Polymer blends based on regenerated thermoplastics with low flammability

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Abstract: *Composite materials based on regenerated thermoplastics of the polyolefin class with high parameters of stress-strain characteristics, which are highly resistant to open flame and combustion, have been developed. A synergistic effect was achieved by introducing a complex of modifiers into the matrix polymer, including regenerated particles of polytetrafluoroethylene, positioned as ultrafine particles (UPTFE), and residual products of the production of phosphate fertilizers – phosphogypsum (PG). The developed composite materials, processed by injection molding, make it possible to manufacture elements of metal-polymer rollers of belt conveyors used in the mining industry.*
KEYWORDS: COMPOSITE MATERIAL, ENVIRONMENTAL IMPERATIVE, CONVEYOR BELTS, REGENERATED THERMOPLASTICS, SYNERGISTIC EFFECT

1. Introduction

The current trend of the mechanical engineering and other industries development is focused on achieving optimal parameters for the operational characteristics of functional products while ensuring increased safety requirements in combination with the implementation of the concept of the environmental imperative [1, 2].

In the nomenclature of composite materials used for the manufacture of functional elements of machines, mechanisms, technological equipment, a special position is occupied by composites with pronounced parameters of resistance to high temperatures and flames. This is due to the increasing consumption of such materials in mechanisms operated under specific conditions, when a violation of the regime can lead to consequences that are difficult to eliminate. These mechanisms include belt conveyors used in the mining industry to transport functional components of various composition, structure and technology for their subsequent processing [3].

The purpose of this work was to study the structural features and fire-retardant characteristics of polymer blends based on regenerated thermoplastics for their use in the manufacture of elements of belt conveyors used in the extraction of mineral components.

2. Materials and research methods

For the development of functional materials used in the construction of belt conveyors, thermoplastic polymers of the polyolefin class were used – original polypropylene (PP), regenerated production of Polish companies (PP(P)), regenerated production of JSC "Belvtorpolimer" (PP(B)), regenerated production of JSC “Soligorsk Institute of Resources Saving Problems with Pilot Production” (SIRSPwithPP) (PP(S)) and a composite material based on polypropylene with low flammability PP(LF).

As modifiers of polymer matrices, waste products from the production of phosphate fertilizers were used – phosphogypsum (PG), ultrafine polytetrafluoroethylene (UPTFE), obtained by thermogasdynamic synthesis, produced under the trademark "Forum", regenerated elastomer (TPE) (Poland).

Mixed composites were obtained on an injection molding machine with a screw plasticizer under technological conditions characteristic of the processing of the base polymer.

The dispersed product Arguflame fr 30pp, which is part of the regenerated granulate based on polypropylene, was used as a flame retardant.

To assess the structural, deformation-strength and rheological characteristics of composites, the parameters of melt flow index (MFI), tensile strength parameters, fire and explosion hazard parameters and resistance to combustion, determined by standard methods, were used.

The evaluation of the effectiveness of the developed composite materials was carried out in the metal-polymer rollers used in the belt conveyors of SIRSPwithPP in the extraction and transportation of sylvinite ores.

3. Results and discussion

Analysis of literature sources indicates a high efficiency of the use of polymer blends with low flammability modified with target components [4–6]. At the same time, the effectiveness of the modifier on the parameters of the composite structure and the characteristics of the stress-strain and thermophysical properties are largely determined by their dispersion. With a certain dimensional dispersed particles can exhibit the effect of the nanostate, which consists in the formation of adsorption bonds of the physical type, which lead to a qualitative change in the structure and parameters of the characteristics of the composite [4].

To modify polymer blends, we selected products of physicochemical synthesis for the production of phosphate fertilizers – phosphogypsum (PhG), which are technological waste products. These products with a particle dispersion of 1–50 μm, which are phosphorus-containing compounds, can have an effect similar to classical flame retardants [4, 5].

Another modifier was the products of thermogasdynamic synthesis of polytetrafluoroethylene, which are its highly dispersed particles, UPTFE. Our studies have shown that these products are not the result of synthesis, but are particles consisting of a polymer core surrounded by oligomeric compounds formed during thermal action on matrix particles of PTFE in an oxidation-free environment, due to the processes of degradation of the matrix with the formation of various oligomeric fractions, since the directed synthesis of PTFE macromolecules is not possible in the absence of a catalyst for the polymerization of low molecular weight fractions (monomeric).Therefore, the polymer-oligomeric structure of single particles of UPTFE is due to the processes of thermal degradation of matrix particles and is not associated with thermogasdynamic synthesis, which is possible only if the conditions of pressure and catalyst are met [6].

Studies of single particles of UPTFE have shown [5] that their central part has a size range corresponding to the nanostate, which significantly changes their activity in the processes of interaction with the polymer components of the composite material. At the same time, the presence of an oligomeric component in such particles significantly changes their structuring effect on the matrix. In addition, it is known that fluorine-containing compounds (polymer and oligomeric) are resistant to elevated temperatures and can act as flame retardants of composite materials based on thermoplastics [6].

As a polymer matrix in the development of composite materials with high resistance to temperature and low flammability, polypropylene and elastomer blends were used, obtained by thermomechanical combination of melts in the material volume of an injection molding machine with a screw plasticizer, which provides a sufficiently high homogeneity of the resulting product, which is necessary for its use as a composite material for the manufacture of structural elements of metal-polymer rollers of belt conveyors. The presence of modifier particles (UPTFE, PhG) in the polymer blends does not significantly affect the parameters of their rheological characteristics, allowing processing by injection molding (Table 1). At the same time, the studied composites have sufficiently high stress-strain characteristics (parameter of yield strength (σ_y) is in the range of values of 17–30 MPa for composites based on regenerated polypropylene from various manufacturers PP(P), PP(B), PP(S) (Table 2).

The developed composite materials were evaluated in terms of resistance to high temperatures and flammability (Table 3) according to GOST 28157-2018 Plastics. Burning Resistance Methods, which is identical to ASTM D 3801 Standard Test Method for Measuring the Comparative Burning Characteristics of Solid Plastics in a Vertical Position. The essence of this method is to determine the burning and smoldering time of a vertically fixed sample.

Table 1. *Rheological parameters of composite materials*

No.	Sample composition	MFI parameter at temperature: MFI, g/10 min	T, K
1	PP(P)+0.5wt.% UPTFE	2.88	473
2	PP(P)+1.0wt.% UPTFE	2.80	473
3	PP(B)+0.5wt.% UPTFE	3.58	473
4	PP(B)+5.0wt.% UPTFE	3.80	473
5	PP(S)+0.5wt.% UPTFE	7.55	523
6	PP(S)+1.0wt.% UPTFE	17.10	523
7	PP(S)+5.0wt.% UPTFE	16.85	523
8	PP(LF)+0.5wt.% UPTFE	4.85	473
9	PP(LF)+1.0wt.% UPTFE	5.53	473
10	PP(LF)+5.0wt.% UPTFE	5.00	473
11	PP(B)+1.0wt.% PhG	4.80	483
12	PP(B)+5.0wt.% PhG	4.52	483
13	PP(B)+10.0wt.% PhG	5.15	483
14	PP(S)+1.0wt.% PhG	5.35	483
15	PP(S)+5.0wt.% PhG	2.20	483
16	PP(S)+10.0wt.% PhG	2.00	483
17	PP(P)+1.0wt.% PhG	3.95	483
18	PP(P)+5.0wt.% PhG	3.70	483
19	PP(P)+10.0wt.% PhG	4.33	483
20	PP(LF)+1.0wt.% PhG	6.70	483
21	PP(LF)+5.0wt. % PhG	7.25	483
22	PP(LF)+10.0wt.% PhG	6.00	483
23	PP(P)+10.0wt.% TPE + 5.0wt.% PhG	3.30	473
24	PP(P)+10.0wt.% TPE + 10.0wt.% PhG	2.78	473
25	PP(P)+20.0wt.% TPE + 5.0wt.% PhG	3.65	483
26	PP(P)+20.0wt. % TPE + 10.0wt.% PhG	3.62	483
27	PP(B)+10.0wt.% TPE + 5.0wt.% PhG	5.13	483
28	PP(B)+10.0wt.% TPE + 10.0wt.% PhG	5.15	483
29	PP(B)+20.0wt.% TPE + 5.0wt.% PhG	3.48	473
30	PP(B)+20.0wt.% TPE + 10.0wt.% PhG	4.53	473
31	PP(LF)+10.0wt.% TPE + 5.0wt.% PhG	6.15	483
32	PP(LF)+10.0wt.% TPE + 10.0wt.% PhG	2.95	483
33	PP(LF)+20.0wt.% TPE + 5.0wt.% PhG	5.08	483
34	PP(LF)+20.0wt.% TPE + 10.0wt.% PhG	7.20	523
35	PP(S)+10.0wt. % TPE + 5.0wt.% PhG	2.50	483
36	PP(S)+10.0wt.% TPE + 10.0wt.% PhG	2.33	483
37	PP(S)+20.0wt.% TPE + 5.0wt.% PhG	2.33	483
38	PP(S)+20.0wt.% TPE + 10.0wt.% PhG	1.40	483
39	PP(P)+10.0wt.% TPE	2.70	473
40	PP(P)+20.0wt.% TPE	2.03	473
41	PP(P)+30.0wt.% TPE	2.30	473
42	PP(B)+10.0wt.% TPE	3.25	473
43	PP(B)+20.0wt.% TPE	3.00	473
44	PP(B)+30.0wt.% TPE	2.95	473
45	PP (S) + 5.0wt.% TPE	14.95	523
46	PP (S) + 10.0wt.% TPE	15.65	523
47	PP (S) + 20.0wt.% TPE	2.98	523
48	PP (S) + 30.0wt.% TPE	9.75	523
49	PP(LF)+10.0wt.% TPE	4.43	473
50	PP(LF)+20.0wt.% TPE	4.15	473
51	PP(LF)+30.0wt.% TPE	4.05	473
52	PP(LF)+10.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	3.78	483
53	PP(LF)+20.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	5.90	483

Table 2. *Stress-strain characteristics of composites*

No.	Sample composition	Characteristic parameter for the sample: Physical yield strength. MPa	Deformation at physical yield strength. %	Strength at maximum force. MPa	Deformation at maximum force. %	Fracture strength. MPa	Deformation at fracture. %
1	PP(P)+0.5wt.% UPTFE	25.70	14.82	25.70	14.82	18.65	100.94
2	PP(P)+1.0wt.% UPTFE	23.45	11.45	23.45	11.45	14.53	100.41
3	PP(B)+0.5wt.% UPTFE	31.03	13.61	31.03	13.61	18.13	52.21
4	PP(B)+5.0wt.% UPTFE	27.88	7.21	30.25	13.60	30.25	13.60
5	PP(S)+0.5wt.% UPTFE	26.83	3.73	26.83	3.73	25.05	7.98
6	PP(S)+1.0wt.% UPTFE	25.40	3.64	25.40	3.64	23.38	9.56
7	PP(S)+5.0wt.% UPTFE	25.53	3.98	25.53	3.98	23.43	7.89
8	PP(LF)+0.5wt.% UPTFE	27.78	12.96	27.78	12.96	17.70	96.59
9	PP(LF)+1.0wt.% UPTFE	24.98	13.28	24.98	13.28	14.40	71.31
10	PP(LF)+5.0wt.% UPTFE	27.88	13.11	27.88	13.11	23.58	31.79
11	PP(B)+1.0wt.% PhG	30.20	9.07	31.98	14.61	31.98	14.61
12	PP(B)+5.0wt.% PhG	17.18	2.03	29.25	13.43	29.25	13.43
13	PP(B)+10.0wt.% PhG	27.30	10.11	27.63	13.63	27.63	13.63
14	PP(S)+1.0wt.% PhG	16.00	1.19	22.90	2.99	22.90	2.99
15	PP(S)+5.0wt.% PhG	18.08	1.53	21.65	2.67	21.65	2.67
16	PP(S)+10.0wt.% PhG	18.43	1.52	24.45	3.16	24.45	3.16
17	PP(P)+1.0wt.% PhG	23.33	21.90	23.33	21.90	17.30	104.04
18	PP(P)+5.0wt.% PhG	24.68	14.81	24.68	14.81	17.88	103.70
19	PP(P)+10.0wt.% PhG	18.78	16.00	18.78	16.00	13.20	58.21

20	PP(LF)+1.0wt.% PhG	21.24	12.53	21.24	12.53	19.56	23.80
21	PP(LF)+5.0wt. % PhG	22.68	14.11	22.68	14.11	20.55	25.02
22	PP(LF)+10.0wt.% PhG	23.38	10.94	23.38	10.94	21.73	22.58
23	PP(P)+10.0wt.% TPE + 5.0wt.% PhG	23.03	15.92	23.03	15.92	14.03	190.36
24	PP(P)+10.0wt.% TPE + 10.0wt.% PhG	19.23	17.26	19.23	17.26	16.30	226.55
25	PP(P)+20.0wt.% TPE + 5.0wt.% PhG	17.05	21.45	17.05	21.45	15.53	201.43
26	PP(P)+20.0wt. % TPE + 10.0wt.% PhG	16.83	21.30	16.83	21.30	14.50	160.49
27	PP(B)+10.0wt.% TPE + 5.0wt.% PhG	23.58	15.41	23.58	15.41	21.68	23.14
28	PP(B)+10.0wt.% TPE + 10.0wt.% PhG	25.10	14.75	25.10	14.75	23.08	24.34
29	PP(B)+20.0wt.% TPE + 5.0wt.% PhG	21.60	13.81	21.60	13.81	15.40	167.37
30	PP(B)+20.0wt.% TPE + 10.0wt.% PhG	10.20	2.70	14.50	11.23	14.50	11.23
31	PP(LF)+10.0wt.% TPE + 5.0wt.% PhG	25.03	16.92	25.03	16.92	21.80	36.00
32	PP(LF)+10.0wt.% TPE + 10.0wt.% PhG	17.10	1.87	25.85	9.95	25.85	9.95
33	PP(LF)+20.0wt.% TPE + 5.0wt.% PhG	20.95	15.93	20.95	15.93	17.10	203.09
34	PP(LF)+20.0wt.% TPE + 10.0wt.% PhG	19.43	18.56	19.43	18.56	15.63	64.81
35	PP(S)+10.0wt. % TPE + 5.0wt.% PhG	17.13	1.69	18.22	2.82	18.22	2.82
36	PP(S)+10.0wt.% TPE + 10.0wt.% PhG	20.20	2.21	20.20	2.21	17.13	7.90
37	PP(S)+20.0wt.% TPE + 5.0wt.% PhG	15.35	1.02	19.85	2.32	19.85	2.32
38	PP(S)+20.0wt.% TPE + 10.0wt.% PhG	15.33	1.02	19.85	2.32	19.85	2.32
39	PP(P)+10.0wt.% TPE	21.13	20.23	21.13	20.23	16.83	101.50
40	PP(P)+20.0wt.% TPE	16.48	22.92	16.48	22.92	13.93	103.96
41	PP(P)+30.0wt.% TPE	21.20	25.96	21.20	25.96	17.10	112.55
42	PP(B)+10.0wt.% TPE	29.23	13.96	29.23	13.96	18.13	62.28
43	PP(B)+20.0wt.% TPE	22.15	15.76	22.15	15.76	17.35	201.39
44	PP(B)+30.0wt.% TPE	22.20	21.30	22.20	21.30	16.75	201.51
45	PP (S) + 5.0wt.% TPE	15.70	1.18	22.68	2.99	22.68	2.99
46	PP (S) + 10.0wt.% TPE	17.33	1.60	22.63	3.81	22.63	3.81
47	PP (S) + 20.0wt.% TPE	18.23	1.68	22.98	3.31	22.98	3.31
48	PP (S) + 30.0wt.% TPE	18.35	14.16	18.35	14.16	14.40	287.33
49	PP(LF)+10.0wt.% TPE	23.75	12.88	23.75	12.88	11.30	124.04
50	PP(LF)+20.0wt.% TPE	26.23	15.57	26.23	15.57	10.00	67.83
51	PP(LF)+30.0wt.% TPE	28.43	15.25	30.33	18.45	14.32	121.45
52	PP(LF)+10.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	23.20	12.66	23.20	12.66	19.70	36.32
53	PP(LF)+20.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	19.78	15.09	19.78	15.09	15.88	118.66

Table 3. *Parameters of resistance of composite materials to high temperatures*

No.	The composition of the composite material	Characteristics parameter	
		Flame retardant	Flam-mability
1	PP(P)+0.5wt.% UPTFE	V-2	Average
2	PP(P)+1.0wt.% UPTFE	V-2	Average
3	PP(B)+0.5wt.% UPTFE	V-2	Average
4	PP(B)+5.0wt.% UPTFE	V-1	Average
5	PP(S)+0.5wt.% UPTFE	V-2	Average
6	PP(S)+1.0wt.% UPTFE	V-2	Average
7	PP(S)+5.0wt.% UPTFE	V-1	Average
8	PP(LF)+0.5wt.% UPTFE	V-0	Average
9	PP(LF)+1.0wt.% UPTFE	V-0	Average
10	PP(LF)+5.0wt.% UPTFE	V-0	Difficult
11	PP(B)+1.0wt.% PhG	V-2	Average
12	PP(B)+5.0wt.% PhG	V-2	Average
13	PP(B)+10.0wt.% PhG	V-1	Average
14	PP(S)+1.0wt.% PhG	V-2	Average
15	PP(S)+5.0wt.% PhG	V-2	Average
16	PP(S)+10.0wt.% PhG	V-2	Average
17	PP(P)+1.0wt.% PhG	V-2	Average
18	PP(P)+5.0wt.% PhG	V-2	Average
19	PP(P)+10.0wt.% PhG	V-1	Average
20	PP(LF)+1.0wt.% PhG	V-0	Average
21	PP(LF)+5.0wt. % PhG	V-0	Average
22	PP(LF)+10.0wt.% PhG	V-0	Difficult
23	PP(P)+10.0wt.% TPE + 5.0wt.% PhG	V-2	Average
24	PP(P)+10.0wt.% TPE + 10.0wt.% PhG	V-1	Average
25	PP(P)+20.0wt.% TPE + 5.0wt.% PhG	V-2	Average
26	PP(P)+20.0wt. % TPE + 10.0wt.% PhG	V-1	Average
27	PP(B)+10.0wt.% TPE + 5.0wt.% PhG	V-2	Average
28	PP(B)+10.0wt.% TPE + 10.0wt.% PhG	V-1	Average
29	PP(B)+20.0wt.% TPE + 5.0wt.% PhG	V-2	Average
30	PP(B)+20.0wt.% TPE + 10.0wt.% PhG	V-1	Average
31	PP(LF)+10.0wt.% TPE + 5.0wt.% PhG	V-2	Average
32	PP(LF)+10.0wt.% TPE + 10.0wt.% PhG	V-1	Average
33	PP(LF)+20.0wt.% TPE + 5.0wt.% PhG	V-1	Average
34	PP(LF)+20.0wt.% TPE + 10.0wt.% PhG	V-1	Average
35	PP(S)+10.0wt. % TPE + 5.0wt.% PhG	V-2	Average.
36	PP(S)+10.0wt.% TPE + 10.0wt.% PhG	V-1	Average
37	PP(S)+20.0wt.% TPE + 5.0wt.% PhG	V-2	Average
38	PP(S)+20.0wt.% TPE + 10.0wt.% PhG	V-2	Average
39	PP(P)+10.0wt.% TPE	V-2	Average
40	PP(P)+20.0wt.% TPE	V-2	Average
41	PP(P)+30.0wt.% TPE	V-1	Average
42	PP(B)+10.0wt.% TPE	V-2	Average
43	PP(B)+20.0wt.% TPE	V-2	Average
44	PP(B)+30.0wt.% TPE	V-1	Average
45	PP (S) + 5.0wt.% TPE	V-2	Average
46	PP (S) + 10.0wt.% TPE	V-2	Average
47	PP (S) + 20.0wt.% TPE	V-2	Average
48	PP (S) + 30.0wt.% TPE	V-1	Average.
49	PP(LF)+10.0wt.% TPE	V-1	Average.
50	PP(LF)+20.0wt.% TPE	V-1	Average.
51	PP(LF)+30.0wt.% TPE	V-1	Average.
52	PP(LF)+10.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	V-0	Difficult
53	PP(LF)+20.0wt.% TPE + 10wt.% PhG + 3.0wt.% UPTFE	V-0	Difficult

The tests carried out made it possible to select for practical use several variants of composite materials based on regenerated thermoplastics with a combination of the necessary stress-strain characteristics, high manufacturability of processing into products by modern technologies and allowing the use of products from them in special conditions – with high requirements for flammability and exposure to an open flame. One of the areas of application of such materials is production of metal-polymer rollers of belt conveyors used in the mining industry. In addition to the requirements noted above, the materials for the manufacture of elements of metal-polymer rollers are also subject to requirements for high impact strength (Table 4).

Table 4. *Charpy impact strength parameter for composite materials based on regenerated thermoplastics*

No.	The composition of the composite material	Charpy impact strength parameter, kJ/m^2
1	PP(LF)+0.5wt.% UPTFE	1.39
2	PP(LF)+1.0wt.% UPTFE	1.44
3	PP(LF)+5.0wt.% UPTFE	1.49
4	PP(LF)+1.0wt.% PhG	1.12
5	PP(LF)+5.0wt.% PhG	1.74
6	PP(LF)+10.0wt.% PhG	1.34
7	PP(LF)+10.0wt.% TPE + 10wt.% PhG+3.0wt.% UPTFE	2.93
8	PP(LF)+20.0wt.% TPE + 10wt.% PhG+3.0wt.% UPTFE	5.92
9	PP(LF)	1.06

The presented data indicate that the developed materials based on polypropylene are significantly superior to the basic thermoplastic and can be recommended for the manufacture of elements of the metal-polymer roller of the belt conveyor used in special conditions.

4. Conclusion

The studies of the structural features and performance characteristics of composite materials obtained on the basis of regenerated thermoplastics made it possible to develop compositions with high parameters of stress-strain, technological characteristics and resistance to high temperatures and combustion.

The use of the developed materials for the manufacture of elements of metal-polymer rollers of belt conveyors has shown the high efficiency of their practical application due to the reduction in cost and the return to the production of residual products of recycling of polymer components.

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