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The influence of the fibre nature on the physical and mechanical properties of composites based on polytrifluorchloroethylene

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The article examines the effect of discrete carbon fibre (Toray T700SC brand) and organic fibre (Tanlon T700 brand) on the physical and mechanical properties of polytrifluorochloroethylene. It was established that the introduction of fibres leads to an increase in the modulus of elasticity by 2 times for carbon fibre and 1.7 times for organic fibre. It should be noted that the nature of the loading curves of plastics reinforced with carbon fibre and organic fibre is different. Carbon plastics are characterized by elastically homogeneous-plastic behaviour, which leads to irreversible changes in the shape of the samples. While for organoplastics, heterogeneous plastic behavior is observed. This difference in the nature of the curves is associated with the high stiffness of the carbon fibres. At the same time, the organic fibres have a flexible structure due to amorphousness and a lower degree of crystal orientation, as evidenced by the X-ray patterns of the fibres. The developed fibrous polymer composite materials can be recommended for the manufacture of tribotechnical products used in various areas of modern industry.
Keywords: polytrifluorochlorethylene, carbon, organic, fibre, modulus of elasticity, yield strength, strength limits

Вплив природи волокна на фізико-механічні властивості композитів на основі політрифторхлоретилену. *А.-М.В.Томіна, К.А.Єрьоміна, С.В.Калініченко, Т.В.Калініна*
У статті розглянуто вплив дискретного вуглецевого (марки Toray T700SC) та органічного волокна (марки Tanlon T700) на фізико-механічні властивості політрифторхлоретилену. Встановлено, що введення волокон призводить до зростання модуля пружності в 2 рази для вуглецевого та в 1,7 разів для органічного. Слід відмітити, характер кривих навантаження вугле- та органопластиків різний. Вуглепластикам характерна пружно гомогенно-пластична поведінка, яка призводить до незворотних змін форми зразків. У той же час для органопластиків спостерігається гетерогенна-пластична поведінка. Дана відмінність в характері кривих пов'язана з високою жорсткістю вуглецевого волокна, в той час як органічні мають гнучку структуру через аморфність і меншу ступінь кристалічної орієнтації, про що свідчать рентгенограми волокон. Розроблені волокнисті полімерні композиційні матеріали можна рекомендувати для виготовлення виробів триботехнічного призначення, що використовуються у різних сферах сучасної промисловості.

1. Introduction

Nowadays, some of the most common polymer materials in various branches of modern technology are fluoropolymers: polytetrafluoroethylene (PTFE, F4 fluoroplastic), polytrifluorochlorethylene (PTFCE, F3 fluoroplastic), and ethylene-tetrafluoroethylene copolymer (F40 fluoroplastic) [1]. However, their use in pure form is limited by low strength, insufficient wear resistance, and a high coefficient of thermal linear expansion. For this reason,

Table 1 - Technical characteristics of fibres

Indicator	Fibre	
	Toray 700SC	Tanlon T700
Density, ρ, g/cm^3	1.70–1.80	1.42
Tensile modulus, E, GPa	230	7.45
Tensile strength, σ, MPa	4900	650

various powder fillers (FLs) are introduced into fluoropolymers to improve their tribological properties. In particular, these are graphite [2], silica gel [3], and molybdenum disulphide [4]. However, such FLs can worsen the physical and mechanical properties of fluoropolymers.

In recent years, fibrous polymer composite materials (FPCMs) have become a priority choice in the manufacture of tribotechnical and structural parts, successfully replacing such traditional materials as ceramics, aluminium, steel, and titanium. The use of organic (OF) and carbon (CF) fibres makes it possible to obtain materials with high strength, wear resistance, and stiffness. This is due to the fact that during the operation of products made from FPCMs, fibres are the main element that ensures the transmission and uniform distribution of mechanical loads [5]. This, in turn, leads to an increase in the reliability and durability of such materials. The advantages of FPCM products include a fast manufacturing cycle (even of a complex shape) [6], a low coefficient of thermal linear expansion [7], high resistance to mechanical and fatigue failure, corrosion, and exposure to low and high temperatures [8].

Taking into account the above, the aim of the work is to study the effect of carbon and organic fibres on the physical and mechanical properties of polytrifluorochloroethylene.

2. Experimental

The first commercial polymer - PTFCE - was chosen as a polymer matrix for the creation of FPCMs. This polymer material is characterized by high-impact toughness (with a low degree of crystallinity). PTFCE maintains stable physical and mechanical properties when exposed to cryogenic (78 K) and high (523 K) temperatures, corrosion, liquefied natural gas, and liquid oxygen [9].

For the current study, two types of fibres were selected as FLs:

- High-modulus carbon fibre Toray T700SC (manufactured by “Toray Group”, Japan) [10], which, due to its inorganic nature and crystalline structure, exhibits exceptional physical and mechanical properties (see Table 1). This inorganic filler is widely employed in industries such as aviation, automotive, and agriculture, where material reliability under high loads and extreme conditions is crucial.

- Tanlon T700 organic polysulfonamide fibre (manufactured by “Shanghai Tanlon Fiber Co., Ltd”, China) [11] belongs to the group of organic materials. Its organic nature provides a special set of properties that complement those of inorganic fillers.

To summarize, inorganic carbon fibre and organic polysulfonamide fibre offer complementary advantages, making their combined use in composites particularly effective.

Tanlon T700 OF is characterized by high strength (Table 1), resistance to wear, tear and exposure to many aggressive environments, stable operation over a wide temperature range. Therefore, Tanlon T700 is used in the textile and automotive industries.

Carbon fiber reinforced plastics and organoplastics (CP and OP) based on PTFCE, containing 5-20 wt.% of discrete (2-4 mm) CF or OF, were prepared by compression pressing according to the regime given in the paper [9]. Physico-mechanical properties of PTFCE, CP, and OP were examined on the FP-100 machine. Diffraction patterns of carbon and organic fibres were recorded using the DRON-2.0 diffractometer in monochromatic CuKα radiation (λ=0.15420 nm) in the range of 2θ angles from 10° to 45° [11].

3. Results and discussion

In the course of research, curves of the dependence of compressive stress (σ, MPa) on strain (ε, %) were obtained. Note that the nature of the CP and OP curves is different (Fig. 1).

Carbon plastics are characterized by an elastically homogeneous-plastic behavior, which leads to irreversible changes in the shape of the samples (as evidenced by the absence of yield strength under compression (see Table 2)). The introduction of CFs reduces the ability for plastic deformation of FPCMs. As a result, brittle destruction of the samples occurs.

Table 2 – Physical and mechanical properties of polytrifluorochlorethylene and composites based on it

Indicator	Content of CF/OF wt.%				
	0	5	10	15	20
Compressive proportionality limit (σ_{pr}), MPa	27	28/30.5	33/30.8	35/32	56/31.1
Compressive yield strength (σ_y), MPa	44	-/49.4	-/50	-/52.6	-/53.6
Compressive tensile strength (σ_t), MPa	-	131/119.5	162/121.5	168/126	204/152
Compressive modulus of elasticity (E), MPa	455	670/655	812/695	875/755	900/760

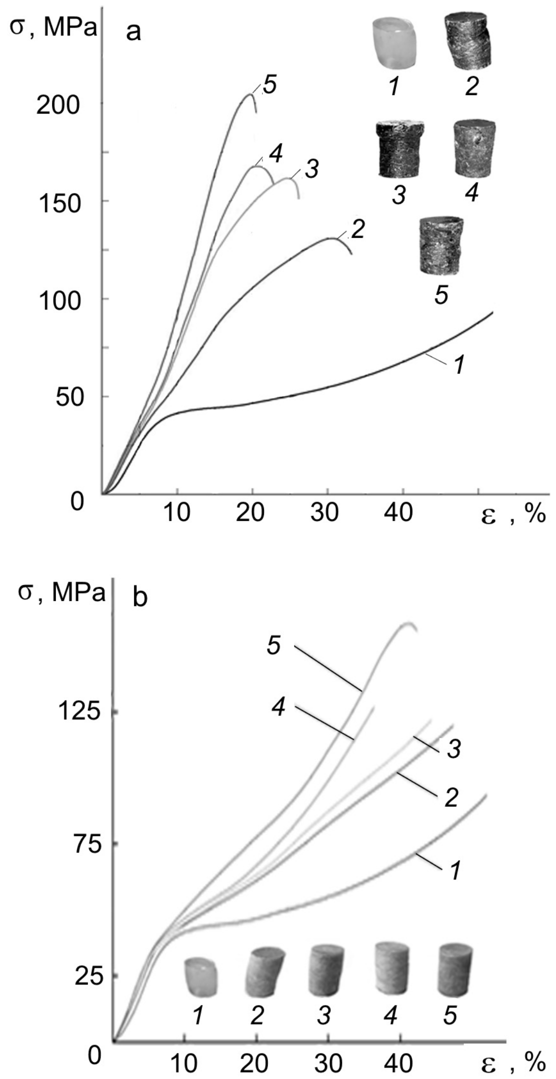

Fig. 1 – Dependence of compressive stress (σ, MPa) on strain (ε, %) of polytrifluorochloroethylene (1), carbon plastics (a), and organoplastics (b) based on it, reinforced with 5 (2); 10 (3); 15 (4); 20 (5) wt. % fibre

At the same time, elastic-heterogeneous-plastic behaviour is observed for OP: on the compression "stress-strain" curve, completely elastic behavior is observed up to a load of 30 MPa. Then, structural destruction begins. During this, the stresses accumulated as a result of the increase in load contribute to the re-

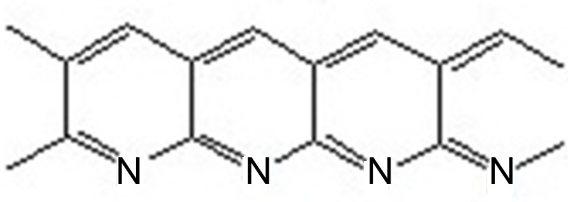

Fig. 2 – Diagram of the carbon fibre structure

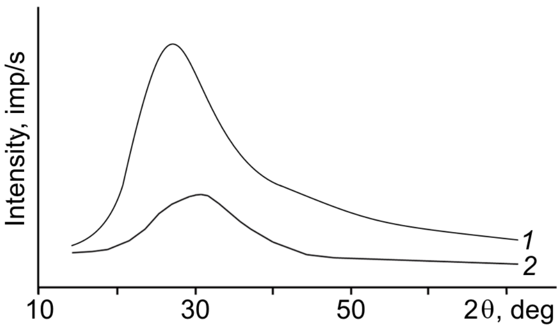

Fig. 3 – X-ray diffraction patterns of carbon (1) and organic (2) fibre

construction of the destroyed structure into a new one. This structure is characterized by a high degree of orientation and strength, which significantly increases the resistance of the OP to further growth of the load [3].

1Note that the modulus of elasticity under compression of CP is higher than that of OP. This is explained by the fact that CF is more rigid, and its modulus of elasticity under compression significantly exceeds the indicators of many other materials, including OFs (see Table 1).

In addition, CFs consist of strongly oriented graphite-like layers of carbon (see Fig. 2), which gives them high rigidity, while OFs have a flexible structure due to their amorphousness and a lower degree of crystal orientation, as evidenced by the X-ray diffraction patterns of CFs and OFs (Fig. 3). It limits their ability to elastic resistance.

As can be seen from Fig. 3, the diffraction pattern of CF contains an intense peak at 25.75°, which indicates its ordered structure. While the broad halo observed for OF indicates its amorphous structure.

In general, it should be noted that the introduction of organic or carbon fibre to PTFCE leads to an increase in the physical and mechanical properties of the latter: an increase in the modulus of elasticity by 2 and 1.7 times, respectively.

4. Conclusion

The analysis of the physical and mechanical characteristics of the developed FPCMs shows that the use of Toray T700SC carbon fibre as the FL for PTFCE is a promising way to increase the modulus of elasticity and the limit of proportionality by about 2 times. When Tanlon T700 OF is introduced, the modulus of elasticity and the yield strength of PTFCE increase by 1.7 and 1.2 times, respectively. The high strength and elasticity of the developed FPCMs allow us to recommend them for the manufacture of parts of moving joints of machines and mechanisms used in various spheres of modern industry, such as textile, metallurgical, agricultural, etc.

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