Original Article

Investigation Of The Influence Of Technological Factors Of Magnetic Treatment Of Polymer Coatings On Their Adhesion And Physical And Mechanical Properties

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Abstract

Development of an effective technology for obtaining composite polymer coatings by electromagnetic treatment based on the regularities revealed in the study of the effect of an external magnetic field on the physical and mechanical properties of polymer and composite coatings and the development of an optimal composition and modes of electromagnetic treatment that provide high adhesive, strength, and protective properties. contributing to the increase in the reliability and durability of coatings in climatic and other operating conditions. Research and clarification of the effect of the electromagnetic field during the processing of polymer coatings in the technological stages of their production; investigation of the influence of the type and directions of the lines of force of the electromagnetic field on the properties of unfilled polymer and filled composite polymer coatings; study of the influence of the type of substrate on the adhesive properties of unfilled polymer and filled composite polymer coatings, treated in an electromagnetic field; study of the influence of the intensity and time of exposure to an electromagnetic field on the adhesive and physical and mechanical properties of unfilled polymer and filled composite polymer coatings; study of the influence of the electromagnetic field on the physical and mechanical properties of composite polymer coatings containing mineral fillers of various types and nature; study of the influence of the degree of filling the compositions with mineral ingredients on the physicomechanical properties of coatings formed during processing by an electromagnetic field; a comprehensive analysis of the results obtained and the development of optimal technological modes for obtaining composite polymer coatings by electromagnetic treatment; development of an effective technology for obtaining composite polymer coatings based on the identified optimal technological modes of their electromagnetic treatment [1, 2, 3].

Keywords: Polymer, processing, electromagnetic field, composite polymer, physical and mechanical properties, efficient technology.

Introduction

The main task of the Republic of Uzbekistan in the transition to a market economy is the acceleration of scientific and technological progress, the transition to an intensive path of development, the creation of export-oriented technologies and import-substituting materials, their rational and effective use.

In this aspect, it is noteworthy to conduct comprehensive studies to improve the physical, mechanical and operational properties of polymer and composite materials and their introduction into production. The high efficiency of these materials is especially manifested when they are used in the form of thin-layer coatings on the surface of metal products, structures and parts, when the properties of the metal are successfully combined with the properties of polymer and composite materials.

In recent years, works have appeared on changing the properties of various polymers due to the action of an external electromagnetic field, which makes it possible to obtain coatings with an oriented structure. The processes of processing coated parts in an electromagnetic field are technologically advanced and safe, as well as cheaper in comparison with other chemical and physical modification methods. However, they have not been sufficiently studied, and therefore the electromagnetic treatment of polymer and composite materials has not received wide application in production. In this regard, a comprehensive study of the effect of a magnetic field on the physical, mechanical and operational properties of polymer composite materials and surface coatings of metal structures and parts based on them is an urgent problem.

The work uses modern methods of studying the physical and mechanical, adhesive properties of composite polymer coatings in accordance with GOST. The physicochemical properties and structure of composite polymer coatings were determined by IR spectroscopic analysis and an optical microscope. The processing of polymer coatings was carried out on an electromagnetic installation. For the application of powder polymers and compositions, vibro-vortex and electrostatic spraying methods were used. A computer program was used to calculate the parameters of the electromagnetic installation.

It consists in the development of optimal technological parameters of electromagnetic effects on composite polymer coatings with various substrates and fillers, which can increase the reliability and durability of organic coatings for polyfunctional purposes and the durability of organic coatings for polyfunctional purposes.

Methods and Analysis

As the analysis of literary sources shows, to date, a comprehensive study of the physical and mechanical properties of coatings has been insufficiently carried out depending on the type and direction of the magnetic field lines, its intensity and exposure time, as well as the influence of the type, nature of the substrate (substrate) and the content of mineral ingredients introduced into composition of coating compositions. In addition, there are practically no data on the methods and optimal technological modes of processing in a magnetic field of coatings, which would make it possible to develop an effective technology for obtaining composite coatings using their electromagnetic processing.

In this regard, this chapter discusses and presents the results of research in the development of an effective technology for electromagnetic treatment of polymer coatings by conducting comprehensive studies of the regularities of the influence of a magnetic field on the physical and mechanical properties of epoxy (ED-16), pentaplastic (PNP) and polyethylene (HDPE)) coatings depending on various technological and objective factors: the type and direction of the magnetic field lines, its intensity and exposure time, as well as the type and nature of the substrate on which the coatings are formed.

To identify the moment of application of an external electromagnetic field, the mode of action of an electromagnetic field on polymer coatings based on ED-16, PNP and HDPE was investigated at a magnetic field strength of $12 \cdot 10^4$ A / m, exposure time of 1800 s. It turned out that the pretreatment of polymeric materials before application provides the adhesive strength of coatings based on ED-16 and HDPE within 0.10 MPa, pentaplast - 0.17 Mpa [4, 5, 6].

The effect of a magnetic field is revealed during the processing of polymer coatings in the process of their formation (crosslinking or crystallization). At the same time, there is an improvement in physical and mechanical properties by 35-40%. This is apparently due to the activation of surface forces and polarization processes, leading to an improvement in the interaction processes at the interface between the adhesive - substrate phases during crosslinking or crystallization of polymers.

By studying the influence of the interval of the onset of exposure to a magnetic field after the application of a polymer coating on adhesive and other strength properties, it was found that the optimal interval for the onset of exposure to an external magnetic field for epoxy composites is 600 s, and for FAED-20 - 3600 s. after adding a hardener and applying a coating to the substrate, which is in good agreement with the beginning of an intensive increase in the viscosity of the composition. For thermoplastic polymers, this interval is not observed, which is caused by the rapid formation of thermoplastic and delayed - thermosetting polymers after their application to the substrate. Therefore, thermoplastic coatings were magnetically treated immediately after application or during application. In this case, for coatings made of thermosetting polymers, the optimal processing mode: the intensity of the external magnetic field $H=8\div10\cdot10^4$ А/м, exposure time $30\div39\cdot10^2$ с. For coatings made of thermoplastic polymers $H = I4\div I6\cdot I0^4$ А/м, $\tau = 12\div15\cdot10^2$ с.

It should be noted that the adhesive strength during magnetic treatment according to the above-mentioned regime of already formed (after production) polymer coatings increases by only 5-10%, which is apparently associated with the end of the crosslinking (thermosetting) and crystallization (thermoplastics) processes of coating materials.

It should be noted that, to simplify further experiments, only ED-16, PNP, and HDPE were chosen from the studied polymers. This choice is also due to the fact that changes in the properties of FAED-20 and PVB during electromagnetic treatment are similar to the properties of the selected polymers.

Thus, the external magnetic field effectively affects the physical and mechanical properties of polymer coatings during their formation, that is, in the process of crosslinking thermosets and crystallization of thermoplastics. In this case, as expected, due to the high polarity of ED-16 and PNP compared to HDPE, the effect of changing the physical and mechanical properties of the former after exposure to a magnetic field is much more noticeable.

Further, the influence of the type of magnetic field (constant, variable) and the direction of its lines of force (longitudinal or transverse to the surface of the coatings) on the physical and mechanical properties of polyethylene, pentaplastic and epoxy coatings was investigated.

Studies have shown that the physical, mechanical and electrical properties of the studied polymer coatings are effectively influenced by both constant and alternating magnetic fields with different directions of the field lines (Table 1). In this case, a constant magnetic field more effectively affects the improvement of the properties of both thermosetting and thermoplastic polymer coatings. This is apparently due to the fact that the action of a constant magnetic field on thermoplastic polymer coatings leads to some orientation of the segments of macromolecules relative to each other. This, apparently, is also facilitated by metallic impurities, consisting of metal oxides such as oxides of zinc, nickel, cobalt, chromium, molybdenum, etc. others located in the volume of the polymer from the remains of the catalysts.

Table 1 Dependence of the physical and mechanical properties of polymer coatings on the influence of the type and direction of the magnetic field lines

Names of coatings	Characteristics	Control values of characteristics	The type and direction of the magnetic field			
			permanent		variable	
			Longitudinal	Transverse	Longitudinal	Transverse
HDPE	σ_A, MPa	0,10	0,135	0,14	0,125	0,14
	$\sigma_{рп}$, MPa	13,5	17,5	15,5	16,0	14,0
	$\sigma_{уд}$, Н·м	5,0	7,1	5,5	6,4	5,2
	$H_м$, MPa	40,2	49,1	44,1	44,0	43,1
Tnp	σ_A, MPa	0,17	0,22	0,24	0,20	0,22
	$\sigma_{рп}$, MPa	31,1	42,6	38,1	39,0	31,4
	$\sigma_{уд}$, Н·м	2,5	3,0	2,8	2,0	2,6
	$H_м$, MPa	74	91	89	79	79
ED-16	σ_A, MPa	0,10	0,135	0,15	0,14	0,15
	$\sigma_{рп}$, MPa	21,5	27,7	23,1	23,0	21,9
	$\sigma_{уд}$, Н·м	0,8	1,8	1,5	1,4	1,2
	$H_м$, MPa	143	193	195	171	167

Note: $H=12\cdot10^4$ А/м; τ =1800 с

Experimental results confirm the orientation of supramolecular formations along the magnetic field - a decrease in the values ρ_v and ρ_s (Table 2), which is fully consistent with the data of M.A. Akutina, V.E. Gulya and their co-workers, obtained for block - polymers. Minor decrease ρ_v, ρ_s when exposed to an alternating field is apparently due to the fact that the orientation of the segments of polymer macromolecules is difficult due to the high frequency of the alternating magnetic field. At the same time, a certain orientation of the segments of thermoplastic macromolecules (PNP and HDPE) is also visible from a decrease in the specific volumetric ρ_v and superficial ρ_s electrical resistances [7, 8, 9].

table 2

Dependence of the electrical properties of polymer coatings on the type and direction of magnetic field lines

Names of coatings	Characteristics	Control values of characteristics	The type and direction of the magnetic field			
			permanent		variable	
			Longitudinal	transverse	longitudinal	transverse
HDPE	ρ_v , Ом·см	$1\cdot10^{17}$	$0{,}4\cdot10^{17}$	$0{,}42\cdot10^{17}$	$0{,}6\cdot10^{17}$	$0{,}6\cdot10^{17}$
	ρ_s , Ом	$1\cdot10^{16}$	$0{,}5\cdot10^{16}$	$0{,}62\cdot10^{16}$	$0{,}63\cdot10^{16}$	$0{,}7\cdot10^{16}$
	tgδ	0,005	0,0035	0,0039	0,0045	0,004
	ε	0,0035	0,0026	0,0029	0,0028	0,0031
Tnp	ρ_v , Ом·см	$1\cdot10^{16}$	$1{,}1\cdot10^{16}$	$1{,}6\cdot10^{16}$	$1{,}6\cdot10^{16}$	$1{,}5\cdot10^{16}$
	ρ_s , Ом	$1\cdot10^{16}$	$0{,}6\cdot10^{16}$	$0{,}7\cdot10^{16}$	$0{,}8\cdot10^{16}$	$0{,}8\cdot10^{16}$
	tgδ	3,2	2,6	2,8	2,7	2,8
	ε	0,011	0,006	0,009	0,008	0,010

ED-16	ρ_v , Ом·см	$1\cdot10^{15}$	$0{,}8\cdot10^{15}$	$0{,}85\cdot10^{15}$	$0{,}85\cdot10^{15}$	$0{,}85\cdot10^{15}$
	ρ_s , Ом	$1\cdot10^{14}$	$0{,}8\cdot10^{14}$	$0{,}85\cdot10^{14}$	$0{,}9\cdot10^{14}$	$0{,}85\cdot10^{14}$
	tgδ	3,4	2,7	2,8	2,86	2,8
	ε	0,012	0,008	0,009	0,009	0,011

Note: $H=12\cdot10^4$ А/м; τ =1800 с

In the case of thermosetting plastic (ED-16), processing in a magnetic field also causes structural changes in the polymer - the degree of cross-linking of the oligomer increases, ρ_v, ρ_s, tgδ, ε, and also improves the mechanical strength of the polymer coating, which indicates the presence of more ordered network structures in the coating and the density of macromolecules in the coating volume, in comparison with coatings untreated in a magnetic field. When processing in a magnetic field, the compaction and packing of polymer macromolecules in their volume along the magnetic field lines are also improved, which can be seen from an increase in the microhardness values (Table 1). Studies have shown that when processing in a magnetic field, the protective properties are also improved due to a decrease in micropores in the coating.

It should be noted that, as expected, due to the higher polarity of ED-16 and PNP, as compared to HDPE, the effect of physicomechanical and electrical changes in epoxy and pentaplastic coatings is much greater than that of polyethylene coatings.

When processing polymer coatings in an external magnetic field, the direction of its lines of force plays an important role. The research results showed that when exposed to an external magnetic field of both the longitudinal and transverse directions of the field lines, the physical and mechanical characteristics of the coatings are improved. The reinforcing effect of transverse (perpendicular to the surface) lines of force on the adhesive strength of coatings is greater than that of longitudinal (parallel to the surface to be treated), regardless of the type of polymer and the nature of the substrate. This is apparently due to the fact that under the transverse action of magnetic field lines, the segments of polymer macromolecules are oriented along the thickness of the coating, which also increases their diffusion into the pores of the substrate (this significantly increases the adhesive strength) and, at the same time, decreases bonds in the longitudinal direction. In this case, anisotropy of properties appears, which is confirmed by experimental data. In this case, the anisotropy of properties manifests itself in the study of not only physical and mechanical properties, but also electrical ones.

It should be noted that the effect of a magnetic field, along with an improvement in the physical and mechanical properties, also leads to a decrease in internal stresses in the coatings, which is apparently also associated with the acceleration of relaxation processes during the formation of coatings.

As shown by the results of the study, the magnetic treatment of polymer coatings can significantly improve their physical and mechanical properties. So, the adhesion strength increases from 0.10 to 0.125-0.140 MPa, tensile strength - from 13.5 to 14.0-175.5 MPa, impact strength - from 5.0 to 5.2-7.1 N · m, microhardness - from 40.2 to 43.1-49.1 MPa, depending on the type of magnetic field, i.e. constant or variable and directions longitudinal or variable. In this case, the optimal option for the effect of an external magnetic field on polymer coatings is to form them in a constant magnetic field with the direction of field lines longitudinal to the sample surface, and if adhesive strength is important for the coating, then in these cases it is recommended to magnetically treat it with lines of force transverse to the substrate.

To reveal the effect of the influence of an external magnetic field on the coatings, depending on the electromagnetic properties of the substrate, polymer coatings formed on steel aluminum and copper substrates and processed in a constant magnetic field with different strengths were investigated [10, 11, 12, 13].

Due to the fact that the magnetic field strongly affects ferromagnetic, weakly - on paramagnetic and negatively - on diamagnetic materials, we investigated the change in the properties of polymer coatings obtained under the influence of a magnetic field on materials with different magnetic properties. In particular, the dependence on the strength of the external magnetic field during the curing of epoxy, polyethylene, pentaplastic coatings on steel, aluminum and copper substrates has been investigated. The research results show that the effect of the influence of the magnetic field depends on the nature of the polymer and the substrate, where the increase in adhesion strength for epoxy coatings on a steel substrate is 54%, on an aluminum substrate - 45%, on a copper substrate - 29%, i.e., the adhesion strength depends on the magnetic properties of the substrate.

The adhesive strength of systems treated in a magnetic field also depends on the polarity of the polymer. So, for non-polar polyethylene HDPE, the adhesive strength on a steel substrate increases by 40%, aluminum - by 35%, copper - by -25%.

As shown by the experimental results, the adhesive strengths of HDPE, PNP, and ED-16 coatings, treated in a magnetic field and formed on ferromagnetic, paramagnetic, and diamagnetic substrates, differ sharply. At the same time, a certain increase in the value of adhesion strength is observed for all studied polymers both on steel substrates and on aluminum and copper substrates when they are processed in a magnetic field with a strength 12·10⁴ A/м. It should be noted that the highest values of σ_A, which, apparently, is associated with the residual voltage of the magnetic field of the steel substrate, which is retained for a long time (up to 5-10 days) in the coating - substrate system. And this, in turn, contributes to the preservation of the active state of the substrate and the formed polymer material for a certain time, as a result of which the physical and mechanical properties of the coatings are improved.

Thus, the dependence of the adhesive strength on the type of substrate after magnetic treatment is due to the magnetic characteristics of the latter; the greater the magnetic susceptibility of the substrate, the more effective the action of the magnetic field.

Table Figures 3 and 4 show the dependences of the adhesive strength of epoxy and polyethylene coatings with aluminum foil on the magnetic field strength and the duration of treatment. Coated parts were processed in a pulsating electromagnetic field so that the lines of force penetrated the coatings and the substrate to be coated. As can be seen from the data in the table. 3, 4, with an increase in the intensity of the pulsating field to a certain value, the adhesion strength of epoxy and polyethylene coatings increases. A further increase in H reduces the adhesion strength. Optimum adhesive strength for epoxy coatings is observed at magnetic field strength $8 \cdot 10^4$ A/м, from polyethylene – $5{,}6 \cdot 10^4$ A/м. As expected, due to the higher polarity of the epoxy composition compared to polyethylene, it exhibits a greater effect of adhesive changes after magnetic treatment. The change in adhesion strength depending on the duration of processing in a pulsating magnetic field has an extreme character. The optimum adhesion strength for epoxy and polyethylene coatings is observed at treatment times of 35 and 25 minutes.

Table 3
Dependence of the adhesive strength of polymer coatings on the magnetic field strength H, MPa

Coating type	Magnetic field strength, A / m					
	0	$3{,}2 \cdot 10^4$	$5{,}6 \cdot 10^4$	$8 \cdot 10^4$	$10{,}4 \cdot 10^4$	$12{,}8 \cdot 10^4$
EC (ED-16 100 + DBF 20 + PEPA 12.8 parts by weight)	0,175	0,20	0,219	0,255	0,222	0,219
HDPE	0,11	0,154	0,176	0,152	0,125	0,102

The adhesion strength of epoxy, pentaplastic, polyamide and polyethylene coatings when treated in a constant electromagnetic field also increases with increasing field strength and processing duration up to a certain value [14, 15, 16].

Table 4
Dependence of the adhesive strength of polymer coatings on the duration of processing in a magnetic field, MPa

Cover material	Magnetic field strength, A / m	Processing time, min								
		0	10	20	25	30	35	40	50	60
ЭК	$8 \cdot 10^4$	0,15	0,18	0,202	0,235	0,240	0,255	0,241	0,225	0,21
HDPE	$5{,}6 \cdot 10^4$	0,11	0,122	0,150	0,175	0,162	0,160	0,140	0,122	-

With a further increase in tension and processing time, the adhesive strength of the investigated coatings is stabilized. It should be noted that the value of adhesion strength after treatment in a constant magnetic field increases by 1.6 - 2.8 times, depending on the type of coating, in comparison with untreated coatings. Research results have shown that processing in a constant magnetic field can increase the adhesive strength of filled polymer coatings. An increase in the adhesive strength of polymer coatings after treatment in a magnetic field is probably associated with the orientation of polymer macromolecules along the magnetic field lines, as well as with an increase in the wettability of the substrate. At the same time, the possibility of increasing the power of the microelectrocapacitor at the interface increases, which is confirmed, in particular, by the synchronous increase in the glow intensity of the gas discharge during the adhesive destruction of polyethylene coatings obtained on the surface of aluminum and steel foil during processing in a magnetic field. Similar results were obtained for epoxy coatings.

Thus, the possibility of changing the adhesive and strength properties of coatings by applying external magnetic fields has been shown, which is of direct practical importance.

As you know, in production conditions, not "pure" polymer materials and coatings based on them are used, but mainly filled polymer coatings, i.e. composite polymer coatings.

In this regard, at the next stage of the work, the effect of a magnetic field on the physical and mechanical properties of composite polymer coatings was investigated.

Conclusion/Recommendations

Investigations of the physical and mechanical properties of polyethylene, pentaplastic, polyvinyl butyral, epoxy and furan-epoxy coatings during their electromagnetic treatment were carried out, depending on their nature and structure. At the same time, it was found that the magnetic field effectively affects the coatings obtained on the basis of polar polymers. So, for example, due to the high polarity of ED-16 and PNP, in comparison with HDPE, the effect of changing the physical and mechanical properties of the former after exposure to a magnetic field is much more noticeable.

Studies have shown that the physical, mechanical and electrical properties of the studied unfilled polymer coatings are effectively influenced by both constant and alternating magnetic fields with different directions of the field lines. In this case, a constant magnetic field more effectively affects the improvement of both thermosetting and thermoplastic properties of polymer coatings. This is apparently due to the fact that the action of a constant magnetic field on thermoplastic polymer coatings leads to some orientation of the segments of macromolecules relative to each other.

The research results showed that when exposed to an external magnetic field, both longitudinal and transverse directions of the field lines, the physical and mechanical characteristics of polymer coatings are improved. The reinforcing effect of transverse (perpendicular to the surface) lines of force on the adhesive strength of coatings is greater than that of longitudinal (parallel to the surface to be treated), regardless of the type of polymer and the nature of the substrate. In this case, the optimal variant of the effect of an external magnetic field on polymer coatings is to form them in a constant magnetic field with the direction of the field lines longitudinal to the sample surface, and if the adhesive strength is important for the coating, then in these cases it is recommended to magnetically treat it with the field lines transverse to the substrate. It should be noted that in this case, high values of the properties of coatings are achieved due to the formation of their anisotropic structure, which is due to the presence of coatings in an oriented state.

It is shown that the adhesive strength of unfilled polymer coatings treated in a magnetic field depends significantly on the nature of the substrate - substrate. In this case, polymer coatings obtained on the surface of a ferromagnetic substrate have a higher adhesive strength than on diamagnetic and paramagnetic substrates. Research results show that the adhesive strength of polar epoxy coatings on a steel substrate increases by 54%, on an aluminum substrate - by 45%, on a copper substrate - by 29%. For non-polar polyethylene (HDPE), the adhesive strength on a steel substrate increases by 40%, on an aluminum substrate - by 35%, and on a copper substrate - by -25%, i.e. the effectiveness of the influence of the magnetic field depends both on the nature of the substrate - substrate, and on the polymer - adhesive. Consequently, the dependence of the adhesive strength on the type of substrate after magnetic treatment is due to the magnetic characteristics of the latter; the greater the magnetic susceptibility of the substrate, the more effective the action of the magnetic field.

The studies carried out have shown that the physical and mechanical properties of unfilled polymer coatings obtained under the influence of a magnetic field significantly depend on the intensity and time of exposure to the magnetic field. The optimal modes of processing in a magnetic field of coatings are revealed, depending on the type and nature of the polymer material.

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