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SYSTEMS FOR AUTOMATIC CONTROL OF THE CHARACTERISTICS OF COMPOUNDS BASED ON COMPOSITE MATERIALS

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Abstract. *The paper deals with the study and analysis of the antenna array shell formed by the method of electric arc spraying and coating with a composite material. An assessment of the stiffness and strength properties of antennas made in both solid and reinforced structures is presented graphically. The calculation of their stress-strain state under the influence of wind load and gravity is carried out. The inhomogeneities in the composite materials of the shell structures were determined using the conductometric method, and calculations were performed, including the calculation of the resistivity of the composite material and visualization of the results.*
Key words: *Composite material, electric arc spraying, reinforced composite material, mirror, offset antenna.*

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1. CLASSIFICATION OF METHODS OF MANUFACTURING PLASTIC PRODUCTS

Currently, there are several dozen basic and specialized methods of manufacturing plastic products. Each method is a way to implement the technology of manufacturing a product from a polymeric material, which is determined by several factors.

First, it is determined by the class of polymer. There are two classes of polymers: thermoplastics and thermosets. The production of products from thermosets (fixation of their shape) is accompanied by physical and chemical processes (reactions of three-dimensional polymer - curing). As a result, the thermoplastic becomes insoluble, i.e. does not sink. Processing of thermoplastics is accompanied only by physical processes.

The shape of a thermoplastic product is fixed by cooling below the glass transition temperature (or crystallization). When heated above the flow temperature, thermoplastics can again change from a glassy (solid) state to a viscous state without significant changes in the chemical structure. Therefore, thermoplastic waste can be recycled into products with little deterioration in their properties [1].

Secondly, the polymer processing method is determined by the aggregate state in which the polymer is at the time of manufacture: glassy (cold pressing, cutting, etc.), highly elastic (thermoforming), viscous (casting, pressing, extrusion, etc.) [2]. During the formation of products, polymers are often in a viscous (viscoplastic) or transitional (from highly elastic to viscous) state, and during operation, they are in a glassy or crystalline or highly elastic state.

Third, the method of manufacturing plastic products depends on their configuration and size. For example, hollow tanks are produced by extrusion followed by blow molding, and very bulky tanks are produced by rotational molding. Thus, the processing method can still be represented as a general, fundamentally special technology that combines the same type of process, equipment, machinery, and material. McKelvey organized the various methods of manufacturing thermoplastic products into typical groups. The first group covers methods of manufacturing plastic products in which the formation of products occurs at high shear rates of a polymer that is in a viscous state, followed by its cooling. The second group is characterized by joint diffusion-adhesion processes. The third group of methods for manufacturing plastic products combines methods of molding them from a solution. The fourth group includes methods for manufacturing foamed thermoplastic products. All methods of the fifth group are characterized by chemical reactions of polymer formation, which are combined with the formation of the product in the mold. The sixth group includes methods that can be either independent or final stages of the main technological process [3].

These are thermoforming methods. They are performed when the polymer is in a highly elastic state. Reactoplast processing methods are also combined into one classification scheme. In all methods of the seventh group, the product is formed by flow under the influence of shear stress of the press material, which is in a visco-plastic state, and subsequent curing (structuring) of the cohesive.

Therefore, all methods of manufacturing reactoplastic products, which are grouped in the seventh group, are characterized by common physical and chemical processes that occur during processing.

The eighth group includes methods for processing reinforced plastics, and the ninth group includes methods for manufacturing foamed thermoset products. There is also a classification of methods of manufacturing plastic products, which was developed during the preparation of standard technological processes and consists in the division of methods of manufacturing products by raw materials; technological stages performed during their implementation; technological modes; equipment and machinery used, etc.

2. TYPES OF PLASTIC AND LABELING

To begin with, it should be noted that a «polymer» is a raw material that will be used in production, and the finished product is called a «plastic». Currently, the variety of synthetic polymers is quite large [5].

The choice of processing methods and special additives has a certain impact on the material's properties. There are two principles for dividing polymers: thermoplastic and thermosetting, as well as consumer and technical. A significant difference between thermosets and thermoplastics is that they do not correspond to polymerized products.

Polyethylene

– high density HDPE / HDPE;
– low density HDPE / LDPE;
– Polyethylene terephthalate PET/PETE/PET;
– Polyvinyl chloride PVC / PVC/V;
– Polypropylene PP/PP;
– Polystyrene PS/PS.

Polyethylene is produced by polymerizing ethylene gas under pressure or elevated temperature using metal catalysts (Fig. 1).

$$n\,CH_2{=}CH_2 \xrightarrow{\text{kat.}} \left(-CH_2-CH_2-\right)_n$$

Figure 1. The reaction of polyethylene production

Such materials can have the same molecular weight. Their properties are affected by the nature of the side chain branching. A particular difference is observed in the density values.

Molecules of linear structure have the ability to compact compactly, forming LDPE (density value 0.945–0.960 g/cm^3). And branched molecular chains prevent such a close compaction, resulting in HDPE (0.915–0.920 g/cm^3). HDPE is resistant to chemicals and also exhibits relative oil and grease resistance.

Most often used for the manufacture of technical products. It can withstand temperatures from -81 to +111°C. LDPE can maintain its strength at fairly low temperatures (down to -75), is chemically stable, but is exposed to oil and grease, and is waterproof and vaporproof. It is widely used for the manufacture of containers – barrels, vessels, canisters for transportation and storage of acid and alkali solutions. However, LDPE is permeable to gases, so it should be limited to products that tend to oxidize. It is also used in medicine, toy manufacturing, and the food industry as a film for food packaging. Polyethylene is a polymer that can be recycled into «recycled pellets».

Polyethylene terephthalate is obtained as a result of the polymerization of terephthalic acid and ethylene glycol (Fig. 2).

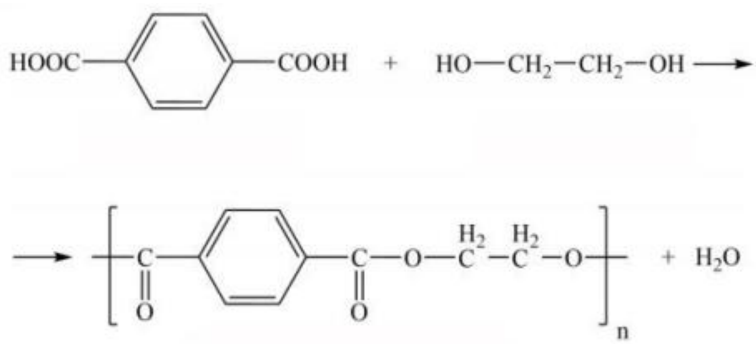

Figure 2. The reaction of polyethylene production

The presence of oxygen in the structure of the substance gives the material the ability to withstand low temperatures, and the benzene ring – high temperatures. This polymer is insoluble in water and in solutions of weak acids, and is almost impermeable to gas. The material is harmless only for short-term storage without heating, without direct sunlight.

The most common use of PET is as a raw material for the production of plastic bottles [6]. This type of consumption waste is the most widespread in the world. It can be recycled. The resulting products are used as roofing materials, packaging tapes, and tiles. Polyvinyl chloride is formed as a result of the polymerization of gaseous synthetic vinyl chloride (Fig. 3 and Fig. 4).

$$CH_2{=}CHCl \longrightarrow \left[CH_2{-}CHCl \right]_n$$

Figure 3. The reaction of polyvinyl chloride production

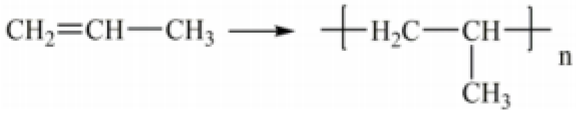

Figure 4. The reaction of polypropylene production

Its properties are similar to HDPE, but it has improved oil and grease resistance and mechanical density. In comparison with PE, it has a low ability to withstand low temperatures. It is waterproof and vaporproof, oxygen impermeable. Due to the fact that PP has a high melting point (~ 180℃), products packaged with this plastic can withstand short-term processing at 135℃.

Polystyrene is a product of the polymerization of liquid synthetic styrene (Fig. 1.5).

Polystyrene is a fairly hard and rigid polymer. It has low permeability to gases, but has vapor permeability properties.

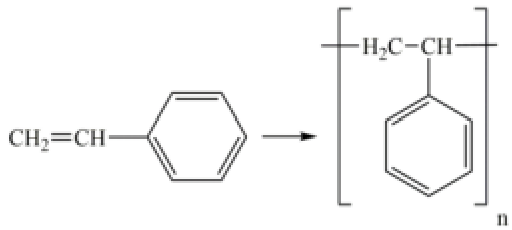

Figure 5. The reaction of polystyrene production

Plastic can be labeled differently:

PET is polyethylene terephthalate. It is a dielectric that is strong and resistant to wear. It cannot be dissolved in organic solvent or water.

Polyethylene terephthalate can be used to create containers for liquids, such as beverages or household chemicals. It is a component of some chemical fibers for the production of clothing or technical devices. It is also used in many other areas [7].

HDPE is a high-density polyethylene. It is resistant to water and does not react with acids and alkalis. It can be decomposed using nitric acid (50% solution at room temperature), as well as fluorine and chlorine.

PVC – polyvinyl chloride, is the 3rd type of plastic labeling. It has no color at all, i.e. it is transparent. This material is chemically resistant to mineral oils, solvents, alkalis, and most acids. It is not resistant to ultraviolet rays [7].

LDPE is a low-density polyethylene. It can be used in the same places as the previous materials (except for hard products). This type of plastic is one of the safest [7].

PP stands for polypropylene, the fifth marking of plastic products. It does not have the same high density as polyethylene, but it is more resistant to abrasion. It is also practically unaffected by temperature. Corrosion cracking will have almost no effect.

PC – polystyrene.

O-marking of other types of plastic products. They are most often used in construction.

3. PHYSICAL AND CHEMICAL PROPERTIES OF PLASTICS

Plastics or plastic mass are artificially created materials based on synthetic or natural polymers. According to DSTU 2406-94: plastic is a material based on a polymer that is in a viscous-liquid or highly elastic state during the molding of the product, and in a glassy or crystalline state during operation. Plastics are molded at an elevated temperature, at a time when they have high plasticity. The raw materials for the production of polymers are oil, natural gas, and coal [8].

The antifriction characteristics of many plastics make it possible to use them as raw materials for production in various industries. Among the manufacturing industry, plastic is widespread due to its low density, viz: 0.80–1.9 g/cm^3, which significantly reduces the weight of parts, high corrosion resistance and a wide range of other properties.

Other characteristic properties of plastics are high thermal insulation characteristics, high transparency, etc. An important advantage of plastics is that they can be processed into products using the most productive methods with a material utilization rate of 0.8–0.85, such as molding, extrusion, etc. Plastics play a significant role in human life. Most household items are made of plastic in whole or in part. From an economic point of view, the emergence of plastic in our lives is a great breakthrough because it is cheap to produce in a short period of time. But from an environmental point of view, plastic has a number of disadvantages, namely: the period of self-degradation is very long. The time ranges from 250 to 450 years. Since the rate of plastic production is ten times higher than the rate of recycling, this leads to the accumulation of polymer products in the world.

The following main disadvantages of plastic can be identified:

- low strength;
- hardness and mechanical stiffness;
- Low heat resistance (no more than 200°C);
- Low thermal conductivity (500-600 times less than that of metals);
- Susceptibility to aging (loss of properties under the influence of heat, light, water).

With aging, the elasticity and strength of plastics decrease, while their mechanical stiffness and brittleness increase. Elasticity refers to the ability of a material to undergo large reverse deformations. This term is physically similar to elasticity, but the former is used for amorphous and the latter for crystalline bodies. Most plastics are in a glassy state. Such polymers are called resins. A certain amount of the crystalline phase may be present in plastics, which increases the strength, stiffness, and heat resistance of the polymer. Synthetic resins are used in the production of plastics. In addition to polymers, plastics can contain fillers, plasticizers, and special additives that give the plastic certain properties. In addition to polymers, plastics may contain fillers, plasticizers, and special additives that give the plastic certain properties.

Fillers (reinforcing components) can be organic or inorganic substances in the form of powders (graphite, wood or quartz flour), fibers (paper, cotton, asbestos, glass) or cloths or sheets (fabric, paper, wood veneer). Fillers increase the strength, wear resistance, heat resistance, and other properties of plastics. Their share in plastics can reach 45–85%.

Plasticizers are added to increase the plasticity and elasticity of plastics (glycerin, castor or paraffin oil, etc.).

Additives can be:

- stabilizers – substances that slow down aging (soot, sulfur compounds, phenols);
- lubricants – substances that eliminate the adhesion of the material to the mold,

increase its fluidity, reduce friction between the particles of the composition (wax, stearin, oleic acid);

- colorants – substances that give plastic products a decorative appearance;
- catalysts – substances that accelerate the hardening of plastics (urotropin, metal oxides);
- flame retardants – substances that reduce the flammability of polymers (e.g. antimony compounds);
- antistatic agents – substances that prevent the occurrence and accumulation of static electric charge in products made of polymeric materials.

Plastics or polymers and products made from them are widely used in all areas of human activity. The production and use of plastics is one of the manifestations of scientific and technological progress, as it helps to reduce the cost of production of many products, operating costs, improve quality and enhance their appearance. The light weight of plastic products helps to reduce transportation costs and labor costs for large structures.

The physical, chemical, and mechanical properties, as well as the economic advantages of plastics, determine their important role in the chemicalization of the economy. Polymeric materials replace various traditional materials (metals, glass, paper, cardboard, leather).

In terms of processing methods, plastics have a significant advantage over many other materials. Thanks to the production of plastic products by pressing, injection molding, molding, extrusion and other methods, production waste (wood chips) is eliminated, and there is a possibility of extensive automation of production. Finally, a big advantage of plastics over other materials is the unlimited and readily available raw materials (petroleum gases, oil, coal, forestry and agricultural waste, etc.). One of the most important advantages of plastics compared to other materials is the wide range of materials with a given combination of properties. Plastics are increasingly used in construction, engineering, electronics, furniture, containers, packaging, household items, as well as in agriculture, transportation, medicine, etc. In recent years, a new class of materials – block copolymers that combine the properties of vulcanized rubbers and thermoplastics – has seen an increase in production.

These include butanediene sterol, isoprestylene, polyolefin, and ethylene vinyl acetate copolymers. Thermoplastics, like conventional plastics, can be processed by extrusion, calendering, thermoforming, and injection molding. Plastics not only replace or complement traditional materials, but also contribute to the development of new, more productive construction methods. The advantages of plastics over traditional materials are expressed in simplified designs, easier installation, reduced transportation costs, expanded use of standard parts, improved heat and sound insulation, and, ultimately, shorter construction times and lower capital construction costs. The advantage of plastics is that they require less energy to produce than competing materials. For example, the production of 1 kg of conventional plastics consumes about 11 MJ of energy, iron – 22–52 MJ, aluminum – 62–275 MJ, and bottle glass – 35–55 MJ. The share of energy costs in the production costs of plastics is on average 3%, in the production of iron – 5%, bottle glass – 6%, cement – 16%, and primary aluminum – 24%. The energy consumption of plastic products is also significantly lower.

The technology of plastics production is developing along the path of improving traditional methods, developing and implementing new methods, primarily for the production of large-tonnage products: polyethylene, polypropylene, polyvinyl chloride, and polystyrene.

4. SELECTING THE CONFIGURATION AND CALCULATING THE STIFFNESS CHARACTERISTICS FOR THE ANTENNA

The production of antenna systems using the method of electric arc spraying, as well as the creation of reflective surfaces, is based on innovative technological and design solutions.

The process of forming shells from mesh material is investigated. The challenge in describing the deformation processes is due to the fact that the mesh behaves qualitatively differently compared to a solid sheet of material. This is due to its special structure, in particular, the possibility of rotation of perpendicular mesh wires relative to each other at the nodes. In the presented research, offset antennas are studied to identify their capabilities and improve their use in modern radio engineering systems [9].

Developed in response to the dynamic demands of radio communications environments, offset antennas play an important role in modern data communications systems fig. 6.

Figure 6. Offset antenna

They provide high signal directivity and communication stability even in severe weather and electromagnetic interference. Experimental and practical results confirm the high reliability and stability of offset antennas even in critical situations, which makes them attractive for use in various fields such as telecommunications, satellite communications, military equipment, and scientific research [10].

The basic principles of offset antennas are based on focusing technology. The signal from the satellite is directed to a reflective surface, from where it is reflected in the direction of the support structure, where the antenna concentrator (usually in the form of a lens or cone burner) is placed. The concentrator accumulates the signal and transmits it to the receiver or converter for further processing.

Offset antennas have a number of advantages, including reduced susceptibility to signal loss due to microwave interference, increased resistance to weather conditions, and the ability to centrally locate the receiver, which greatly simplifies installation and maintenance.

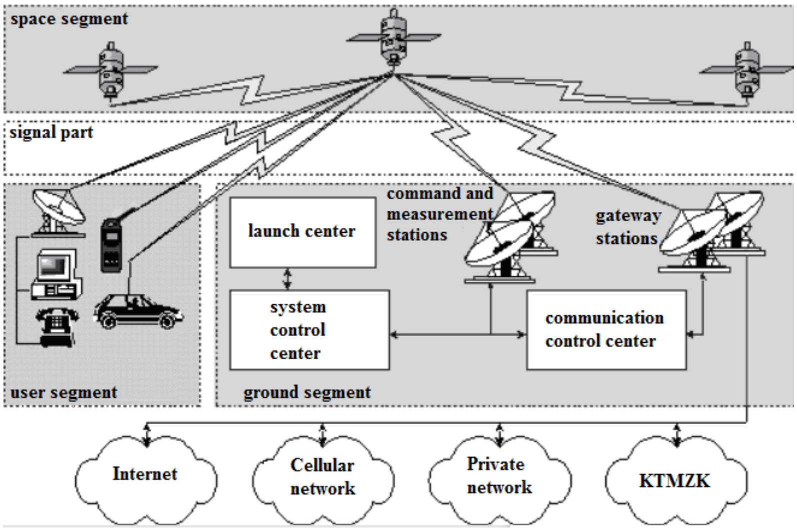

Figure 7. Principles of communication and use of antenna systems

In studying the dynamic stability of an antenna mirror in the form of a spherical segment connected to a ring, the structure is analyzed with consideration of various factors and parameters. To match the solutions, the concept of a cylindrical shell attached to the ring as a flexible base is used, taking into account design features such as protection from external influences [11].

This study focuses on the effective application of electric arc spraying technology to create reinforced material. This method allows for the application of thin layers on various surfaces and has significant potential in various sectors, from industry to construction and telecommunications. Electric arc spraying helps to increase the strength, protection against corrosion and other negative effects on materials subjected to high loads, including wind. In our study, we examine the effect of electric arc spraying on reinforced material under wind loads and analyze its potential for creating strong and reliable structures.

The main stages of electric arc spraying include: surface preparation, material preparation, electric arc generation, spraying, cooling and fixing. The surface to be coated must be thoroughly cleaned of contaminants such as dirt, oil, and rust; in some cases, grinding may be required to improve adhesion. The material for spraying is usually supplied in the form of wire or powder, which is melted by an electric arc to a high temperature. The molten material is sprayed onto the prepared surface using a gas jet (usually argon or air) and quickly solidifies to form a thin coating.

After that, sheet plastic material such as polystyrene, ABS plastic and polypropylene is applied to create reflective reinforced shells. After the coating is applied, the material is cooled and cured to the surface. To achieve maximum strength, additional processes such as heat treatment or ultrasonication are used.

Wind loads can affect the reinforcing material applied by electric arc spraying, especially in structures operated in open spaces, such as antennas, masts, or towers used in telecommunications systems, power transmission, or building construction [12]. Wind loads can cause deformation or damage to structures. The reinforcing material serves as a protective layer, reducing the impact of wind loads on the base material of the structure. When making calculations, it is important to take into account potential errors in manufacturing and installation, such as incorrect positioning of antenna components or mismatching of material parameters.

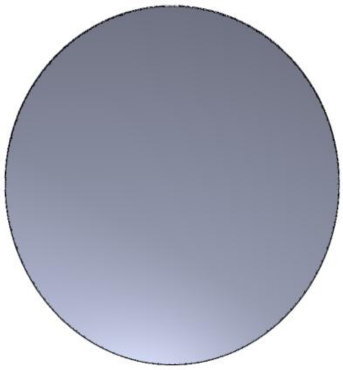

Figure 8. Offset aluminum antenna with a thickness of 2 mm (front view and side section)

Figure 9. Offset composite antenna with a thickness of 2 mm (general view of the antenna structure)

An offset antenna can deviate from the ideal due to the focusing of the signal on a reflective element. This requires complex calculations and modeling to determine the exact characteristics of the antenna

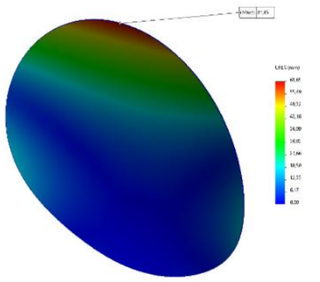

Figure 10. Displacement diagram

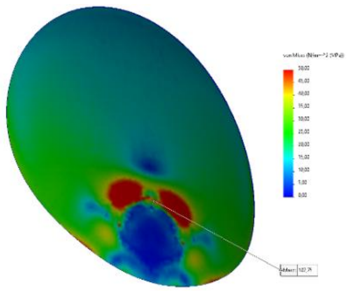

Figure 11. Stress diagram

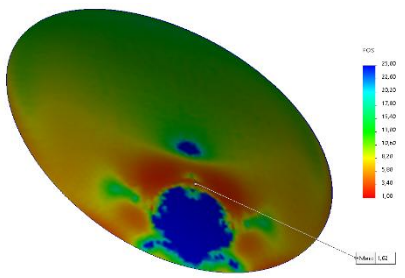

Figure 12. Safety factor diagram

In this study, it was found that the manufacture of offset antennas using electric arc spraying and two-layer plastic application is not inferior in terms of rigidity and durability to other manufacturing methods. Electric arc spraying provides a high quality coating that meets the requirements for efficient operation of antennas in various operating conditions

5. DETERMINATION OF HETEROGENEITY OF COMPOSITE MATERIALS BY CONDUCTOMETRIC METHOD

In order to detect inhomogeneities in composite materials of shell structures using the conductometric method, several stages should be performed, such as theoretical calculations, modeling, and practical measurements [13].

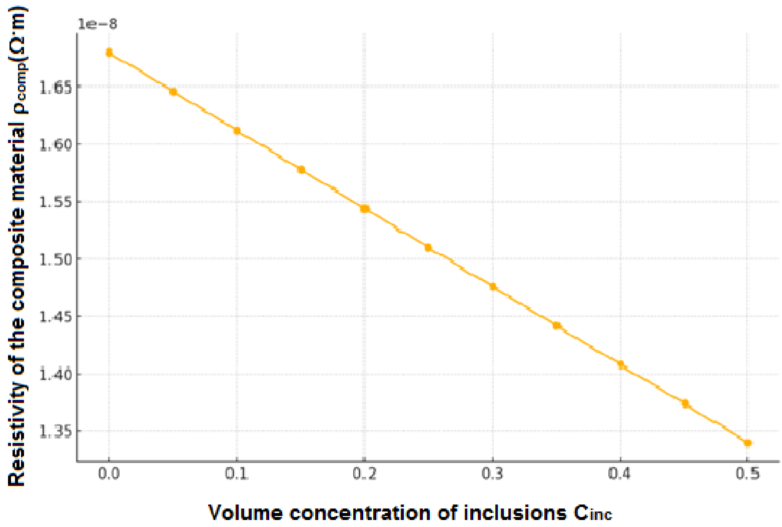

Figure 13. Dependence of the resistivity of a composite material on the concentration of inclusions

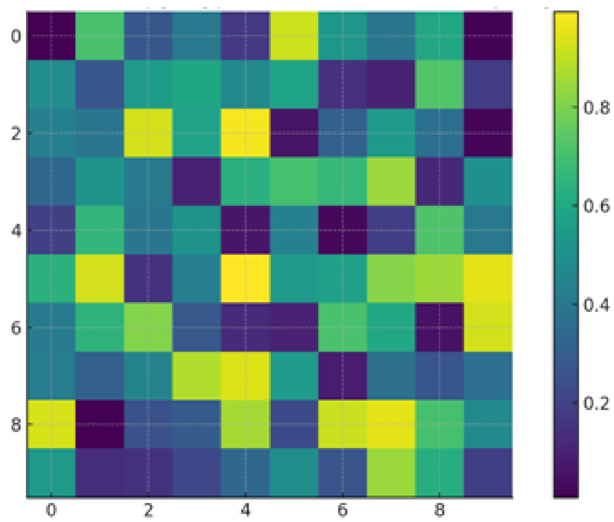

Figure 14. Safety factor diagram of a monolithic composite material

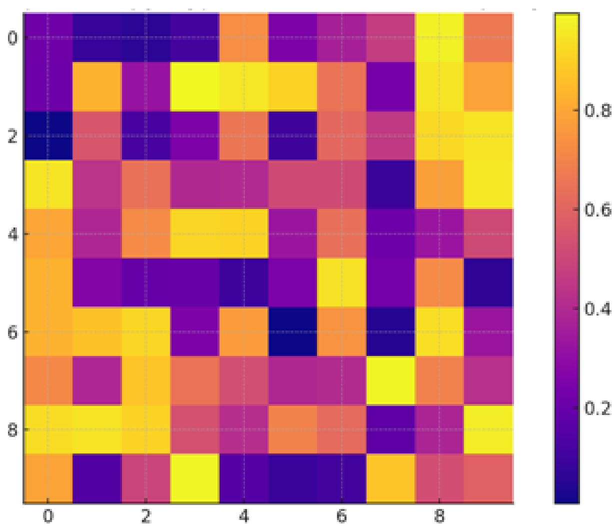

Figure 15. Safety factor diagram of a porous composite material

The conductometric method fig. 13–15 allows for the effective detection of inhomogeneities in composite materials, which includes theoretical calculations, modeling, practical measurements, and data visualization for analyzing the results [14].

6. CONCLUSIONS

The analysis of the stress-strain state of the two variants of the offset antenna design showed that the safety factor for the antenna of the proposed design is 5.7 times lower than that of the base design, but exceeds the minimum allowable value of 1.5 for such structures. The normal stresses in the antenna of the proposed design are 4.5 times higher than in the baseline design and amount to approximately 108 MPa. The maximum displacements of the upper edge of the antenna of the proposed design are 20 times higher than in the baseline design and amount to about 62 mm, which makes normal operation of the antenna impossible in wind conditions with a speed of 20 m/s.

To determine the heterogeneity of composite materials of shell structures, calculations were performed using the conductometric method, which included the calculation of the resistivity of the composite material and visualization of the results.

In general, these results show the prospects of using electric arc spraying and two-layer plastic deposition in the production of offset antennas, confirming it as an efficient and competitive process.

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СИСТЕМИ АВТОМАТИЧНОГО КОНТРОЛЮ ЗА ХАРАКТЕРИСТИКАМИ СПОЛУК НА ОСНОВІ КОМПОЗИТНИХ МАТЕРІАЛІВ

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Резюме. *Відомо багато методів. основних та спеціалізованих, виготовлення виробів з пластику та пластмас. Кожен спосіб з них – це спосіб реалізації технології виготовлення виробу з полімерного матеріалу, який визначається кількома факторами. Результатом роботи є дослідження та аналіз оболонкових конструкцій відбиваючих решіток (офсетних та параболічних антен) утворених методом електродугового напилення, та нанесення композиційного матеріалу на пуансоні. Графічно представлено оцінювання жорсткісно-міцнісних характеристик антен суцільної та армованої конструкції, проведено розрахунок їх напружено-деформованого стану при дії вітрового навантаження та сили земного тяжіння. Визначено неоднорідності композитних матеріалів оболонкових конструкцій кондуктометричним методом, проведено розрахунки, що включають обчислення питомого опору композитного матеріалу та візуалізацію результатів. Визначено основні методи виготовлення пластикових виробів на основі типу полімеру, агрегатного стану та конфігурації виробу. Виділено дев'ять груп методів за класифікацією Маккелві, включаючи екструзію, термоформування, пресування та виготовлення спінених виробів. Визначено переваги та недоліки кожного з методів, а також їх вплив на якість та міцність кінцевого виробу. Розглянуто основні види пластмас: поліетилен (HDPE, LDPE, PET), полівінілхлорид (ПВХ), поліпропілен (ПП) та полістирол (ПС). Аналіз маркування показав, що ПЕТ є найпоширенішим у виробництві упаковки та може бути повторно перероблений. Визначено основні сфери застосування кожного виду пластику та їх придатність до вторинної переробки. Дослідження підтвердило низьку густину, високу корозійну стійкість, теплоізоляційні властивості та можливість повторної переробки пластмас. Разом з тим, екологічні виклики вимагають подальших досліджень у напрямку біорозкладних матеріалів та ефективних методів утилізації. Окрему увагу приділено впливу пластмас на навколишнє середовище та можливостям зниження їх негативного ефекту шляхом удосконалення технологій виробництва та переробки.*

Ключові слова: *композиційний матеріал, електродугове напилення, армований композиційний матеріал, дзеркало, офсетна антена.*

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