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Peculiarities of the structure of copper- and nickel-fluoropolymer composites fabricated by explosive pressing

L.N. Ignatieva [a,*], G.A. Zverev [a], N.A. Adamenko [b], A.V. Kazurov [b], I.V. Sergeev [b], A.Yu. Ustinov [a], I.A. Tkachenko [a], V.M. Bouznik [c]

[a] Institute of Chemistry FEBRAS, 159, Prosp. 100-letya Vladivostoka, Vladivostok 690022, Russia
[b] Volgograd Sate Technical University, Volgograd, Russia
[c] FSUE All-Russian Scientific Research Institute of Aviation Materials, Moscow, Russia

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ABSTRACT

The present study demonstrates investigation two composites based on PTFE. The composites were obtained by explosive pressing of powder mixtures: 30%PTFE and 70%Cu and 30%PTFE and 70%Ni. The morphology, composition, molecular structure, thermal and magnetic properties of these materials were researched. Differences in the characteristics of composites depending on using a metal were detected.

1. Introduction

Polytetrafluoroethylene (PTFE) is one of the well-known basic fluoropolymers. The PTFE structural unit comprises a linear macromolecule—a polymer chain composed of monomer units –CF_2– [1,2]. High strength of the bond between fluorine and carbon atoms yields a unique combination of useful properties of this material that distinguishes it from other polymers [1]. Although PTFE and products based on it are extensively applied in different fields of industry, in household, and even in medicine, the requirements of advanced technologies stipulate for the necessity of improvement of the materials functioning parameters, which is implemented through modification of available materials or fabrication of novel ones. Modified forms of the material having some promising properties were fabricated using different methods of PTFE treatment. For instance, the thermal gas-dynamic treatment was used to obtain ultradispersed PTFE (UPTFE–FORUM™) [1,3]; the PTFE laser ablation yielded a fiber-porous material “Griftex” [4]; whereas the PTFE radiation treatment at a temperature above that of the crystalline phase melting increased its wear resistance by four orders of magnitude and its radiation stability by two orders of magnitude [5].

One of the promising methods of polymer modification is the explosion treatment (explosive pressing, EP) [6]. Application of explosives in materials treatment enables one to create shock waves in a solid body, which propagate at high velocity from the loading surface to the solid depth. Explosive detonation can provide pressures from dozens of MPa to a few hundreds of GPa and a broad range of temperatures from dozens to a thousand of centigrades in the material to be treated. The latter affects not only the material density, but also its other characteristics, which provides the emergence of new properties not inherent to any individual component [7]. In [8,9], this method was applied to PTFE and UPTFE–FORUM™ materials. The studies demonstrated that, aside from changes in a number of characteristics of these materials during treatment, metal atoms had been found in the surface layer of polymer samples. The latter fact was explained by penetration of metal into polymer in the process of explosion as a result of a partial interaction of polymer with the steel ampoule containing the sample. The possibility of fabrication of powder mixtures of composite metal–polymer materials (for instance, PTFE + metal) using the explosive pressing was shown in a series of works performed at the Volgograd State Technical University [10,7,11–15]. The present work was devoted to studying of the composites 30%PTFE + 70%Cu and 30%PTFE + 70%Ni. The main attention was paid to revealing of the composite morphology, molecular structure, phase composition, and thermal properties.

2. Results and discussion

2.1. Sample 30%PTFE + 70%Cu

2.1.1. Morphology

In the course of the SEM study of the morphology and element composition of the sample 30%PTFE + 70%Cu, two types of areas marked as 1 and 2 in Fig. 1 were revealed. The data of the

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[*] Corresponding author. Tel.: +7 4232 311889; fax: +7 4232 311889.
E-mail address: ignatieva@ich.dvo.ru (L.N. Ignatieva).

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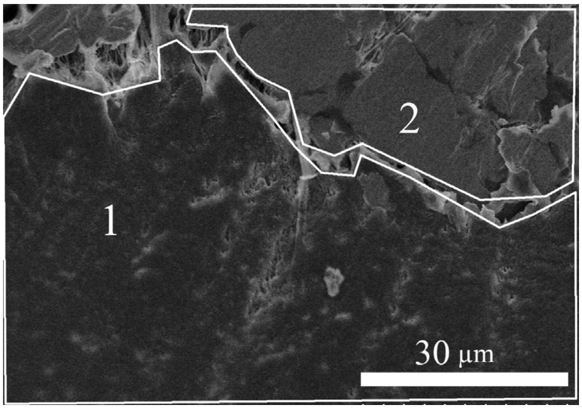

Fig. 1. SEM images of the sample 30%PTFE +70%Cu.

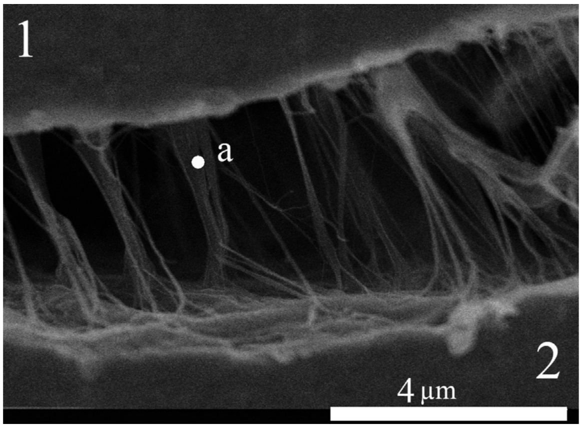

Fig. 2. SEM image of the sample 30%PTFE +70%Cu.

performed element analysis of these areas, as compared to the initial PTFE, are shown in Table 1. According to the obtained data, the area 1 comprises the metal part containing carbon, whereas the area 2 consists of fluoropolymer formations.

Since PTFE was the initial fluorocarbon material, it was expected that the area 2 would consist of PTFE particles. In addition, as was found in [8], the explosion treatment of PTFE did not significantly change the material composition. As was already mentioned, a linear polymer chain $[C_2F_4]_n$ was the PTFE structural unit, so that the carbon/fluorine ratio was 1/2. However, in the area 2 the C/F ratio is almost 1/3. Such an increase of the number of fluorine atoms could occur at the expense of destruction (at least, partial) of PTFE under effect of explosion treatment. A part of the released carbon remains in the form of carbon black, thus transferring into the area 1. The released fluorine forms CF_3 groups (end or side ones). The above features are characteristic for PTFE destruction [16]. In the area of transition of these monolith areas (1&2), one observes from the SEM data the area composed of fibril structures (length 1–5 μm, thickness 40–150 nm).

Table 1
Element analysis of the sample 30%PTFE + 70%Cu and PTFE (F4) performed using the SEM method.

Sample	C at.%	F at.%	O at.%	Cu at.%	F/C
PTFE initial	33.2	66.8			2
PTFE + Cu (1)	24.78			75.22	
PTFE + Cu (2)	25.57	74.43			3
Fibril in the point (a) in Fig. 2	27.31	43.53	8.25	20.91	1.6

Fibril structures were also observed in the initial PTFE, but they were scattered over the whole volume [17]. Accumulations of nanofibrils of diameters of 50–200 nm and of lengths of 5–10 μm were observed in the UPTFE surface layer upon explosion treatment even at small magnifications [9]. Loose fibril structures of a size of about 1 μm were observed in the EP-treated PTFE [8], in which case the surface layer fibrils were of a larger length of 10–20 μm. One should mention that the surface layer contained metal particles upon EP treatment in both cases (PTFE and UPTFE). The energy-dispersive analysis of the sample 30%PTFE + 70%Cu demonstrated that the transition area contained copper, carbon, oxygen, and fluorine (Table 1). One can assume that in all three cases (PTFE, UPTFE, Cu + PTFE), under effect of pressure and interaction with metal particles, fibril structures contained in the initial PTFE were separated from each other and removed from PTFE. One should also mention that in all cases the latter comprises the carbon-enriched material.

As was found at studying the sample 30%PTFE + 70%Cu using a Raman microscope, it had a heterogeneous structure. As seen from Fig. 3, it is composed of a monolith mass with embedded particles of sizes from 50 up to 200 nm. The Raman spectra measured in the monolith mass center and in embedded particles are different from each other (Fig. 4). The spectrum of the analyzed particle substance is virtually identical to that of the initial PTFE.

2.1.2. Molecular structures of particles

The above indicates to the fact that, first, these particles are composed of PTFE and, second, the PTFE molecular structure, in general, does not change in spite of the treatment. The spectrum

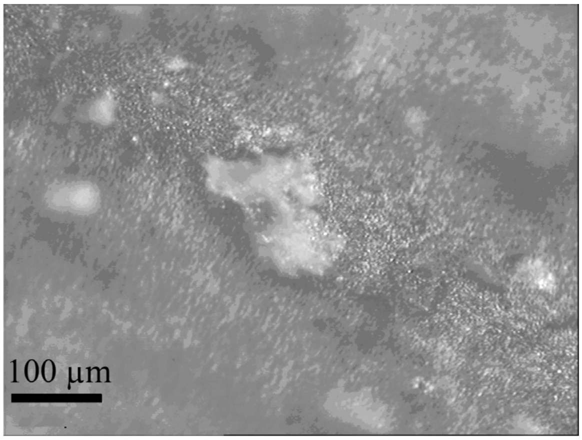

Fig. 3. Microphotograph of the sample 30%PTFE + 70%Cu obtained using a WiTec alpha500 confocal Raman microscope.

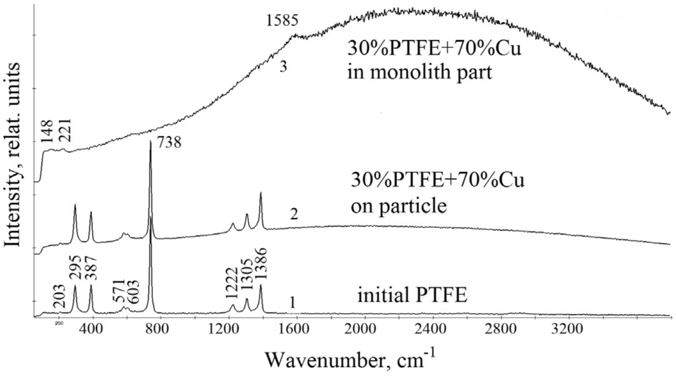

Fig. 4. Raman spectra of the sample 30%PTFE + 70%Cu and the initial PTFE.