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Molding Thermoplastic Materials for Aerospace Industry

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Abstract—Properties of thermoplastic polymers for decorative structural, structural, and special applications (thermoelastoplastics) are described. These materials completely meet domestic (AP-25) and international (FAR-25) requirements for fire safety.

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Molding thermoplastic materials uniquely combine performance and engineering properties, due to which they have found wide application in different machine-building industries, including aircraft and space vehicle building. In flight vehicles, these materials are used in construction and decorative construction details: instrument housings, cantilevers, ventilation system and passenger seat parts, service panels, lighting devices, interface connectors, and audio and electrical equipment parts.

Until present the above-listed articles were mostly fabricated from polyethylene and composite materials on the basis of PA12-L and PA610-L polyamides and polycarbonate. However, when the USSR collapsed, production of PA12-L and PA610-L polyamides and PK-LT-10 and PK-M-2 polycarbonates in Russia stopped, and many facilities producing monomers for thermoplasts remained in FSU countries.

Federal Targeted Programs envision restoration by 2011–2014 small-scale production of PA610-L polyamide and polycarbonate. There are no plans to restore production of PA12-L polyamide and its based composites in the Russian Federation.

Moreover, in modern aerospace technologies much more rigid requirements are posed on polymer materials used in molding parts and constructions. The most important requirements are preservation of mechanical characteristics at levels of no lower than 80% in the working temperature range and at a maximum water absorption. Polymer materials should not also cause corrosion on contact with black and ferrous metals; they should have funginertness of no lower than 3 and meet domestic (AP-25) and international (FAR-25) fire safety standards: residual combustion time $\tau_{res} \leq 15$ s (flammability standard); smoke optical density $D_{max} < 200$ (smoke evolution standard).

In the present paper we consider thermoplastic polymer materials for decorative structural, structural, and functional applications in aircraft and space vehicle building, which fully meet the above-listed requirements.

Materials for Decorative Structural Applications

The molding fireproof composite VTP 1-L (Table 1) and thermoplastic fireproof composite VTP-5 (Table 2) have been designed for fabrication of structural parts for decoration of pilot and passenger cabins. These materials should replace composites on the basis of PA610-L and PA12-L polyamides and -LT-10 and PK-M-2 polycarbonates.

The VTP 1-L composite has high strength characteristics, and its relative breaking elongation is 7%. The maximum water absorption of the composite is 0.5%, and exposure to water has almost no effect on its properties. The VTP 1-L composite is classed with self-extinguishing materials with a low smoke evolution and is recommended to replace unfilled uncolored and colored polyamides PA610-L and PA12-L. The material does not rank below polyamides in physicochemical characteristics and much surpass them in water resistance and fire safety.

Table 1. Comparative characteristics of molded fireproof composites

Parameter	VTP 1-L	PA610-L		PA12-L	
		value	quot	value	quot
Tensile strength, MPa:					
starting	63	57	by 10.5%	48–55	by 23.5%
after exposure to water	45	38	by 18.4%	42	by 6.7%
Water absorption. max. %	0.26–0.28	3.3	12 times	1.35	5 times
Melting point, °C	220–222	212–214	–	187	–
Residual combustion time, s	9	8	–	–	–
Flammability category	self-extinguishing	self-extinguishing	–	self-extinguishing	–
Maximum smoke evolution on pyrolysis, D_{max}	53	620	11.6 times	620	11.6 times
Working temperature range, °C	–60–+100	–60–+80	by 20°C	–60–+80	by 20°C
Standard	TS[a] 1-595-9-733-2003	SS[a] 10589-87		Tentative standard 6-06-425-92	

[a] Here and hereinafter, TS stands for Technical Specifications and SS stands for State Standard.

Table 2. Characteristics of thermoplastic fire safe composites

Parameter	VTP -5	PK-M-2		PA 610-L	
		value	quot	value	quot
Density, kg m^{-3}	1230–1240	1230–1250	–	1080–1100	
Tensile yield, MPa	65.0	57.0	by 12%	45.0	by 44%
Tensile strength, MPa	54.0	61.0	–	57.0	–
Failure elongation, %	91	90	–	100	–
Water absorption, %:					
in 1 day	0.13	0.12–0.15	–	0.34	2.6 times
maximum	0.23	–	–	3.3	14.3 times
Unnotched impact strength, kJ m^{-2}:					
starting	96	105	–	85	by 11.9%
at 80°C	71	–	–	35	by 50.3%
Residual combustion time, s	1	3–4	3–4 times	8	8 раз
Flammability category	self-extinguishing	self-extinguishing	–	self-extinguishing	–
Smoke evolution, D_{max} on combustion	194	130–220	–	630	3.3 times
Working temperature range, °C	–60–+100	–60–+130	–	–60–+80	by 20 °C
Standard	TS 1-595-9-871-2005	TS 1-595-16-490-96		SS 10589-87	

The thermoplastic fireproof composite VTP-5 is recommended for fabrication of structural and decorative structural interior parts, as well as parts of electrical devices by injection molding and extrusion. The material can be operated in the temperature range from –60 to 100°C. The VTP-5 composite possesses high strength and deformation characteristics, low water absorption, and completely meets AP-25 standards in terms of fire safety. The residual combustion time is 4.5-fold shorter than for PK-M-2. The material is better processed: The shrinkage of injection-molded samples is as little as 0.5%.

The VTP 1-L and VTP-5 composites are fungi-resistant, their funginertness rates are 1–2 and 2–3, respectively. After exposure to 100 and 120°C for 500 and 1000 h, all mechanical characteristics of the composites remain virtually unaffected.

The materials can be applied in contact with titanium and aluminum alloys with anodic oxide coatings, stainless steels, copper, brass, tin-plated copper, and chromate-passivated cadmium-plated steel.

The VTP 1-L and VTP-5 composites can be easily colored in any color. Processing of the developed materials into articles should be performed to form at automatic molding machines with screw injection molding.

Structural Thermoplastics

Thermoplastics for structural applications are recommended for fabrication of components of devices and aggregates: coils, terminal boots, device housings and basic components, as well as other component parts with working temperatures ranging from –60 to 150–180°C and resistant to oils and fuels.

In foreign countries the above articles are fabricated from molding fireproof thermoplastics: polyetherimide (PEI), polyphenylene sulfide (PPS), polyether ether ketone (PEEK), and liquid crystalline thermoplastics (LCT). In Russia such materials are not produced. For organizing production of structural thermoplastics we have to build chemical enterprises to produce monomers and polymers themselves, which necessities huge capital investments. Therefore, domestic industry takes a different, cheper, way to attack this problem, specifically physical and chemical modification of already commercialized polymers. The properties of materials obtained by the modification of a com-mercially produced polysulfone (trademark PSF-150) are listed in Table 3.

This polymer possesses high mechanical characteristics, thermal stability, resistance to aggressive media, good electric properties, and good

Table 3. Characteristics of structural thermoplastics

Parameter	PSF-150	PSF-150-1	PS-KS	PSF-150-L-U25	Polisart-KS	PSFF-40
Density, kg m^{-3}	1300–1400	1250	1400–1420	1290	1300	1220–1230
Tensile yield, MPa	72.0	77.5	–	–	–	79.5
Tensile strength, MPa	56.0	58.0	110.0	132.0	80.0	78.0
Failure elongation, %	55	15.2	3.5	7.6	9.5	10.5
Charpy impact strength, kJ m^{-2} (unnotched samples)	110	125	27.5[a]	19.5[a]	34[a]	125
Residual combustion time, s	–	–	4	0	3	2
Oxygen index	34	33–35	34	48	41.8	–
Flammability category	self-extinguishing	fire-resistant	self-extinguishing	fire-resistant	self-extinguishing	self-extinguishing
Smoke evolution, D_{max}	58	–	–	82	21	62
Working temperature range, °C	–60–+150	–60–+165	–60–+150	–60–+160	–60–+150	–60–+190
Standard	TS 6-05-1969-84	TS 6-05-211-1266-81	TS 6-05-211-1412-85	TS 6-06-86-89	Pilot batches	Pilot batches

[a] Arbitrary value: The sample is not destroyed.

Table 4. Characteristics of molding sealing weather-resistant material VTEP 1-L and its analogs

Parameter	VTEP 1-L	IRP-1078 rubber (Russia)		Riteflex 425 (Germany)		Ellastolan 1154 DFHF (Germany)	
		value	quot	value	quot	value	quot
Density, kg m^{-3}	1115.1117	1370	by 23%	1004	–	1270	by 13%
Tensile strength, MPa	20.0.20.4	11.0	1.85 times	10.0	2 times	30.0	–
Failure elongation,	615–645	130–150	4.7 times	>550	by 15%	400	1.5 times
Residual combustion time, s	7.8	>15	meets AP-25 standards	>15	meets AP-25 standards	>15	meets AP-25 standards
Flammability category	self-extinguishing	flammable		flammable		flammable	
Item production time, min	1–3	30	10.30 times	1–3	–	–	–
Working temperature range, °C	from –60 to +80	from –40 to +100	–20	from –60 to +80	–	from –60 to +80	–
Standard	TS 1-595-9-1041-2008	TS 38 005166-98		import		import	

processability; high transition temperatures (glass transition and melting) and thermal stability ensure its long service life at elevated temperatures.

The material completely meets the requirements of the AP-25 aviation rules (certificate FAR-25) to flammability and smoke evolution, and it is recommended for structural and electrotechnical items with working temperatures of up to 150°C.

Physical modification of the PSF-150 polysulfone gave polysulfones of PSF-150-1, PS-KS, PSF-150-L-U25, and Polisart-KS trademarks (Table 3).

The introduction of a fluorinated polymer into the PSF-150 formulation (material PSF-150-1) not only enhanced its strength and impact characteristics by 4–14%, but also to raise its working temperature to 165°C.

The glass-filled polysulfone PS-KS is the PSF-150 polysulfone modified with a chopped glass fiber. This material has double as high tensile strength (103 MPa), half as high linear expansion coefficient (26×10^{-6} deg^{-1}), and shrinkage range (0.2–0.25%) than PSF-150-1. Such properties allow this materials to be recommended for high-precision parts of instruments, including gyrocompasses.

The modification with a chopped carbon fiber (carbon-filled polysulfone PSF-150-L-U25) increases the tensile strength by 20% and thermal conductivity coefficient by a factor of 1.8 times and decreases factor of 1.5 service-induced changes in item dimensions compared with the glass-filled polysulfone PS-KS. The carbon-filled polysulfone can be used for fabrication of high-precision instrument parts with enhanced thermal conductivity, dimensional stability, and fire safety at working temperatures of up to 160°C.

Thin-wall items of complex shape can be fabricated from the composite Polisart-KS obtained by the doping of a liquid crystal thermoplastic to PSF-150, which enhances processability of the latter.

Compared with the the glass-filled polysulfone PS-KS which is presently used for fabrication of instrument parts, Polisart-KS has a lower density (by 9%), higher oxygen index (by 22%) and flexural impact strength (by 24%), and better processability (the mold temperature is lower by 33%).

The co-polysulfone PSFF-40 is the polysulfone PSF-150 modified with card groups. Such modification transfers PSF-150 into the group of superstructural materials: tensile yield 79.5 MPa, tensile strength 78 MPa, working temperature 190°C.

The polysulfone PSFF-40 exhibits a high fatigue strength and fairly stable linear expansion coefficient (LEC) in the working temperature range; this is a self-extinguishing materials with a low smoke evolution.

Table 5. Characteristics of the sealing impact-resistance electroinsulting thermoelastoplastic VTEP 2-L and its analogs

Parameter	VTEP 2-L	IRP -1078 rubber (Russia)		Riteflex 425 (Germany)	
		value	quot	value	quot
Density, kg m^{-3}	1100	1370	by 24.5%	1004	–
Charpy impact strength, kJ m^{-2} (unnotched samples)	is not destroyed	–	–	is not destroyed	–
Impact resistance index, kJ m^{-2}	10.90–11.08	–	–	–	–
Failure elongation, %	375–395	130–150	2.6–3.0 times	>550	–
Specific volume electric resistance, Ω m	> 1.3×10^{14}	–	–	3.0×10^{8}	4.3×10^{5} times
Flammability category	self-extinguishing	low-flammable	meets AP-25 standards	low-flammable	meets AP-25 standards
Residual combustion time, s	3–4	>30	> 10 times	>30	> 10 times
Water absorption, %	0.05–1 days 0.42–3 months	–	–	0.6–1 days	> 12 times
Item production time, min	1–3	30–60	> 20–30 times	1–3	–
Processing methods	injection molding	rolling molding		injection molding	
Working temperature range, °C	–60–+100	–40–+100	by 20°C	–60–+80	by 20°C
Standard	TS 1-595-9-1092-2009	TS 38 005166-98		import	

Functional Thermoplastics: Thermoelastoplastics

Over the past years much effort has been put on the research on thermoelastoplastics, a new class of polymer materials possessing deformational properties of rubbers and strength and processability of thermoplastics.

Thermoelastoplastics are recommended as a material for seals of pneumatic, hydraulic, and fuel flow systems, shells of electric cables, vibration-absorbing and other items, which is envisioned as a partial substitute for environmentally dirty, hazardous, and difficult-to-process rubbers.

Russia does not produce self-extinguishing thermoelastoplastics (TEP) for technical applications. The demand for these materials is satisfied due to import. The RIAM has developed two types of self-extinguishing TEPs and mastered their pilot production.

The molding sealing weather-resistant material VTEP 1-L is designed for hermetization of doors and hatches which should meet enhanced requirements to fire safety, weather resistance, processability, and paint coating (Table 4). The material possesses enhanced durability and weather resistance and completely meets the AP-25 (FAR-25) requirements in fire safety.

The VTEP 1-L composite has a low density (1115–1117 kg m^{-3}), as well as high (for thermoplastics) tensile strength (20.0–20.4 MPa) and deformation characteristics (615–645 %). The good fluidity of the material allows its processing by means of such high-throughput technologies as injection molding and extrusion.

The advantages of this material over its analog, the IRP-1078 rubber, include decreased density, increased strength and failure elongation, complete fitting of the AP-25 standards in fire safety, shorter processing time, and lower negative working temperatures.

The foreign analogs of the molding sealing enhanced weather-resistant VTEP 1-L are Riteflex 425 (Ticona, Germany) and Elastollan 1154 DFHF (Elastogran, Germany). Compared with these foreign analogs, the developed material has a lower density (by 13–23%) and higher failure elongation.

The sealing impact-resistant electroinsulating thermoelastoplastic VTEP 2-L is designed for fabrication, by injection molding and extrusion, of seals, cable shells, and other articles which should meet enhanced requirements to fire safety and electroinsulation characteristics (Table 5).

The material meets the AP-25 (FAR-25) standards in terms of fire safety, exhibits enhanced electroinsulating characteristics, resistant to hydrolysis, microorganisms (fungi and mold), and aviation fuels and oils, and high melt fluidity. Compared with the IRP-1078 rubber, the material has decreased density (by 24.5%), increased failure elongation (2.6–3.0 times), decreased residual combustion time (more than 10 times), increased fungi resistance (by 1–2 grades), shorter item production time (20–30 times), and lower negative working temperature limit (by 20°C). The working range of VTEP 2-L is –60°C to 100°C.

The Riteflex 425 thermoelastoplastic ranks below VTEP 2-L in water absorption, electroinsulating characteristics, flammability, and working temperature.

The use of the developed materials VTEP 1-L and VTEP 2-L makes it possible to solve the problems of waste utilization and improvement of indoor environment in shops, increase the material utilization factor by a factor of 1.5 times, and to decrease the labor consumption of item production time by a factor of 20–30 times (1–3 min instead of 30–60 min).