size from 5 to 15 µm, which accounted for 5% of the total volume of water. The test conditions included a sliding speed of 10 m/s, a load of 2.94 MPa, a cyclic test mode with maximum cycle duration of 10 minutes, during which 5 minutes of tests were carried out in the mode of boundary friction and 5 minutes in an abrasive medium. The data is presented in Table 4.

Table 4. Testing of antifriction carbon materials.

Sample	Wear rate, µm/h	
	Boundary friction mode	In an abrasive environment
From the material of the new composition 1	1.6	0.7
Standard sample, composition 2	4	32

Source: compiled by the authors.

From the data presented in Table 4, it can be seen that the material containing a filler in the form of a $C\text{-}SiO_2$ composite obtained from rice straw lignin has a high resistance to wear under various friction conditions, including boundary conditions and abrasive media. This material can be especially useful, for example, in marine centrifugal pumps.

The production of the $C\text{-}SiO_2$ composite from lignin produced from rice straw raises the question of the possibility of efficient use of waste plant raw materials. This study confirms that even agricultural waste can become a valuable raw material for the production of new materials. The resulting $C\text{-}SiO_2$ composite has many advantages, such as fine-grained structure, high wear resistance and service life in abrasive conditions. These characteristics make it promising for use in various industries where structural carbon materials are required. The process of producing the $C\text{-}SiO_2$ composite from rice straw is more environmentally friendly compared to conventional methods of producing carbon materials. It allows reducing the amount of waste and recycling agricultural residues, reducing the impact on the environment.

Despite the promising results, it is necessary to conduct additional research to more comprehensively investigate the properties and capabilities of the $C\text{-}SiO_2$ composite. Optimisation of the production process can also improve its economic efficiency and competitiveness in the market. The $C\text{-}SiO_2$ composite can be used in various industries, such as the production of semiconductor materials, integrated circuits, nuclear power[24]. Its high wear resistance and chemical stability make it a valuable material for creating high-tech products[25]. The research on the production of $C\text{-}SiO_2$ composite from waste plant raw materials is an important step in the development of environmentally sustainable and technologically advanced materials that can meet the needs of modern industry and promote sustainable development.

4. Discussion

The production of the C-SiO_2 composite from waste plant raw materials and its use as a filler of structural carbon materials is an important study combining aspects of environmental sustainability and technological development. This approach has the potential to solve several modern problems. Initially, it is worth noting that plant waste is biodegradable materials that are formed in large quantities in agriculture and the food industry. The efficient use of these wastes in the production of C-SiO_2 composites reduces the environmental burden and promotes the transition to sustainable practices. The C-SiO_2 composites themselves are an innovative material with interesting properties. Carbonation of plant waste allows obtaining a carbon matrix that has high strength and structural stability. The introduction of silicon further enhances its properties and makes it applicable in structural materials.[26)]

The use of such composites in structural carbon materials has the potential to improve their mechanical characteristics. This can be used in aviation, automobile manufacturing, sports equipment manufacturing, and other industries. Carbon composites can also be lightweight and durable, which helps to reduce the weight of structures and, as a result, fuel consumption in the transport industry. However, despite the potential benefits, there are challenges that need to be factored. This includes optimising the process of obtaining composites, ensuring their stability and durability, and considering the economic aspects of production. The production of C-SiO_2 composites from plant waste and their use in structural carbon materials is a promising area of research that combines environmental sustainability and technological progress. For the successful implementation of this idea, further research and development of technologies is necessary to assess the technical, economic, and environmental aspects of this process.

According to J. Yousef et al.[27)], that the functionalisation of coal obtained from the pyrolysis of metallised plastic food packaging waste is a unique approach to waste recycling, which has the potential to reduce the negative impact of such materials on the environment. Metallised plastic packages, often containing aluminium coatings, are usually difficult to decompose and recycle, which leads to the accumulation of waste[28)]. Pyrolysis of such materials into coal opens the way to obtaining a valuable product that can be used as a functional filler. The introduction of this functionalised coal into fibreglass/epoxy composites is of great interest in the field of materials and engineering. Coal enriched with functional groups can improve the mechanical properties and chemical resistance of composites[29)]. Despite the results obtained, this approach can contribute to the creation of lighter, stronger, and more durable materials suitable for a wide range of applications, including aviation, automotive, construction, and many others. Thus, the functionalisation of coal and its integration into composites can represent an important step towards sustainable and efficient waste recycling and the development of new advanced materials. The authors of this study consider the findings of J. Yousef and co-workers to be an important contribution to the development of waste recycling and the development of new materials. Their findings suggest that the functionalization of charcoal obtained from the pyrolysis of metallized plastic food packaging is a unique approach to waste recycling that has the potential to reduce the negative environmental impact of such materials. This possibility of using functionalized carbon in fiberglass/epoxy composites is a really interesting prospect for the field of materials science and engineering.

According to M. Bartoli et al.[30)], recent advances in bio-based polymer composites open new perspectives for sustainable and environmentally friendly development of the materials industry. Biocarbon materials are produced from biological sources, such as plant waste and biomass, and have a number of unique properties, making them attractive for use in composites. These materials have a high degree of resistance to corrosion and abrasive wear, which makes them an ideal choice for use in construction, aviation, the automotive industry, and other areas where high strength and durability are required[31)-33)]. An important achievement is the development of new methods for the functionalisation of biocarbon materials, which allows them to improve their chemical and physical properties for specific applications. For example, a functionalised biochar can be easily integrated into polymer matrices, improving adhesion and compatibility with the materials with which it interacts. It also helps to reduce the harmful impact on the environment, as biocarbon materials are produced from renewable sources. These data are consistent with the theses given in the previous section. All this makes the latest achievements in the field of biocarbon polymer composites significant and promising for the future development of the field of materials science and industry[34),35)].

The authors of this study agree with the conclusions of M. Bartoli et al.[30)] regarding the prospects for the development of biopolymer composites. They support the view that recent advances in this area open up new opportunities for sustainable and environmentally friendly development of the materials industry. Functionalization of biocarbon materials, which allows to improve their chemical and physical properties for specific applications, is also considered an important achievement in the industry. The analysis of authors is considered a strong argument, as they have considered the relevant aspects of the development of biopolymer composites and supported their conclusions with data on the benefits of using biocarbon materials in various industries.

Researcher F. Ortega et al.[36)] determined that biocomposites created from waste and by-products of the agro-industrial complex represent an important direction in the field of sustainable development and utilisation of organic materials. One of the key aspects of this approach is to reduce waste and maximise the use of each part of crops. For example, plant residues, usually left behind after harvesting, can be converted into useful biocomposites, preventing their decomposition, and reducing the impact on the environment. Biocomposites based on agro-industrial waste can have a variety of uses, including construction materials, packaging, automotive and aerospace industries, and medical equipment. Analysing the results obtained and the conclusions, these materials have a number of advantages, such as low production costs, the absence of toxic components, and natural biodegradability. They can also be enriched with various additives and improving agents to meet the requirements of specific applications. Thus, biocomposites from agro-industrial waste represent an important direction in the development of sustainable materials, contributing simultaneously to the elimination of waste and the creation of innovative products.

The conclusions drawn by the authors are very important for the development of the field of sustainable development and the use of organic materials. The analysis of the research shows that biocomposites based on waste and by-products of the agro-industrial complex have great potential in this area. They can be used in a variety of industries, including construction, packaging, automotive and aerospace, and medical equipment. The main advantages of these materials, such as low production costs, the absence of toxic components, and natural biodegradability, make them particularly attractive for use in sustainable development. Such biocomposites can also be enriched with a variety of additives and enhancements to meet the requirements of specific applications.

M. Gargol et al.[37] determined that the synthesis of composites using waste hemp fibres as a filler is an important area of research aimed at creating environmentally friendly and sustainable materials. Hemp is a plant that grows quickly and has a high resistance to pests, which makes it a potentially valuable raw material for composites. The use of hemp fibres as a filler helps to reduce the environmental burden, as it allows the disposal of agricultural waste and reduces the consumption of synthetic materials. These results confirm the above study, since thermomechanical studies of these composites are important for determining their mechanical and thermal characteristics. Experiments help to identify strength, resistance to temperature influences, and other key parameters that are important for determining the suitability of these materials for various applications. Composites based on epoxy resins and hemp fibres can potentially be used in aviation, automotive, construction and other industries, providing environmentally friendly and lightweight alternatives to traditional materials. Such research contributes to strengthening the concept of sustainable development and the creation of new, more environmentally friendly materials.

The findings of the study by M. Gargol et al.[37] support the ideas put forward by the authors in the above-mentioned study. The use of waste hemp fibers for the synthesis of composites is an important and promising area of research in the creation of environmentally friendly and sustainable materials. Since hemp grows quickly and has high pest resistance, it can be a valuable raw material for composites. The use of hemp fibers as a filler helps to reduce the environmental burden, as it allows the use of agricultural waste and reduces the consumption of synthetic materials. Confirming the results with thermomechanical tests is an important aspect, as it helps to determine the mechanical and thermal characteristics of the composites. Experiments help to identify strength, temperature resistance, and other key parameters that are important in determining the suitability of these materials for various applications.

Q. Liang et al.[38] have shown that the creation and application of composite materials with a phase transition based on bio-coal is an interesting area of research in the field of materials science and energy. Bio-coal is produced by pyrolysis of biomass, such as wood, straw, or other organic waste, and has unique properties that can be used in various applications. One of the key aspects of such materials is their ability to phase transition, which means a change in the aggregate state depending on temperature. However, it is important to note that composites with a phase transition based on bio-coal can also be used in the fields of food storage and preservation, transportation of medicines and vaccines, and even in cooling and air conditioning technologies. These materials represent a promising way to develop more sustainable and efficient heat storage systems and other innovative technologies.

The research of Q. Liang et al.[38] confirms that the creation and application of biochar-based phase transition composites is an interesting area of research in the field of materials science and energy. Biochar is produced through the pyrolysis of biomass such as wood, straw or other organic waste and has unique properties that can be used in a variety of applications. One of the key aspects of such materials is their ability to undergo phase transitions, which means that their aggregate state changes depending on temperature. However, it is important to note that phase transition composites based on biochar can also be used in food storage and preservation, transportation of medicines and vaccines, and even in refrigeration and air conditioning technologies.

In general, the studies discussed above indicate a great potential for creating sustainable development and efficient use of organic materials in various industries. The use of waste plant materials to create composites opens up opportunities to reduce the negative impact on the environment and support the transition to sustainable practices. New materials, such as carbon fiber composites with silicone additives, biopolymer composites, biocomposites based on agricultural waste, and composites using hemp fibers, represent an important area of development in materials science and industry. Studies show that the use of these materials can lead to improved mechanical performance and reduced weight of products, which stimulates the prospects for their use in various industries such as aviation, automotive, construction, and others. While there is significant potential, it is also important to address the challenges associated with optimizing production processes, ensuring the stability and durability of materials, and the economic aspects of production.

5. Conclusions

The production of C-SiO_2 composite from waste plant raw materials is an important area of research that can lead to the creation of new materials with a wide range of applications and significant benefits for industry and the environment. The study of the phase of obtaining a filler for structural carbon materials from lignin obtained from rice straw is the following process. In the experiment, it was found that when processing rice straw with a 1% solution of H_2SO_4 in an autoclave at 200°C, the yield of lignin was 37%, which is 1.5 times higher than when using rice husks.

The composition, structure, morphology and other characteristics of lignin were determined using various research methods. These studies have shown that during the heat treatment of lignin, a C-SiO_2 composite is formed, containing about 50% carbon, 36% C-SiO2, and 12-14% hydrocarbons. Analysis of the X-ray structure and phase composition confirmed the presence of a graphite-like carbon phase and two hydrocarbon phases in the composite. Experimentally, it was found that carbon and C-SiO2 are present in an amorphous and highly active form, have particle sizes ranging from 1 to 60 nm. Samples of products made of carbon material, including the composite C-SiO_2, obtained from lignin and having a fine-grained structure, have demonstrated outstanding resistance to wear and long service life even in aggressive abrasive environments. These materials have the potential for a wide range of applications, including the production of semiconductor materials, integrated circuits, nuclear power, mining and metallurgical industries, chemical industry, and other fields.

Additional areas of research may be to determine the influence of various processing conditions and compositions on the properties of the C-SiO_2 composite and its behaviour in different environments and operating conditions, which will more fully reveal its potential and applicability in various industrial fields.

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