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MACROMOLECULAR CHEMISTRY AND POLYMERIC MATERIALS

Relationship between the Strengths of the Composite and Binder

E. A. Bondareva, N. V. Sirotinkin, Yu. V. Omel'chuk, and M. G. Davudov

St. Petersburg State Institute of Technology (Technical University), St. Petersburg, Russia

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Abstract—A quantitative relationship between the strengths of a latex compound and the binder, allowing prediction of the properties of the material, has been revealed.

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Choice of latexes for various polymeric compounds is a topical and complicated problem.

Here we attempt to predict the physicochemical properties of a compound on the basis of properties of the binder.

Both in Russia and in other countries, the most common are butadiene–styrene latexes. The properties of materials and goods made of them are quite satisfactory, and the monomers (butadiene and styrene) used for their production are cheaper and more readily available than alternative monomers for similar purposes.

Butadiene–styrene latexes are used most widely in production of finishing materials: paints, spackling compounds, primers, and relief coatings, which is due, on the one hand, to fairly high characteristics of latex films (resistance to hydrolysis, tensile strength, elongation at break) and, on the other hand, to relatively low cost and availability of latexes produced in Russia (BS-65, SKS-65-GP) and in other countries (Rhodopas SB278, DL950, DL461).

Acrylic latexes are also produced in large amounts. Acrylic (including styrene–acrylic) emulsion polymers are used in production of textile and nonwoven articles, adhesives, polishes, waxes, paper, sealants, and cement additives. Numerous kinds of acrylic latexes developed for specific applications are known. In particular, the glass transition point of latex polymers varies from –80 to +100°C. Some of the latexes show high resistance to oil or polar solvents. The most valuable property of acrylic latex polymers is high resistance to light, compared to butadiene–styrene, butadiene–acrylonitrile, chloroprene, and other polymers.

Weather resistance and longevity (resistance to degradation under sunlight, to yellowing, to hydrolysis) are the main advantages of acrylic polymers.

To prepare a composite, it is necessary to choose a latex with definite properties: strength, heat resistance, frost resistance, and elasticity. Latexes are effective binders for many filters in composites, in particular, for light hollow glass spheres in heat-insulating materials.

In this study we examined how the strength of a composite depends on that of the binder, latex polymer.

EXPERIMENTAL

As investigation objects we chose the following latexes: styrene–acrylate A5, A8, A10; butadiene–styrene–acrylate A70; butyl acrylate B-2; butyl acrylate–acrylonitrile BN-2; butyl acrylate–acrylonitrile containing carboxyl component (methacrylic acid) Primal E1950; carboxylated acrylate A6000; butadiene–styrene BS-65; butadiene–styrene without carboxy groups SKS-65GP; carboxylated butadiene–styrene SB 278. We also tested poly(vinyl acetate). As filler we used borosilicate glass spheres [of MS type, group A2, TU (Technical Specification) 6-48-108–94]. Modified urea–formaldehyde resin KFZh-M cured with orthophosphoric acid was used as additive.

Based on the above components, heat-insulation materials consisting of a binder (latex), a filler (glass

spheres), and additives have been developed. In this study we examined the following characteristics of the material: peel strength, compression strength, and compression set.

Latex films were prepared by the surface renewal procedure, in accordance with GOST (State Standard) 24920–81 [1]. The procedure consists in using as support cellophane fixed in a tin plate ring 205 mm in diameter.

The tensile strength of films was measured with a Zwick tensile-testing machine. From cured films 1–1.5 mm thick, prepared and dried at room temperature, we cut strips 6 cm long and 1 cm wide. The specimen thickness (mm) was measured with a thickness meter to the second decimal place. The specimens were fixed in grips of the tensile-testing machine so that the length of the working section was 25 mm. The measurements were performed in accordance with GOST 270–75 [2]. The tensile strength (MPa) was calculated by the formula

$$\sigma = \frac{P \cdot 9.8 \times 10^{-4}}{\delta h \times 10^{-4}},$$

where P is the dynamometer scale reading at break (g); h, specimen thickness (mm); and δ, width of the working section of the specimen, δ = 10 mm.

The elongation at break χ (%) of the film was measured with the vertical scale of the device.

The error of measuring the tensile strength is 1%.

The peel strength was evaluated in accordance with GOST 270–75 [2]. The test consists in measuring the load causing the cotton fabric impregnated with the latex to peel from a support. A latex is applied with a small brush onto glass or metal plates which are then covered with cotton fabric strips. The latex impregnates the fabric and gets dry in 24 h. Peeling of the fabric from a glass or metal plate was performed with a Zwick tensile-testing machine, with measuring the adhesion force. The peel strength P (N m^{-1}) was calculated by the formula

$$P = \frac{P_0 \cdot 9.8}{l \times 10^{-2}},$$

where P_0 is the adhesion force shown by the device (kg), and l is the length of the working base of the specimen (mm), l = 15 mm.

The peel strength was measured with an accuracy of 1%.

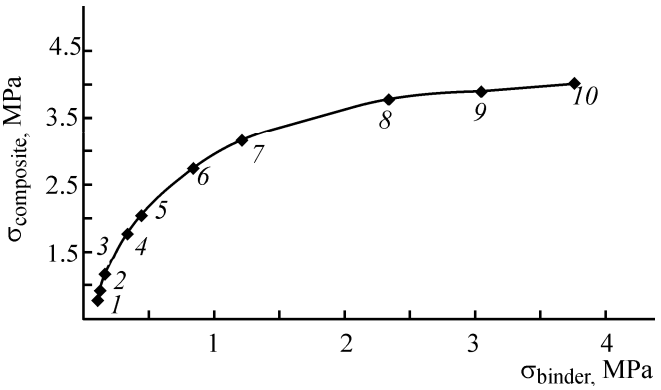
Physicomechanical properties of latex films

Film	Elongation at break, %	Tensile strength of film, MPa	Polymer–glass peel strength, N m^{-1}
Latex:			
A5	Not broken	0.34	110.0
A70	1600	0.10	30.0
B-2	2800	0.45	350.0
BN-2	1600	0.16	350.0
Primal E1950	3000	0.12	450.0
A6000	1800	1.23	500.0
BS-65	230	2.35	110.0
SKS-65GP	450	3.07	100.0
SB 278	500	3.76	450.0
PVA	160	2.17	300.0

The breaking compression stress (compression strength) was determined in accordance with GOST 46451–82 [3] with a Zwick-1445 tensile-testing machine. In accordance with the design features of the device, the specimen size was 20 × 20 × 20 mm. The compression velocity was 0.3 mm min^{-1}. The measurement error was ±0.03 MPa. The compression strength σ_c was calculated by the formula

$$\sigma_c = \frac{P_{max}}{S},$$

where P_{max} is the breaking force (recorded as a jump in the diagram) (N), and S is the specimen area (m^2).



Correlation between the strength of the composite and that of the binder (binder concentration 40 wt %): (*1*) A70, (*2*) Primal E1950, (*3*) BN-2, (*4*) A5, (*5*) B-2, (*6*) PVA, (*7*) A6000, (*8*) BS-65, (*9*) SKS-65, and (*10*) SB 278.

From the latexes under consideration, we prepared films and determined their tensile strength and elongation at break.

To evaluate the adhesion between the polymer and filler (glass spheres), we determined the latex–glass peel strength. As the minimal temperature of film formation of A8 and A10 latexes is 38 and 30°C, respectively, the films cracked, and these latexes were not further tested. The test results are given in the table.

The strength of a composite can be determined by two factors: strength of the binder proper and adhesion of the polymer to the filler. If an increase in the strength corresponds to an increase in the adhesion, both factors act simultaneously [4]. As seen from the figure, the strength of the composite is determined by the strength of the binder proper. In this case, replacement of A70 latex by SB 278 leads to a fivefold increase in the strength of the composite (from 0.78 to 4.0 MPa). It should be noted that, at comparable thermal conductivity, the strength of commercially produced foamed polyurethanes is lower by an order of magnitude than that of the suggested heat-insulating materials based on hollow borosilicate spheres [5].

As seen from the figure, of most interest are A6000, BS-65, SKS-65GP, and SB 278 latexes, and also poly (vinyl acetate) dispersion. The use of glass spheres as a filler makes it necessary to evaluate the adhesion between the polymer and glass. BS-65 and SKS-65GP latexes have low polymer–glass peel strength and cannot be recommended as binders.

All the acrylate latexes are hydrophilic, and the lower the glass transition point of the latex, the higher its hydrophilicity. The components of A6000 latex are butyl acrylate and methyl methacrylate, which decrease the hydrophilicity. Based on the results obtained, A6000 latex seems to be the most promising as binder among the examined butyl acrylate and styrene–acrylate latexes.

SB 278 latex exhibits low water absorption, good adhesion to glass, and high strength. In comparison with BS-65 and SKS-65 latexes, it has more reproducible properties. Therefore, we chose it among butadiene–styrene latexes.

The advantages of poly(vinyl acetate) dispersion are adhesiveness and elasticity. However, PVA is inconvenient in drying: It is a thermoplastic, and therefore, it cannot be applied onto high-temperature pipelines. Furthermore, a major disadvantage of films prepared from poly(vinyl acetate) dispersion is insufficient resistance to water. Polyvinyl acetate is relatively readily hydrolyzed with the release of acetic acid. Therefore, the specimens exhibit increased water absorption.

Acrylic latex A6000 with a moderately low glass transition point imparts to composites good flexibility, weather resistance, resistance to temperature changes, and high adhesion to various materials: wood, ceramics, glass, cements, and metals [6].

Butadiene–styrene latex SB 278 exhibits high strength, fairly good elasticity and plasticity, good heat resistance, and enhanced chemical resistance. Furthermore, the polymer of this latex is water-resistant and has high dielectric characteristics [4].

Methacrylic acid units incorporated in these polymers provide additional hardening, improve the colloid stability at relatively high pH values and the adhesion, and can act as cross-linking sites (e.g., in the reaction with aziridine or carbodiimide [6]).

In polymerization of carboxyl-containing polymers, methacrylic acid remains on the surface of latex globules, and addition of orthophosphoric acid leads to protonic curing of the system [4].

SB 278 latex is a copolymer containing a large amount of styrene units imparting the strength to the latex. Therefore, the glass transition point of SB 278 is +5°C, which is higher than that of A6000 latex (–19°C) [6]. The lower the glass transition point of the polymer, the lower the film strength. Therefore, the polymer of SB 278 latex is stronger than that of A6000 latex, which affects the strength of the composite.

Urea–formaldehyde resin is simultaneously a fireproofing and reinforcing additive to latexes of acrylic and butadiene–styrene polymers. Therefore, it enhances the strength [7].

As seen from the figure, the dependence obtained is described by the function $y = f(x)$ [8], which allows prediction of the strength of composites.

CONCLUSIONS

Among a series of acrylate, styrene–acrylate, butadiene–styrene, and butyl acrylate latexes, carboxylated acrylate latex A6000 and carboxylated butadiene–styrene latex SB 278 ensure the highest strength of the material.

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