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Classification of composite materials used in aerospace industry applicable to their microwave non-destructive diagnose

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Abstract. The increasing use of composite materials in the aerospace industry necessitates the analysis of the possibilities for their diagnosis and for the non-destructive control of their quality, taking into account their specific features.
The paper suggests a classification approach of the composite materials used in the aerospace industry, oriented toward methods of their non-destructive microwave diagnostics. The main features of the suggested classification are: the material composition of composite details, their shape and structure and the system or device in which it is used.

Key words: composites, aerospace, classification, non-destructive microwave diagnostics

1. Introduction

It is well-known composites (composite materials) consist of two or more materials with different physical or chemical properties that together form a composite with properties other than their compound parts. In most cases composites are created to achieve better options for their use in various mechanical effects (friction, shocks, vibrations, accelerations, loads, etc.), temperature characteristics of the environment in which they operate (extra is formal or faster varying over a wide range of temperatures), chemical and electromagnetic parameters of the environment in which they function (salinity, acidity, radiation, etc.), as well as to achieve certain physicochemical parameters at less weight or with smaller production costs[1-9].

One of the priority areas for the use of composite materials is the aerospace industry. A number of evaluations show that their use in the production of modern rockets, aircraft and helicopters results in a 20-30% reduction in the weight of the parts concerned, compared to those produced from conventional materials. Often during the process, an increase in the resistance of the corresponding detail towards external influence is achieved. As a result, in many cases a reduction of production cost is achieved.

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The increasing use of composite materials in the aerospace industry necessitates the diagnostic analysis of non-destructive quality control in accordance with their specific features. Various diagnostic methods show various efficiencies for the different types of composites due to complex and vast variety of their materials.

The composite material used in the aerospace industry allows for a classification approach for the classification of composite materials, oriented toward methods for their non-destructive microwave (ultra-high frequency) diagnostics.

2. General approach

Microwaves are known to interact with the medium in which they propagate, in which they are reflected, refracted, and damped. These phenomena depend mainly on the electromagnetic characteristics, the geometric shape and the physicomechanical structure of the medium with which the electromagnetic waves interact. Furthermore, the possibilities for the practical implementation of microwave diagnostics in aerospace systems depend on the particular device in which the composite material is used, its accessibility and the conditions for its operation.

Therefore, composite materials used in the aerospace industry can be classified by the following main features:

- composition of building materials,
- the form and structure of the materials forming them,
- a system or device where they are used.

2.1. Classification of composite materials according to the composition of the constituent materials.

The materials, the composites are made of, have different electromagnetic and physicomechanical characteristics. The effects of the interaction of microwave radiation with them depend mainly on their electromagnetic characteristics. Therefore, by the notion of "stock material" for research purposes, appropriate composite materials can be classified into three large groups – metal, non-metal and hybrid[10,11].

The metal composites refer to a composite of titanium, nickel, niobium, steel, platinum, aluminum, compositions of nanoparticles of various metals and so on. The meta metal composite material (NiAl) together with intermetallics, especially – TiAl, NiAl, and platinum group metal compounds (PGM) are of particular interest in the aerospace industry.

PGM- based intermetallic alloys are of two types – Isomorphic with Ni_3Al (e.g., Pt_3Al) and Isomorphicwith NiAl (e.g., RuAl). In both cases, the advantages of PGM- based intermetallics over Ni-based superalloys are significantly higher melting points (1500° C for Pt_3Al and 2100° C for RuAl) and inherent oxidation resistance (although and with some increase in density).

Inconel (nickel-chromium-iron) alloys are often used in gas turbine engines because of their ability to maintain their strength and corrosion resistance at extremely high temperatures.

Other promising metallic composite materials are Form Memory Stores (SSMs). When SSMs heat up, they return to their original form. These composite materials typically consist of copper and nickel-based alloys.

The metallic composite materials are characterized by ultra-high frequency oscillations that are reflected and/or absorbed to a considerable extent by them, and the propagated decay within them is extremely large. Therefore, ultra-high-frequency diagnostics can only be performed on their surface layers or on layers close to their surface.

The non-metallic composite materials include carbon fiber, glass and ceramic composites, often reinforced with aramid, polyamide, carbon fiber reinforced materials(polyester sulfone, polyphenyl sulfone, phenol-novolac, Bismaleimide, phenol, epoxide, polyurethane and with aramid fibers), polyester, etc.

Fiberglass is made of glass as a reinforcing material, which is in the form of fine fibers or woven in the form of a cloth, and the matrix is made of plastic. Typically, a plastic matrix holds the glass fibers together and also protects them from damage by the shearing forces acting on them when bent. Some non-metallic composites use carbon fibers instead of glass. Carbon fiber materials are lighter and more durable than fiberglass, but more expensive to manufacture. Carbon-carbon composites are also widely used, from which 3-D fabrics can be successfully produced. Fiberglass and carbon-carbon composites have different electrical conductivity. So carbon composites is almost impenetrable by electromagnetic waves.

Carbon nanotubes are relatively new components of non-metallic composites that are even lighter and sturdier than ordinary carbon fibers, but for the time being, they are extremely expensive.

Ceramic matrix composites (CMCs) are widely used in a number of aerospace systems and devices because of their ability to withstand extreme temperatures.

Spider silk is another material that is used as a fibrous material in composites because of its high plasticity (allows suturing of the fiber when stretched to 140% of its normal length). Moreover, spider silk retained its strength characteristics at low temperatures of -40° C.

A molybdenum-silicon-boron-reinforced titanium carbide alloy is a promising new material whose high-temperature strength has been identified at constant forces in the temperature range from 1400° C to 1600° C when reinforced with boramaterials on the tungsten core.

Niobium-silicide-based composites exhibit good oxidation resistance, reasonable breakage resistance, good pest resistance (medium temperature spraying), good high-temperature strength and good impact resistance, good fatigue resistance.

There are various types of sophisticated fiber architecture (two-dimensional and three-dimensional fabrics, knitted and woven) being developed and used as composite blanks. Of particular interest are the specially developed carbon fiber reinforced polymers (CFRP) for the aerospace industry, such as those of the Japanese company Nakashima Propeller.

The hybrid composites include composites made of metallic and non-metallic materials. This is usually done by filling a matrix of metallic material with a non-metallic material (the so-called Metallic Matrix Composites - CMM). The CMM matrix is usually sandwich or honeycomb made of light metal (aluminum, magnesium, titanium, etc.). The hybrid composites are most often filled with ceramic particles or short ceramic fibers that slightly improve the mechanical properties of the matrix or with long ceramic or metal fibers that significantly increase the mechanical properties of the matrix but require expensive molding processes.

It is worth noting that the hybrid composite materials also include components with a non-metallic matrix (e.g. organic, ceramic, fiberglass or Nomex) but it is filled with metallic materials.

Since metal matrices already have intrinsically good mechanical properties, the reinforcement of the composite can only be done in certain areas or in one direction. This is generally not possible for organic matrices (low resistance) or for ceramic and glass matrices (brittleness).

It is worth notingthat there are also non-matrix hybrid composites, in which the mixing of metal and non-metal components is not possible through the use of matrix structures. For example, silicon carbide (SiC) is a composite material that is suitable for the aerospace industry because of its high impact resistance and its ability to maintain its mechanical strength at high temperatures.

Nanocomposites and hybrid multi-scale composites are also available for use in the aerospace industry. They use nanomaterials such as carbon fibers, carbon nanotubes and metal nanoparticles implanted in conventional composites.

2. 2. Classification of composite materials depending on the form and structure of the building them materials.

The shape and structure of the materials that make up a composite element mainly influence the degree and direction of reflection of the microwave oscillation, the degree and direction of its refraction, the degree of internal diffusion, etc. Therefore, the shape and structure of the constituent materials, for the purposes of the study, is the most commonly used composites in the aerospace industry, which are to be classified as matrix, multilayer, monolayer, single and combined.

As noted above, matrix composite materials use a matrix that is filled with particles of other substances. The matrix itself is most often a sandwich or honeycomb.

Multilayer composite materials are composed of several layers (sheets), each of which has a relatively uniformly distributed composite composition. The individual sheets are most often joined together by bonding with resins or by mechanical, thermal or other means.

Single-sheet composite materials consist of a single sheet and single-sheet composite materials.

Composite materials consist of different combinations of the above types, formed into a single package – e.g. a single strip material with a matrix material attached thereto, two single or multi-sheet composite materials with a matrix material between them, and the like.

The basis of the individual composites are their individual components, which, depending on their shape, can be classified as follows:

- *Fiber* is an individual strand of material. A thread with a length to diameter ratio greater than 1000 is called fiber. The fibrous form of reinforcement is widely used. Fibers – continuous and short, single and in the form of tissue, random or direction oriented, two-dimensional and three-dimensional, single-layer and multi-layer, laminate (in layers for covering or embedding) or hybrid.
- *Fiber* which may be continuous or short.

The continuous fiber is very long, not torn or cut. The composites made up of continuous fibers are called fibrous. The short fibers are cut into small pieces, which are used to reinforce the so-called short fiber composites.

- *Particles* – they are usually several micrometers in size and are added to reduce the plasticity of the matrix materials. In this case, the load is shared by particles and matrix materials. However, the load absorbed by the particles is much greater than the matrix material. For example, soot (as particulate matter) is used to reinforce rubber (as a matrix material).
- *Flakes*: The flakes are a small, flat, thin piece or layer that breaks into a larger piece. Because they are approximately two-dimensional, they impart almost equal force in all directions to their planes, making them very effective reinforcement components. The flakes can be packed more tightly when they are laid in parallel, even more tightly than unidirectional fibers and spheres. For example, aluminum flakes are used in paints. They are aligned parallel to the surface of the coating, which gives good properties.
- *Whiskers*: The whiskers are almost ideal monocrystalline or polycritical materials usually with high strength, such as graphite, aluminum, iron carbide, silicon and so on. The whiskers are small, discontinuous and having a polygonal cross-section.

2. 3. Classification of composite materials according to the systems in which they are used

The systems and devices in which composite material is used largely to define two basic characteristics related to its ultra-high frequency diagnostics and control. The first is the importance of the security of an aerospace vehicle, which is related to the use of different types of diagnostics performed through independent means to ensure a degree of security commensurate with the importance of the system concerned. In this sense, over-frequency diagnostics and control could be used as the only, basic or additional type of diagnostics.

As the only type of diagnosis, it is appropriate to use it either when other types are impractical (e.g. for porous composites associated with high attenuation of ultrasonic or infrared radiation) or if it is economically feasible for non-vital components (e.g. cabin luggage compartments), interior cabin doors, seats, etc.).

For a basic type of high-frequency diagnostics, it is advisable to use, together with one or more types of diagnostics, of safety-critical components (e.g. gliders and other supporting structures, engines, ailerons, etc.), as well as expensive and economically important products (e.g. missiles, orbital stations, large aircraft, etc.).

As an additional type, the high-frequency diagnostics could be used when other reliable means of control and diagnostics exist. Yet in some situations, their results are unclear and need to be confirmed by diagnostics using a method based on other principles.

Considering the above and for the needs of the research, composite materials can be classified, according to the indicator, in different ways. For example[1-9]:

- according to the types of aerospace vehicles in which they are used – composite materials used in rockets, artificial satellites, airplanes, and helicopters, as well as for composites used in the respective civil or military means;
- according to the main types of devices and systems in which they are used: composite materials used in basic (basic) structures – in fuselages, wings, ailerons, chariots, etc.; composites used in systems operating in extreme (especially temperature) conditions – in engines, turbines, rocket nose compartments, external thermal insulation coatings, etc.; composite materials used in aerospace auxiliaries – in cabins, transport compartments, in fixing and fixing means, in countertops, seats, etc.;
- according to their physical accessibility – generally, by this indicator, they can be classified as composite materials located on the surface of the system or device in question (e.g. rocket guards, external thermal insulation housed in cargo compartments and etc.), and composite materials housed within a given system or device (e.g., composites used in helicopter rotors, propellers and other aircraft and rocket engine parts, fuselage interiors, etc.).

In general, nanoclay-reinforced composites, carbon nanotubes (CNTs) and metal nanoparticles are increasingly used in the aerospace sector both to provide electromagnetic shielding and as fire-fighting components.

For propellers of various aviation means, composite materials are used, such as the carbon fiber-reinforced polymer (CFRP) developed by Nakashima Propeller, which allows propellers to be 40% -50% lighter than conventional products. For its part, the company Rolls - Royce, which is one of the largest manufacturers of aircraft engines, developed SiC CMCs composites that can withstand the high temperatures of 1900 °C.

In particular, the most commonly used systems and devices in aerospace using composite materials are:

In airplanes, for example in the A380, composite materials are used in the wings as a structural material, which is a supporting structure and helps to ensure a 17% lower fuel consumption per passenger than others. Each B-2 contains approximately 40,000 to 50,000 pounds of modern composite materials.

In an ATF fighter jet – the so-called "Advanced Tactical Fighter " 50% by weight is made of composite materials.

Fairings, landing gear, bonnets, handlebars, doors, floorboards, and many other interior fittings are made of sophisticated composites in combination with metal and non-metal combs and metals.

Most commonly, the composite materials used in aircraft basic structures are high-temperature thermoplastic and thermosetting polymers based on carbon fiber reinforced polyethersulfone, phenol-novolac, bismaleimide, epoxide, or phenol or polyurethane reinforced with aramid fibers.

Most often the composite materials used in aircraft cabs are glass fiber, reinforced polymeric matrix, bismaleimide, phenol, melamine, epoxide, polyester, polybutylene terephthalate and more.

Carbon fibrous or filamentary matrix materials impregnated with epoxy resins (prepregs) or laminates with sheets of individual prepreg sheets are often used to repair aircraft structures.

In helicopters they use composite materials for a middle section of the fuselage, parts of the main rotor, tail rotor blades, horizontal and vertical stabilizers, awning, etc. The use of fibrous composite materials leads to improvements in helicopter rotors, to the improvement of aerodynamic shapes and improving their maneuverability.

In the Advanced Light Helicopter (ALH) prototype, about 60% of the surface is composed of composite components, including advanced fiber components and metal sandwich structures.

In space and rocket applications, graphite and epoxy matrix composites with honeycomb design are used in the space shuttle, while silicon fiber composites or polyurethane insulation foam are used for thermal insulation. Reinforced carbon-carbon (RCC) composites are used for the nasal cone and leading edges of the space shuttle.

Ceramic matrix composites (CMCs) and ceramic-metal composites are used in turbines and rocket engines, and a carbon-carbon-enhanced (RCC) composite is used for the front cone of intercontinental ballistic missiles. Ceramic matrix composites in silicon carbide are used in jet engines and in front of fairings.

The space shuttle remote arm, which deploys and extracts payloads, ribs, and antennae from satellite systems, is made of graphite and epoxy-based composites.

Rocket engine outer shells and linings are often made using carbon, aramid and glass composites.

3. Conclusions

In the material above are shown the basic composite materials used in different areas of the aerospace industry. The offered classification of composite materialsis aimed at identifying opportunities for ultra-high-frequency diagnostics. This classification takes into account the composition of the material, their shape and structure, as well as a system or device in which it is used. These composite materials parameters have a decisive influence on the possibilities for their indestructible control and for the diagnosis of their parameters by using ultra-high frequency methods.

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