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# A Radio Absorbing Composite Material Based on Compounded Rubber and Modified Nonwoven Fabric

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**Abstract**—The paper discusses the relationship between the reflection of microwave electromagnetic radiation and the composition of a composite multilayer material made from rubber filled with carbonyl iron particles and nonwoven fabric reinforced with carbon fiber. It is found that the radio absorbing composite material has low reflectivity at electromagnetic wave frequencies less than 4 GHz. It is shown that the composite material has the highest absorption capacity when electromagnetic waves are incident on the nonwoven fabric layer of the material.

*Keywords:* rubber, nonwoven fabric, radio absorbing material, reflectivity, carbonyl iron particles, carbon fiber, electromagnetic radiation

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Production techniques of radio absorbing materials are based on the incorporation of an electrically conductive filler into a dielectric polymer matrix whose chemical nature may vary [1].

As a rule, the radio absorbing properties of composite materials are only partially dependent on the dielectric matrix proper, and the latter is selected primarily on the basis of the requirements concerning the production technique and operating conditions of the final products. These requirements include the following: a high degree of filling the polymer matrix with electrically conductive filler, uniform distribution of the filler across the polymer matrix, and high resistance of the polymer matrix itself to impact of the environment [2].

Dielectric matrices that are based on synthetic rubbers basically meet the above technological and operational requirements. Rubber processing techniques ensure a high degree of filling of materials with electrically conductive fillers of different nature, and rubber-based products have a long service life under the anticipated operating conditions.

The main disadvantage of radio absorbing materials based on compounded rubbers is that they absorb electromagnetic radiation (EMR) in a relatively narrow frequency range. One way to broaden the frequency range is the use of multilayer materials whose layers have different concentrations of conductive fillers of the same or different chemical composition.

The objective of this study was to evaluate the frequency dependence of the reflectivity of multilayer composite materials consisting of rubber filled with carbonyl iron particles and nonwoven fiber fabric filled with dispersed carbon fiber.

We examined 1-mm-thick plates of vulcanized rubber based on SKTNA Grade siloxane rubber (GOST 13835-73). The latter is a low-molecular dimethylsiloxane fluid. Cold-curing of rubber was performed in the presence of catalyst no. 18 (TU 6-02-005-78). The rubber was filled with electrically conductive carbonyl iron particles from 2 to 5 mm in diameter [3].

Needle-punched fabric made of polyester fibers 20 μm in diameter with surface density from 100 to 120 g/m$^2$ was used as a nonwoven fiber layer. The nonwoven fabric was produced using a Dilo nonwoven fabric production line (JSC Montem), the fabric being formed mechanically and then hardened at a needling density of 160 cm$^{-2}$.

The nonwoven fabric was filled with dispersed UGTSV-1 grade carbon fiber (carbon rayon fiber) $(5 \pm 1)$ mm long, with electrical resistivity of 0.025 Ω cm. Carbon fiber was applied to the surface of the fabric and bonded to the second layer of fabric with a needle-punching machine that prevented the in-plane fiber orientation from changing. The concentration of carbon fiber on the surface of fabric ranged from 0.2 to 0.8 g/m$^2$.

The reflectivity was measured at the normal incidence of electromagnetic waves by using voltage standing wave ratio (VSWR) meters that are panoramic in the frequency range from 2.6 to 37.5 GHz. A horn antenna with its own voltage standing wave ratio less than 1.1 was used as the terminating load of the waveguide transmission line. Samples were placed on a metal sheet that ensured total reflection of EM waves passing through the radio absorbing material. The reflectivity ($R$) of rubber, nonwoven fabrics, and multilayer materials based on rubber and nonwoven fabrics was calculated by the formula

$$R = 10(\log E_{ref}/E),$$

where $E_{ref}$ is the power of reflected EMR and $E$ is the power of incident EMR.

Preliminary evaluation of the frequency dependences for rubbers and nonwoven fabrics with different contents of carbonyl iron particles and carbon fibers, respectively, showed that rubbers with a carbonyl-iron concentration of 80% and nonwoven fabrics containing 0.2 or 0.32 g/m$^2$ of carbon fiber are the most suitable for creating effective radio absorbing materials.

The frequency dependences of the reflectivity of rubber and nonwoven fabrics of the above compositions are shown in Fig. 1.

The frequency dependences of the reflectivity of rubber and nonwoven fabrics show that these materials are of the electromagnetic-interference-absorbing type. Absorption of EMR by materials of this type is based on the superposition of waves reflected from several interfaces [1]. If electromagnetic waves reflected from the rubber plate or the carbon fiber interlayer in nonwoven fabric and the metal substrate are opposite in phase and equal in amplitude, they cancel each other. The phase difference of the wave reflected at the metal substrate is dependent on the thickness of the dielectric (the thickness of the rubber plate or the nonwoven fabric overlying the carbon fiber interlayer) and the composition of the conductive filler.

The disadvantage of rubbers and nonwoven fabrics is their low absorption capacity with respect to low-frequency electromagnetic waves (see Fig. 1, curve *1*). Thus, the frequency at which the reflectivity of rubber is less than −10 dB (when the reflected electromagnetic wave energy is 10% of the incident electromagnetic wave energy, which is sufficient for practical use) is within the frequency range from 4 to 8 GHz. For nonwoven fabric containing 0.32 g/m$^2$ of carbon fibers, this is observed at frequencies above 7 GHz. The reflectivity of fabric with a carbon fiber content of 0.2 g/m$^2$ is higher than −10 dB at any EMP frequency.

To produce the composite multilayer material, a mixture of rubber and a hardener was applied to the surface of nonwoven fabric using a doctoring device, and then the mixture was cured at a room temperature. The relatively high viscosity prevented the rubber from impregnating through the nonwoven fabric, but it ensured sufficiently good adhesion of the binder to the surface of the fiber fabric. The resulting material had a pronounced interface between the layers of rubber and nonwoven fabric.

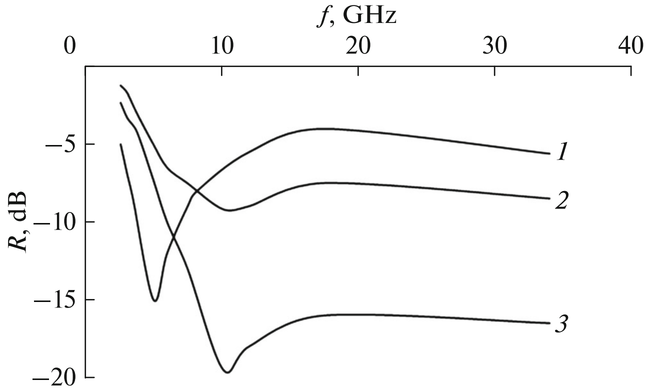


**Fig. 1.** Frequency dependences of the reflectivity of rubber (*1*) and nonwoven fabrics containing 0.2 g/m$^2$ (*2*) or 0.32 g/m$^2$ (*3*) of carbon fibers.

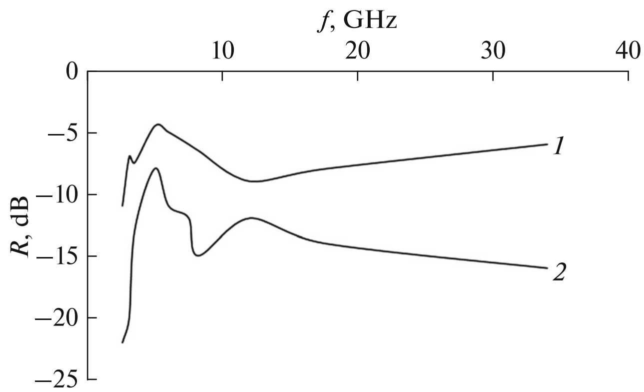


**Fig. 2.** Frequency dependences of the reflectivity of composite material based on rubber (*1*) and nonwoven fabric (*2*) when electromagnetic radiation is incident on the surface of radio absorbing material.

It was experimentally established that the efficiency of absorption of electromagnetic waves by the composite material depends on the layer orientation in the material relative to the direction of electromagnetic wave propagation. Figure 2 shows the frequency dependences of the reflectivity of the composite material based on rubber and fabric with a carbon fiber content of 0.2 g/m$^2$ at different EMR incidences.

The impedance of the nonwoven fabric layer is better matched to the impedance of free space at the material–air interface, which leads to the "smooth" penetration of electromagnetic waves into the material and their refraction and reflection at the interfaces within the composite material and the metal substrate.

Figure 3 shows the frequency dependences for different composite materials.

The high efficiency of the absorption of electromagnetic radiation by composite multilayer materials (with reflectivity less than −10 dB) is observed at frequencies less than 4 GHz and greater than 7 GHz. At

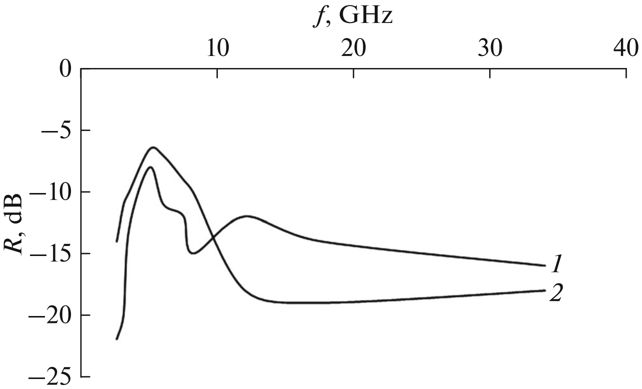


**Fig. 3.** Frequency dependences of the reflectivity of composite material based on rubber and nonwoven fabric with a carbon fiber content of 0.2 $g/m^2$ (*1*) and 0.32 $g/m^2$ (*2*) of carbon fibers.

frequencies greater than 7 GHz, the reflectivity tends to a constant equal to −15 dB. As the frequency falls below 4 GHz, the reflectivity steadily decreases, which implies that electromagnetic radiation is almost completely absorbed.

This is due to internal re-reflection of electromagnetic waves at the interfaces between the layers of rubber, carbon fiber, nonwoven fabric, and the metal substrate. The reflectivity vs. frequency curves for multilayer materials consisting of nonwoven fabrics with carbon fibers suggest that these materials have similar efficiency of absorption of electromagnetic radiation irrespective of the filler content.

This result suggests that it is admissible to relax the requirements concerning the quantity of conducting filler materials. Thereby, one of the difficult technical problems associated with the production of radio absorbing nonwoven materials can be solved.

## CONCLUSIONS

The following conclusions can be made:

(1) The composite material made of rubber filled with carbonyl iron particles and nonwoven fabric reinforced with carbon fiber is able to effectively absorb electromagnetic radiation with frequencies less than 4 GHz.

(2) The effectiveness of absorption of EMR by the composite material decreases at frequencies above 7 GHz; it is comparable with the level of EMR absorption by nonwoven fabric of a certain composition.

(3) The use of composite materials makes it possible to lower the requirements concerning the amount of conductive filler materials in the composition of the fabric.

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