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**PARTICLE MATERIALS EFFECTIVE
AGAINST MICROWAVE RADIATION**

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A b s t r a c t :

The laboratory measurements of the selected particle materials showed that S 244 carbon fibres, Chezacarb electro-conductive carbon black and CR 299 ground natural graphite had been effective when attenuating microwaves in a frequency range $f \approx (8-12)$ GHz, $f \approx (2-18)$ GHz, respectively. The transmittance was decreasing with the increasing thickness of the sample cell (i.e. with the increasing content of the particle material in the measuring path). The mixtures of polyamide fibres or viscose fibres with natural carbon graphite proved to be a suitable carrier of such particle material. The frequency transmittance reached the lowest values with the sample of the mixture containing 30 % of graphite.

1. Introduction

It is desired today that the protection of military objects (e.g. armoured vehicles) against reconnaissance means and especially against precision-guided weapons be secured by means of aerodispersions effective also in the microwave range of the electromagnetic spectrum. The means for the aforementioned intentions are not commonly available so far. Grenades for the fast protection of armoured vehicles with the aforementioned properties were mentioned only sporadically: it is stated [1] that

NICO-PYROTECHNIC multi-spectral grenade secures attenuation > 15 dB in a microwave range (35-140) GHz without any other specific description of the grenade charge and its composition.

2. Particle Aerodispersion Use

In recent years, we were engaged in the research of the particle materials attenuating radiation in the visible and infrared (IR) range of spectrum [2-8]. We confirmed that the particle aerodispersions, as one kind of the camouflage aerodispersions, had showed suitable attenuating abilities for attenuation of IR radiation. Camouflage abilities of carbon aerodispersion of Chezarb conducting black type $MS(\lambda_1) = (0.18-0.19) \text{ m}^2 \cdot \text{g}^{-1}$ at a wave length $\lambda_1 = 0.82 \text{ } \mu\text{m}$, $MS(\lambda_2) = (0.12-0.16) \text{ m}^2 \cdot \text{g}^{-1}$ at a wave length $\lambda_2 = (3-5) \text{ } \mu\text{m}$ and $MS(\lambda_3) = (0.07-0.09) \text{ m}^2 \cdot \text{g}^{-1}$ at a wave length $\lambda_3 = 10.6 \text{ } \mu\text{m}$ were measured under field variable conditions [4-5]. The values of the camouflage abilities of the particle aerodispersions of aluminium and brass under similar conditions [7-8] were, in the case of ALBO aluminium $MS(\lambda_1) = 0.16 \text{ m}^2 \cdot \text{g}^{-1}$, $MS(\lambda_2) = 0.10 \text{ m}^2 \cdot \text{g}^{-1}$ and $MS(\lambda_3) = 0.07 \text{ m}^2 \cdot \text{g}^{-1}$, in the case of sliced brass $MS(\lambda_1) = 0.30 \text{ m}^2 \cdot \text{g}^{-1}$, $MS(\lambda_2) = 0.18 \text{ m}^2 \cdot \text{g}^{-1}$ and $MS(\lambda_3) = 0.09 \text{ m}^2 \cdot \text{g}^{-1}$. Such particle materials are suitable for military use.

The analysis of a simple model of the particle aerodispersion cloud for the interaction of millimetre waves and microwaves showed [9-10] that their use for attenuation of electromagnetic radiation of such kind is possible. It proved necessary from the respect of quantum mechanics that the dispersed particles of the aerodispersion system be either conductive or of such a structure that makes quantum transition among the states corresponding with the energies of the relevant photons of this radiation possible.

The protection in the infrared range is commonly secured by e.g. aerodispersions of a phosphorous character [11]. The multi-spectral protection in the infrared and microwave ranges within wave lengths (0.4-14) μm and (2-100) GHz can be secured by a combination of phosphorous smoke with another suitable agent with attenuating abilities against microwaves, which are some particle materials [12]. The latter may be the conductive particles of metal or carbon or metal-coated particles from glass or plastics; it is recommended that such agents constitute cc 10 % of the generated cloud volume. The aforementioned particles found their use in the application of an aerodispersion from a special thermo-mechanical generator [13], glass fibres in a combined grenade [14], dipoles like metallized cut particles of glass or another suitable dielectric material from a special container [15]. Thus, the particle aerodispersions appear effective in the microwave range of the spectrum. However, necessary theoretical and application data of such aerodispersions is missin. [16].

The proposed research in particle aerodispersions [17] and the study of their physical and chemical characteristics in the field of microwaves was not systematically conducted in our country. The conditions for the research of particle materials in the field of microwaves were created only recently. We were searching for suitable measuring procedures for such purposes as well as applicable equipment and we examined a suitable measuring method. It was detected during the introductory works that such measurement can be conducted under laboratory static conditions [19]. This paper contains the results of the research in the attenuating characteristics of the selected particle materials [18] in the field of frequency transmittance in a range (8.4-12.4) GHz, (1.0-18.0) GHz, respectively.

3. Experimental Part

3.1. The used agents

1. *ALBO 9 aluminium* (ALBO 90), bulk density $\rho = (0.16-0.17) \text{ g.cm}^{-3}$, manufacturer: ZVS Zeveta k.p. Bojkovice, Bojkovice 1993.
2. *3PIBright brass* (MS), manufacturer: Pramet, a.s., Potštejn 1998.
3. *Chezacarb B*, conductive black (CHZB B), former manufacturer: Chemopetrol Group a.s., Litvínov 1996, mean diameter of particles $d_{\text{mean}} = 3.9 \text{ }\mu\text{m}$, the largest diameter of particles $d_{\text{max}} = (46 - 58) \text{ }\mu\text{m}$, specific surface $S = 800 \text{ m}^2.\text{g}^{-1}$.
4. *Chezacarb EC*, conductive black (CHZB EC), former manufacturer: Chemopetrol Group a.s., Litvínov 1990, mean diameter of particles $d_{\text{mean}} = 3 \text{ }\mu\text{m}$.
5. *Crystalline graphite* (G), content 92/96, former manufacturer: Rudné doly n.p., Příbram, závod Netolice 1987.
6. *CR 2995 micro-ground natural graphite* (CR 2995), diameter $d_{90} = 8.0 \text{ }\mu\text{m}$, manufacturer: MAZIVA Týn, spol. s r.o., Týn nad Vltavou 2005.
7. *DONACARBO S244 carbon fibre, ground* (UV S244), diameter $d = 13 \text{ }\mu\text{m}$, length $l = 0.7 \text{ mm}$, bulk density $\rho = 190 \text{ kg.m}^{-3}$, manufacturer: Václav Zedník – MINKO, Kutná Hora 2005.
8. *DONACARBO S231 carbon fibre, ground* (UV S231), diameter $d = 13 \text{ }\mu\text{m}$, length $l = 3 \text{ mm}$, manufacturer: B.O.I.S.-Filtry, spol. s r.o., Brno. Brno 2003.
9. *DONACARBO S231 carbon fibre, ground* (UV S231Cu) with copper surface treatment, diameter $d = 13 \text{ }\mu\text{m}$, length $l = 3 \text{ mm}$, manufacturer: B.O.I.S.-Filtry, spol. s r.o., Brno. Brno 2003.
10. *DONACARBO S231 carbon fibre, ground* (UV S231Fe) with iron surface treatment, diameter $d = 13 \text{ }\mu\text{m}$, length $l = 3 \text{ mm}$, manufacturer: B.O.I.S.-Filtry, spol. s r.o., Brno. Brno 2003.
11. *FLOCK PA polyamide fibre* (PAD 2), length 2.0 mm, fineness 22 dtex, colour 2000 (claret), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.

12. *FLOCK PA polyamide fibre* (PAD 1), length 1.0 mm, fineness 6.7 dtex, colour 8713 (grey), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.
13. *FLOCK PA polyamide fibre* (PAD 0,75), length 0.75 mm, fineness 1.7 dtex, colour 8110 (red), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.
14. *FLOCK PA polyamide fibre* (PAD 0,5), length 0.5 mm, fineness 3.3 dtex, colour 8210 (blue), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.
15. *FLOCK VIS viscose fibre* (VIS 1), length 1 mm, fineness 5.6 dtex, colour 6601 (yellow), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.
16. *FLOCK VIS viscose fibre* (VIS 0.5), length 0.5 mm, fineness 3.3 dtex, colour 0225 (white), manufacturer: UNO JANEBA-FLOCK PRODUCTS, s.r.o., Zábřeh 2005.
17. *Fepren TP 303 iron oxide red* (Fe TP 303) (iron red), content of FeO min. 97.5 %, manufacturer: KOLTEX COLOR, s.r.o., Mnichovo Hradiště 2005.
18. *Filtren polyurethane foam with open pores (TM) 30*, boards with a thickness of 6 mm, manufacturer: EUROFOAM, s.r.o., Brno 2005.

3.2. Samples of mixed materials for measurement with a polyurethane carrier

1. Sample designation **2**: 80 % by weight of PAD 0.75 and 20 % by weight of CR 2995 graphite.
2. Sample designation **3**: 80 % by weight of PAD 2 and 20 % by weight of CR 2995 graphite.
3. Sample designation **4**: 80 % by weight of VIS 0.5 and 20 % by weight of CR 2995 graphite.
4. Sample designation **5**: 80 % by weight of VIS 1 and 20 % by weight of CR 2995 graphite.
5. Sample designation **6**: 20 % by weight of PAD 0.5, 20 % by weight of PAD 0.75, 20 % by weight of PAD 1, 20 % by weight of PAD 2 and 20 % by weight of CR 2995 graphite.
6. Sample designation **7**: 95 % by weight of PAD 1 and 5 % by weight of CR 2995 graphite.
7. Sample designation **8**: 90 % by weight of PAD 1 and 10 % by weight of CR 2995 graphite.
8. Sample designation **9**: 80 % by weight of PAD 1 and 20 % by weight of CR 2995 graphite.
9. Sample designation **10**: 70 % by weight of PAD 1 and 30 % by weight of CR 2995 graphite.
10. Sample designation **12**: 100 % by weight of UV S244 carbon fibre.

11. Sample designation **13**: 90 % by weight of PAD 1 and 10 % by weight of Fe TP 303.

3.3. Used instrumentation

1. *HP 8410B Microwave kit for frequency transmittance measurement*, range (8.4-12.4) GHz, VTÚO Brno, Brno 1999.
2. *VNA Anritsu 37369C Microwave kit*, VTÚO Brno, Brno 2005.
3. *Cell with a carton adjustable distance frame*, acrylic-glass faces 3.5 mm (170x220 mm).
4. *Cell with a fixed polyurethane-foam board*, measured thickness of the particle system 6 mm (280x280 mm), polyethylene-foil faces.

3.4. The test overview

The laboratory tests for the determination of the particle material transmittance comprised the research of the particle material preparation, the filling and preparation of the sample cell with the particle materials and the proper measurement with the evaluation. The following Table 1 lists the tests carried out to evaluate the attenuating characteristics. Table 2 contains a list of the tests of the second series measurement with the innovated laboratory equipment.

Table 1:

The list of the laboratory tests with the particle materials conducted to evaluate the attenuating characteristics from the first series of measurements in the cell with an adjustable frame

Test	Material	Layer thickness (mm)	Bulk density (kg.m ⁻³)	Note
16	UV S244	7.5	141	Compressed
17	UV S244	2.7	192	Hard to shake down
22	CHZB B	5.3	137	-
23	CHZB B	7.3	159	-
24	CHZB B	2.6	173	-

Table 2:

The list of the laboratory tests with the particle materials conducted to evaluate the attenuating characteristics from the second series of measurements on a polyurethane carrier

Test	Material	Ratio of components' content
2	PAD 0.75/CR2995	80/20
3	PAD 2/CR2995	80/20
4	VIS 0.5/CR2995	80/20
5	VIS 1/CR2995	80/20
6	PAD 0.5/PAD 0.75/ /PAD 1/PAD 2/CR2995	20/20/20/ /20/20
7	PAD 1/ CR2995	95/5
8	PAD 1/ CR2995	90/10
9	PAD 1/ CR2995	80/20
10	PAD 1/ CR2995	70/30
12	UV S244	100
13	PAD 1/ Fe TP 303	90/10

4. Results and Discussion

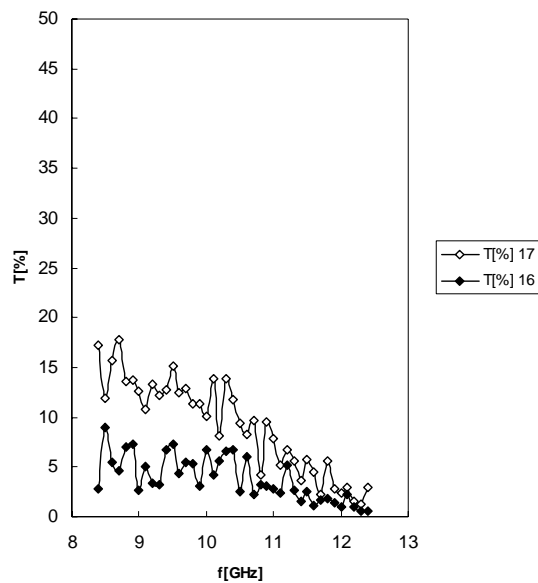
The measurement method of the microwave transmittance through the particle system under the laboratory conditions was devised and an applicable methodology utilising a microwave kit under development was gradually elaborated and tested in 2004 – 2005.

Transmittance was determined using particle materials in the sample cell, securing, with certain minor technological inaccuracies, a sound reproducibility of the measured values subject to the invariability of the prepared layers of the particle materials under the laboratory conditions.

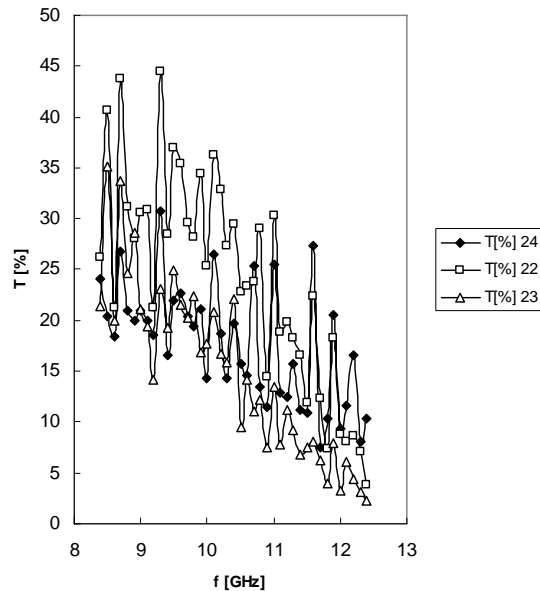
The suitable particle materials mentioned in Chapter 3.1 with the required characteristics were gradually secured by the researchers and co-operators [20].

4.1. The first Series of Measurements

The first series of the measurement of the frequency transmittance through the particle systems was conducted in the frequency range (8-12) GHz by means of a sample cell with a carton adjustable distance frame specifying the thickness of the layer of the poured-in and shaken-down particles. The fixed faces of the cells made from acrylic glass secured the reproduced thickness of the layer. The list of the selected tests with the materials is given in Table 1. The measurement results of the individual tests comprise dependences of the particles' frequency transmittance in Graphs 1 and 2.



Graph 1: The dependence of the frequency transmittance through the particle system of S 244 carbon fibres (17: 2.7 mm; 16: 7.5 mm)



Graph 2: The dependences of the frequency transmittance through Chezacarb B particle system (24: 2.6 mm; 22: 5.3 mm; 23: 7.3 mm)

From the graphs, we can conclude, the high attenuating abilities (low frequency transmittance) of carbon fibres (tests 16-17) and all carbon materials of Chezacarb type (tests 22-24) in the course of the whole frequency range.

The decrease of transmittance with the increasing frequency can be observed in the case of S 244 carbon fibre (with similar bulk densities of the samples in the sample cell). Thicker layers (curve 16) showed lower transmittance (higher attenuation) – as follows from Graph 1.

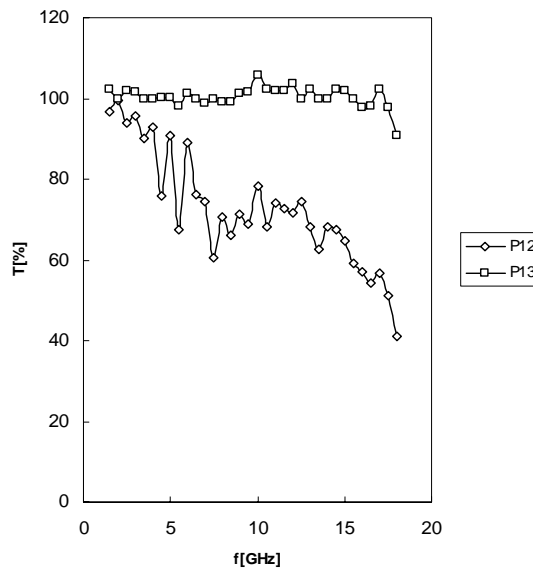
It was similar with Chezacarb B carbon conductive black which was measured with the samples of insignificantly different bulk densities in the sample cell. The thickness of the particle layers was changing from 2.6 mm to 7.3 mm. It is implied by the measured dependences of transmittance in Graph 2, featuring the decreasing frequency transmittance with the increasing thickness of the particles' layer.

It resulted from the frequency transmittance measurements in the first series that both S 244 carbon fibres and Chezacarb B conductive black effectively attenuated the microwave radiation of the aforementioned frequency range, and the decrease of transmittance with the increasing frequency was evident. Such findings of a distinct

attenuating ability of carbon particles were consistent with the sporadically available information [21].

4.2. The second Series of Measurements

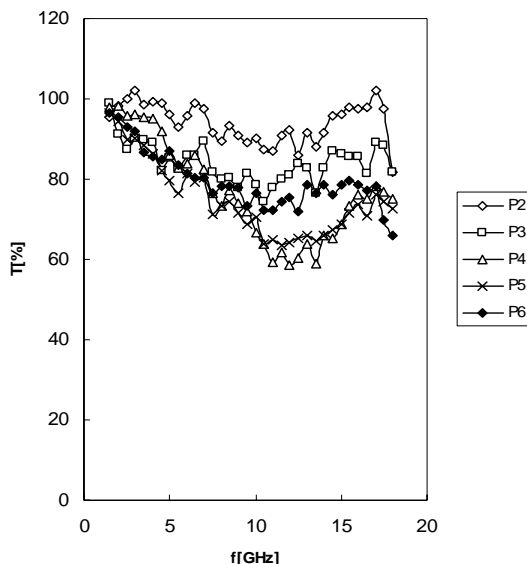
The second series of the frequency transmittance measurements of the particle systems in the frequency range $f = (2-18)$ GHz was conducted by means of a cell in which the particles were always dispersed in a solid board made of porous polyurethane foam with a constant thickness maintained in all the tests. Thus created particle system modelled a more realistic concentration of the particles distributed in the space. The use of the fibre materials consisted in their application as carriers of carbon graphite particles featuring the high attenuating abilities. Table 2 lists the selected tests with the particle materials.



Graph 3: The dependence of the frequency transmittance through the particle fibre system of DONACARBO S244 carbon fibre and PAD polyamide cut (P12: UV S244; P13: PAD 1/ Fe TP 303)

The solitary fibre cut of PAD polyamide fibre but also VIS viscose fibre did not attenuate the electromagnetic waves as compared to carbon fibre (DONACARBO S244) typical for their high attenuating properties (the lowest transmittances in the whole measured frequency range). It is documented by the dependences in Graph 3. It follows from the Graph that UV S244 carbon fibre (curve of test **13**) attenuated in

the whole frequency range $f = (2-18)$ GHz and the attenuation increased with the frequency.

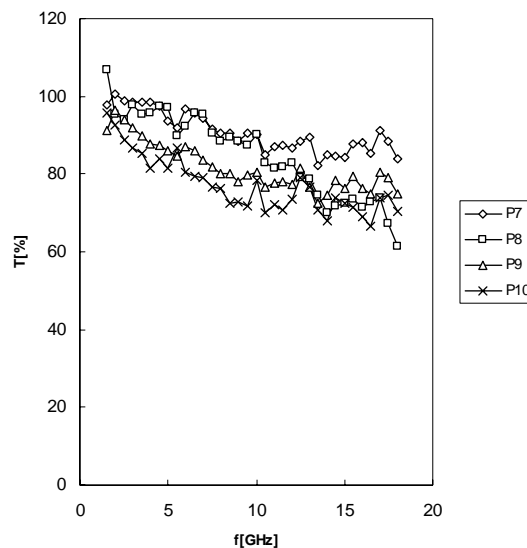


Graph 4: The dependence of the transmittance through the particle fibre systems of PAD polyamide cut and VIS viscose fibre with 20 % of CR 2995 graphite (P2: PAD 0.75/CR2995; P3: PAD 2/CR2995; P4: VIS 0.5/CR2995; P5: VIS 1/CR2995; P6: PAD 0.5/PAD 0.75/PAD 1/PAD 2/CR2995)

CR 2995 particle ground natural graphite was examined, on the one hand, with a carrier of FLOCK PA polyamide fibre and, on the other hand, with a carrier of FLOCK VIS viscose fibre. During these tests, different portion of graphite in the system of fibres was used up to the value of 30 % which seemed, from the respect of complete adhesion of particles on fibres, to be a limiting one, corresponding to the cell fully filled with graphite.

It follows from Graph 4 that the transmittance was decreasing with the increasing content of graphite particles during the whole course of the frequency range and the systems with FLOCK VIS viscose fibres were more effective than the systems with FLOCK PA polyamide fibres. The system with VIS 0.5/CR2995 viscose fibres with the length of fibres of 0.5 mm was the most effective from frequencies $f \approx 7$ GHz. The mixture of FLOCK PA polyamide fibres of all the used lengths with graphite attenuated most effectively in a range $f \approx (2-10)$ GHz.

As far as the influence of the proper graphite in the system of polyamide fibres is concerned – it is sufficiently conclusive from the measurement results of the laboratory-prepared mixtures of FLOCK PA polyamide fibre with CR 2995 graphite in which the graphite content was increased from a minimum of 5 % to a maximum of 30 % (tests **7** through **10**). The measurement of the frequency transmittance through such fibre systems with carbon graphite proved, as it follows from Graph 5, that the content of graphite is significant for the transmittance decrease with its content. The curve of the frequency transmittance dependence on the frequency reached the lowest values with the sample with the maximum content of CR 2995 graphite of 30 % (the curve of test **10**).



Graph 5: The dependence of the transmittance through the particle fibre systems of PAD polyamide cut with a content of CR 2995 graphite (P7: PAD 1/ CR2995 (5 %); P8: PAD 1/ CR2995 (10 %); P9: PAD 1/ CR2995 (20 %); P10: PAD 1/ CR2995 (30 %))

The conducted measurements of the frequency transmittance of the second series proved that CR 2995 ground natural graphite, like another kind of a carbon fibre material, is effective for attenuation of microwaves of the examined frequency range and the presence of the mixture of polyamide fibres or viscose cuts with various lengths contributes to the decreased transmittance.

It also followed from the measurements that the elaborated technology of the preparation of the particle systems for the transmittance determination in cells was

suitable for laboratory work and that its exceeding for other frequency ranges was desirable.

5. The Results

The following conclusions result from the work of the laboratory research related to the determination of the physical and chemical characteristics of the particle multi-spectral camouflage materials performed in the course of 2004 to 2005:

- a) UV S 244 carbon fibres, Chezacarb conductive black and CR 2995 ground natural graphite as the kinds of a carbon particle material were effective when used for the attenuation of microwaves of the examined frequency range $f \approx (8-12)$ GHz, $f \approx (2-18)$ GHz, respectively. The transmittance was significantly decreasing with the increasing thickness of the sample cell (i.e. with the increasing content of the particle materials in the measuring path) in the examined frequency ranges.
- b) The mixtures of FLOCK PA polyamide fibres or FLOCK VIS viscose fibres (cut) of all the used lengths beginning from 0.5 mm to 2 mm proved to be suitable carriers of CR 2995 carbon (ground natural graphite) for the attenuation of microwaves. In a range $f \approx (2-18)$ GHz, the frequency transmittance through the particle fibre systems reached the lowest values with the sample containing 30 % of CR 2995 graphite.
- c) The cells with transparent adjustable faces proved to be suitable for the laboratory measurement of the particles' attenuating characteristics for microwaves. The cell containing a fixed board made of Filtren (TM) 30 polyurethane foam with open pores made it possible to apply a mixed particle system of polyamide or viscose fibres with the ground natural graphite for the transmittance measurement under the laboratory conditions.

The measurement results indicated that the used particle materials attenuating microwaves of the examined frequency range with regard to the earlier measured attenuating abilities of IR range were multi-spectral effective. Therefore, they are promising for the use in the protection of military objects. The work has also showed that it was necessary to measure also other particle materials not only in the aforementioned frequency ranges but also in other ranges of interest.

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