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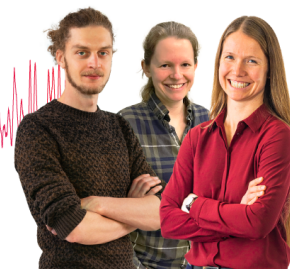
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Dependence of Physical and Mechanical Properties on Various Technological Parameters of Injection Molding in Formation of Composite Polymer Materials

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Abstract. The influence of technological parameters of injection molding on the properties of composite polymeric materials CPM has been studied. The establishment of correlation interrelations of physical-mechanical and tribotechnical properties of antifriction and antifriction-wear resistant composite polymeric materials and technological parameters of injection molding is essential in the development of optimal modes of molding and manufacturing of high-quality parts of working bodies of cotton processing machines. Research on the influence of technological processing parameters on structure, physical-mechanical and tribotechnical properties of AICPM, and optimization of technological parameters of injection molding composite polymeric materials have been conducted. It has been established that the formation of physical-mechanical and tribotechnical properties of composite polymeric materials is directly dependent on technological parameters at their injection molding. At that, the melt temperature and specific pressure of material injection exerts the most significant influence. It was determined that for compositions obtained without activation of fillers, the melt temperature $T_m = 493\text{--}533$ K, pressure $P = 120\text{--}140$ MPa, and for compositions obtained with mechanically activated fillers $T_a = 473\text{--}513$ K, $P = 110\text{--}130$ MPa.

Keywords: Technological parameters, structure, physical and mechanical properties, tribotechnical properties, composite polymeric materials, raw cotton, optimization, wear resistance, machine productivity, power consumption, mechanical fiber damage, seed crushability.

INTRODUCTION

To increase the reliability, durability, and efficiency of machines and mechanisms working with raw cotton during transportation, tunnel digging and disassembly of cotton bunches, polymeric and composite materials, and coatings based on them with high antifriction and damping properties are increasingly used.

In this connection, it is interesting to study the possibility of applying polymer composite materials and coatings on their basis in staking working organs of various cotton machines and mechanisms instead of metal stakes. Below, we will consider the research results carried out in this direction.

Reliable operation of composite parts is determined first of all by the effective composition of composite materials and, in most cases, by the properties of antifriction and antifriction-wear-resistant CPMs interacting under friction conditions with raw cotton, as well as by optimal technological parameters of injection molding. Therefore, the study of the influence of technological parameters of injection molding on the properties of CPM, the establishment of correlation relationships of physical-mechanical and tribotechnical properties of antifriction and antifriction-wear-resistant composite polymeric materials, and technological parameters of injection molding is essential in the development of optimal modes of molding and manufacture of high-quality parts of working bodies of cotton processing machines.

Also, the improvement of material durability and physical-mechanical and tribotechnical properties of composite polymeric materials is influenced by the improvement of the material's rheological properties.

METHOD

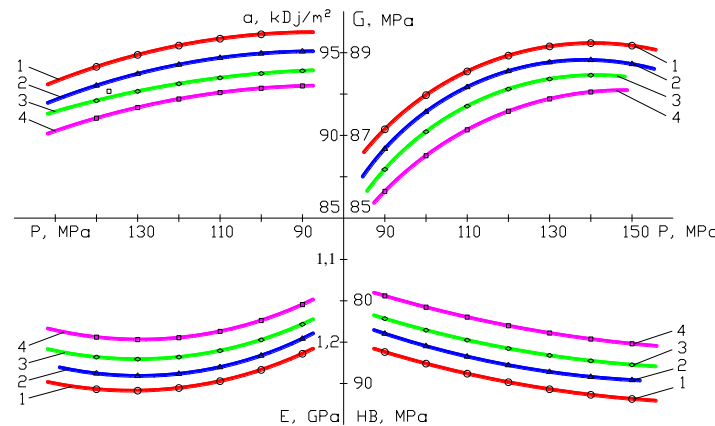
As it is known, injection molding is one of the main methods of processing polymers and compositions into products. The most important technological parameters of injection molding, affecting the quality of molded products, are molding temperature (T_m) and injection pressure (P_i), the rate of mold filling with material, mold temperature (T_f), mold holding time under pressure (τ_h), conditions and rate of material cooling in the mold (τ_c). Therefore, we have conducted studies of the influence of technological parameters of injection molding on the physical-mechanical and tribotechnical properties of antifriction (APPC-1, APPC-2) and antifriction-wear-resistant polypropylene composite materials (AIPPC-1, AIPPC-2) to establish their correlation dependence.

To study physical-mechanical and elastic-strength properties of composite materials, the following were used: the method of static bending test GOST 4648-71; the method of determination of impact toughness by Charpy GOST 4647-80; methods of determination of elastic modulus in tension, compression, and bending GOST 9550-81; method of determination of Brinell hardness GOST 4670-81; method of determination of hardness at indentation with durometer (Shore hardness) GOST 24621-91.

The analysis of the obtained experimental studies showed that the properties of composite polymer materials depend on the technological parameters of injection molding, which is of some interest in this regard. In this connection, the choice of optimal technological modes of molding the choice of optimal technological modes of molding is of certain interest.

For the joint analysis of technological parameters of injection molding, affecting the physical-mechanical and tribotechnical properties of PPM, we, according to the results of experimental studies, made diagrams of correlation dependences of physical-mechanical and tribotechnical properties of antifriction and antifriction-wear-resistant PPM based on polypropylene on various technological parameters of molding, including the melt temperature (T_m) and specific injection pressure (P_i).

As can be seen from Figures 1 and 2, the lower left quadrant of the diagrams shows the dependence of the bending elastic modulus (E_b). In comparison, the lower right quadrant shows the dependence of the Brinell hardness on the specific injection pressure (P_i) and the casting temperature (T_c), respectively. The upper left quadrant shows the dependence of specific viscosity (T_s), and the upper right quadrant shows the dependence of bending failure stress on specific injection pressure and melt temperature, respectively.



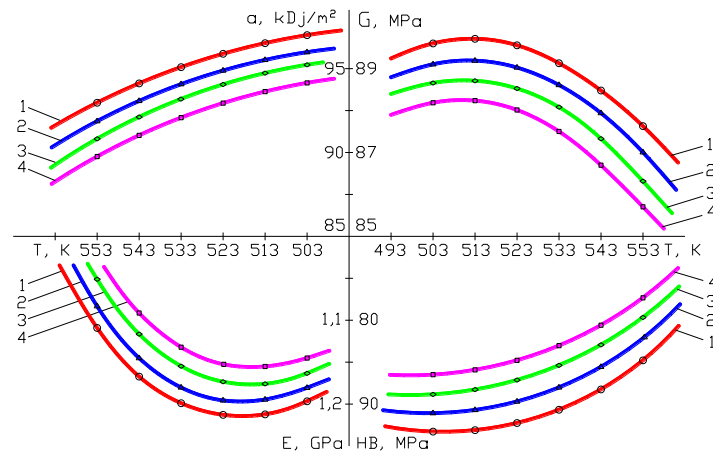
1 is APPC-1, 2 is APPC-2, 3 is AIPPC-1, 4 is AIPPC-2

a is impact toughness; σ is breaking stress in bending; E is modulus of elasticity in bending; HB is Brinell hardness; P is injection pressure

FIGURE 1. Correlation between physical and mechanical properties of antifriction (APPC) and antifriction-wear-resistant polypropylene compositions (AIPPC) and injection pressure.

The analysis of the diagrams shown in Figures 1 and 2 illustrated well the dependence of composite polymer materials' physical and mechanical properties on the technological parameters of injection molding. Thus, with the increase of injection pressure and melt temperature, both breaking stress and bending elasticity modulus and Brinell hardness of antifriction and antifriction-wear-resistant polypropylene composite materials increase, reaching the maximum at $P = 130-140$ MPa and $T = 513$ K, which decrease with further increase of injection pressure and melt

temperature. The specific viscosity of these materials gradually decreases with increasing injection pressure and melt temperature.

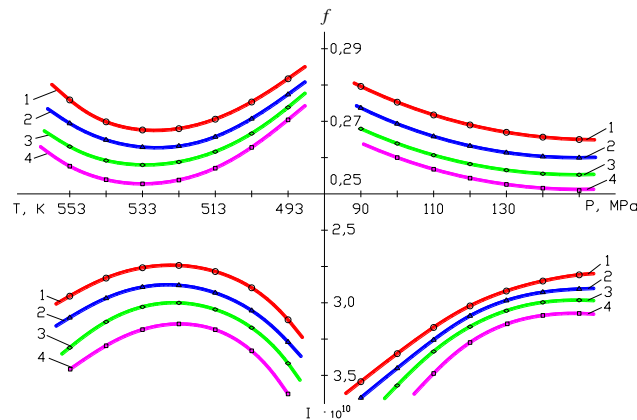


1 is APPK-1; 2 is APPK-2; 3 is AIPPK-1; 4 is AIPPK-2
 a is impact toughness; σ_b is breaking stress at bending; E_b is modulus of elasticity in bending ;
 HB is Brinell hardness; T_m is melt temperature

FIGURE 2. Correlation dependence of physical and mechanical properties of antifriction (APPK) and antifriction-wear-resistant polypropylene compositions (AIPPK) on melt temperature.

Fig. 3 shows the correlation relationship of tribotechnical properties (friction coefficient, wear intensity) of antifriction and antifriction-wear-resistant polypropylene compositions from the specific injection pressure P and casting temperature T_p , from where it can be seen that with increasing injection pressure and melt temperature the friction coefficient and wear intensity decrease, reaching a minimum at $P=130-140$ MPa and $T_m = 513-523$ K. Then at increase of technological parameters of molding tribotechnical properties of CPM increase.

The lower left quadrant of the diagram shows the dependence of wear intensity, and the upper left quadrant shows the dependence of friction coefficient on melt temperature. The lower right quadrant shows the dependence of wear intensity, and the upper right quadrant shows the dependence of friction coefficient on injection pressure.



1 is APPC-1; 2 is APPC-2; 3 is AIPPC-1; 4 is AIPPC-2
 f is coefficient of friction; $I \cdot 10^{-10}$ is wear intensity; T_m is melt temperature; P_1 is injection pressure

FIGURE 3. Correlation dependence of tribotechnical properties of antifriction and antifriction-wear resistant polypropylene compositions on specific pressure and melt temperature.

Correlation dependences presented in the diagrams firstly confirm theoretical ideas and experimental data of research; secondly, the influence of technological parameters of injection molding on physical-mechanical and tribotechnical properties of antifriction and antifriction-wear-resistant polypropylene compositions; thirdly, logical and physical interrelation of the considered factors.

It is known that antifriction and wear resistant composite polymer materials (AICPM) have a complex supramolecular structure, which largely determines their physical and mechanical properties during operation under various conditions. The properties of materials significantly depend on the technological modes of molding and the technology of their processing and manufacturing of parts.

In this connection, the choice of optimum technological modes of casting parts from AICPM of rubbing working organs of cotton processing machines operated at cotton ginning plants and cotton harvesting points of the cotton processing industry is of certain interest. It would allow the development of technology to obtain high-quality parts from CPM. In this case, it was possible to expect wide-range changes in the properties of compositions while preserving the shape of parts. This is not only of practical but also of scientific interest.[33]

RESULTS AND DISCUSSION

The obtained results of studies of the influence of technological parameters of processing on the structure, physical-mechanical, and tribotechnical properties of AICPM allowed us to develop an optimal technological mode of obtaining high-quality parts from AICPM of the rubbing pairs of the working bodies of cotton machines and mechanisms, operating under conditions of frictional interaction with raw cotton, by injection molding.[32]

As it is known, injection molding and regulation of technological modes to ensure high-quality products require knowledge of the regularities of the flow of the separate stages of the process. It should be noted that the temperature and time behavior of the processed composite material are of great importance both in the processes of plasticization and mold filling and holding under pressure, especially from the point of view of selection and maintenance of the temperature regime in the plasticizing cylinder of the injection molding machine and in the injection mold. When selecting a recyclable composite material, the most important criterion for thermoplastic polymers is flowability as a function of mass temperature characterized by the melt flow index.[34]

Considering the mentioned factors, the choice of temperatures of material cylinder and mold, on which the cooling process depends, is made.

The table shows the optimal technological modes of manufacturing working body stakes of various cotton machines and mechanisms from antifriction and antifriction-wear resistant composite polymeric materials based on thermoplastic polymers filled with non-activated and mechanically activated fillers, determined by the results of studies of the influence of technological parameters of molding on their physical-mechanical and tribotechnical properties.

TABLE 1. Optimal technological modes of manufacturing pegs from antifriction and antifriction-wear-resistant compositions filled with non-activated (numerator) and mechanically activated (denominator) ingredients, working bodies of cotton machines, and mechanisms.

Compositions	Molding pressure, MPa	Casting temperature, K	Mold temperature, K	Dwell time of parts in mold, c
APC-1	120-125/110-115	493-513/473-493	323-353	20-60
APPC-2	125-130/115-120	503-523/473-493	323-353	20-60
APEC-1	90-100/80-90	453-463/ 443-453	333-343	20-60
APEC-2	90-100/80-90	453-463/ 443-453	333-353	10-30
AIPPC-1	130-135/120-125	513-523/503-513	323-353	20-60
AIPPC-2	135-140/125-130	513-533/503-513	333-343	20-60
APEC-1	100-120/90-110	483-503/473-483	333-353	10-30
AIPEC-2	100-120/90-110	483-503/473-483	333-343	10-30
AIPAC-2	130-150/120-140	473-513/453-493	323-353	20-60
AIPAC-3	150-160/140-150	503-533/483-513	333-343	20-60

Thus, the research on optimization of technological parameters of injection molding of composite polymeric materials has been carried out. It is established that the formation of physical-mechanical and tribotechnical properties of composite polymer materials is directly dependent on technological parameters during their injection molding. At that, the most significant influence is exerted by the melt temperature and specific pressure of material

injection, the duration of holding the composition in the mold under pressure, the time of holding the products in the mold during their cooling, and the mold temperature have insignificant influence. It is established that for compositions obtained without activation of fillers, melt temperature $T_m = 493\text{--}533\text{ K}$, pressure $P = 120\text{--}140\text{ MPa}$. For compositions obtained with mechanically activated fillers - $T_a = 473\text{--}513\text{ K}$, $P = 110\text{--}130\text{ MPa}$.

The obtained CPMs are characterized by high physical-mechanical ($\sigma = 122\text{ MPa}$, $HB = 107\text{ MPa}$, $a = 125\text{ kJ/m}^2$, $E = 1.55\text{ GPa}$) and tribotechnical properties ($f = 0.22$; $I \cdot 10^{-10} = 2.5$) in comparison with compositions obtained using fillers without activation ($\sigma = 88.0\text{ MPa}$, $HB = 84.5\text{ MPa}$, $a = 92.5\text{ kJ/m}^2$, $E_i = 1.25\text{ GPa}$, $f = 0.23\text{--}0.25$; $I \cdot 10^{-10} = 2.75$).

For approbation of the developed composite polymeric materials based on polyolefins and production of parts of rubbing pairs for working organs of cotton machines, molds were developed and produced, on which various parts of working organs of cotton machines were cast considering certain optimal technological parameters [35].

CONCLUSION

The conducted comparative tests of the experimental batches of parts made of composite polymeric materials in the staking working organs of cotton machines under the optimal technological parameters of injection molding in bench and operational conditions have shown that their application increases wear resistance of composite polymeric parts in 1.5–1.8 times, productivity of machines - on 7–14 %, reduces power consumption - on 5–8 %, mechanical damage of fibers - on 0.12–0.28 %, crushability of seeds - on 0.16–0.32 %, excludes the possibility of burning of raw cotton and formation of fiber windings on the surface of stakes.

Thus, with the help of the presented diagrams, it is possible to determine optimal technological parameters of injection molding for the manufacturing of parts from antifriction and antifriction-wear-resistant polypropylene, polyethylene, and polyamide composite materials (APPC, APEC, AIPPC, AIPEC, and AIPAC) possessing increased physical-mechanical and tribotechnical properties.

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