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SPECIALIZED POLYMER COMPOSITES INTENDED FOR THE REGENERATION OF MACHINE COMPONENTS

Key words

Epoxy resin, polyurethane, interpenetrating polymer networks, polymer composites, polymeric – regeneration, mechanical properties, wear, friction coefficient, guide systems for tool machines.

Abstract

Modern equipment and industrial machinery are characterized by advanced design that allows the implementation of complex manufacturing processes. The complexity of the machine construction results in the high cost of spare element replacements, and in many cases, their condition qualifies them for regeneration with the use of modern composite materials, which guarantee obtaining the required performance parameters of the regenerated element. This article presents the results of a study on the development of special, chemically cured, polymer composite, intended for the regeneration of items of machinery and equipment. The composites' matrix was a modified epoxy resin. Polyester resins and polyurethane were used as polymeric modifiers, which form penetrating epoxy polymer networks with the matrix (IPN-Interpenetrating Polymer Network). Basic fillers of the composites were metallic powders with a specific chemical composition and granular size, and lubricants with anisotropic consistency. Performance characteristics were examined of the designed composites using modern testing apparatus. These polymer composites were applied for the regeneration of the surfaces of used elements. It was found that they ensure relevant performance features of the regenerated elements. Sample applications are also presented.

Introduction

Intensive use of machine parts causes the wear of involved components and is usually manifested by a change in geometric dimensions and damage to the surface. One of the solutions to the problem of refurbishing surface layers is using special composite materials that combine high wear resistance with a simplicity of the technological process of their application. In the recent years in particular, an important role has been played by composites based on a polymer matrix [1, 2, 3]. Performance requirements for modern composites have led to the dynamic development of research on the chemical modification of polymer matrix materials and to the development of innovative formulas for materials with high performance parameters, while ensuring low-cost repair of machinery elements resulting, in particular, from the maximum simplification of the regeneration technology. Such requirements are fulfilled by metal-polymer composites based on the matrix of epoxy resins, which have carefully selected powder and fibre fillers, as well as the modifiers of specified performance features. Epoxy resins are among the most versatile chemically cured polymer products with good performance and simple and convenient processing technology. However, after the cross-linking, they are stiff and brittle, which causes most of their major drawbacks: low resistance to impact and low strain at rupture. Low flexibility and rigid materials very easily produce internal stresses; therefore, the articles made of epoxy resin are prone to cracking during prolonged stress action. Improving these properties is the most common reason for the modification of epoxy materials with other polymers [4, 5, 6].

The modification of epoxy resin with polymers capable of creating spatial networks is an innovative way to improve its properties. The cross-linked polymer mixes are generally divided into physical and chemical. In the case of chemical mixtures, the polymers – as a result of cross-linking – form a common spatial network that is bound chemically. When the interaction between separate, but mutually penetrating polymer networks is only physical in nature, and there are no bindings across the network and these are interpenetrating polymer networks (IPN). Included in this category are also such systems in which only one component creates a spatial network and the other – of a linear structure – is woven among the cross-linked structure. These are called semi-IPN [7–10].

Interpenetrating polymer networks formed from two or more polymers are relatively new engineering materials, which can also be used as the polymer matrices for composite materials in special applications.

The aim of this study is to examine the effects of polymeric modifiers – polyurethane and polyester resin – on the properties of epoxy matrix and to develop specialized polymer composites for the regeneration of machine components, which should have good performance properties in a variety of technical applications.

1. The subject matter and research methods

The subject of this research was the compositions of epoxy resin Epidian 5 with polymer modifiers Polymeric Polimal 109 and 165, which are polyester resins. As a curing agent for unsaturated polyester resins, Luperox was applied, and the reaction accelerator was cobalt naphthenate. The second polymer modifier was Desmokap 12 polyurethane. The contents of the polymeric modifiers in epoxy matrix constituted 5, 10, and 15% of the weight. Samples for testing their mechanical properties were taken from the resulting compositions. The obtained compositions containing different amounts of modifiers were cross-linked using aliphatic polyamine (triethylenetetramine-Z-1) at room temperature for 24 hours, and then further cross-linked at a temperature of 80°C for three hours. After cross-linking, impact resistance was measured using the Charpy method and Zwick 5012 device according to PN-81/89 C-029 norm, and the 3-point flexural strength was measured using the Instron 5566 strength machine, according to PN-EN ISO 178: 2006 norm.

2. Test results

The testing results for the mechanical properties of the produced compositions are presented in Table 1. The obtained results indicate a strong influence of the type and weight participation of modifiers on the mechanical properties of polymeric epoxy resin.

The results indicate that the applied polymeric modifier significantly improves the mechanical properties of chemically cured epoxy resin. For the majority of tested compositions (with the exception of Polimal 109) which contain 10% of the polymeric impact resistance modifiers, the resistance to dynamic impact (impact strength) increased by about double compared to the unmodified resin. There was also far greater resistance to strain and strain in bending. The distinct increase in strength parameters, considering the lack of chemical bonds between epoxy resin and the applied polymer modifiers, may be due to the creation of the structure of interpenetrating polymer networks (IPN) with increased strength. To confirm this thesis and to examine the chemical composition of the obtained compositions, their infrared (FTIR) spectrum was created. Comparing the FTIR spectrum of the compositions containing polymeric modifiers with an unmodified epoxy resin spectrum is shown in Fig. 1.

Table 1. The properties of epoxy resin composition with polymer modifiers (IPN)

No.	Composition symbol	Impact resistance [kJ/m2]	Stress [MPa]	Strain
	Unmodified Epidian 5 resin			
1	EPZ/0/0	1.4	53	0.020
	Epidian 5 – polymer modifier – Polimal 109			
2	EPZ/P109/5	1.3	89	0.033
3	EPZ/P109/10	2.7	93	0.037
4	EPZ/P109/15	1.8	98	0.033
	Epidian 5 – polymer modifier: Desmocap 12			
5	EPZ/D12/5	2.4	70	0.030
6	EPZ/D12/10	2.9	74	0.034
7	EPZ/D12/15	4.0	63	0.035
	Epidian 5 – polymer modifier, Polimal 150			
8	EPZ/P150/5	2.8	116	0.037
9	EPZ/P150/10	3.3	66	0.031
10	EPZ/P150/15	3.2	98	0.032

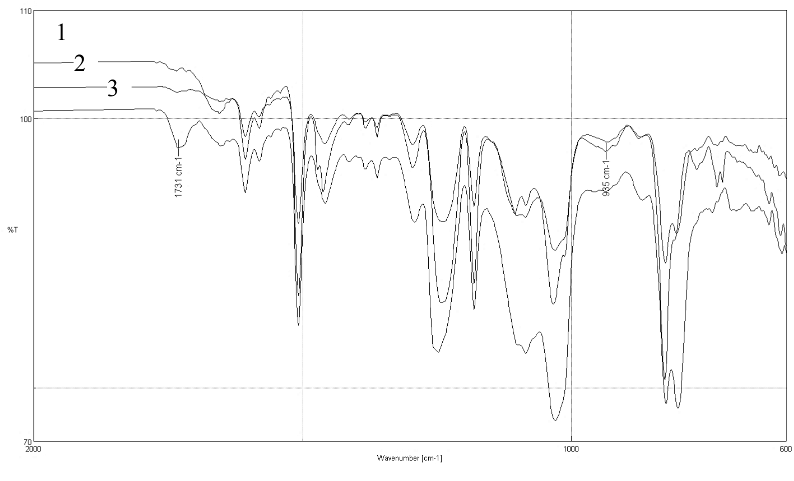

Fig. 1. FTIR spectra of epoxy resin (1), composition containing Desmokap 12 (2) and Polimal 109 (3)

Based on the FTIR spectra, it cannot be unequivocally concluded whether there are chemical reactions between the introduced modifiers and a matrix of epoxy resin. The comparable intensity of the peak characteristic for epoxy groups (935 cm^{-1}) for resin with Desmocap 12 and unmodified resin indicates that it does not affect the cross-linking process, and the composition is a mixture of polymers with interpenetrating spatial networks without inter-network bonds. The lower intensity of the band for the epoxy group with the composition of Polimal (characteristic peaks for ester groups 1730 cm^{-1}) may be a confirmation of the creation of the IPN structure with cross-network bindings. Having adopted as criteria an improvement in resistance to dynamic impact, an increase in flexibility, larger contraction of polyester resins, and no need to use two types of curing agents and the accelerator, the epoxy composite polyurethane resin was selected as the matrix modified with Desmocap 12 in the amount of 10%. Above this value, there is a decrease in bending stress and a significant increase in viscosity of the composition, which prevented the introduction of optimum quantity of metallic fillers and solid lubricants during the process of developing a regenerative polymer composite.

3. Developing a polymer composite

The possibility of using polymer composite as regenerative materials is determined by appropriate strength, thermal, and tribological parameters, which depend on the fillers with a significant quantitative participation in the mass of the manufactured composite. Since the composite is designed to regenerate steel machinery, iron powders were selected with a specific chemical composition and granule size: iron Fe (type NC 100.24), Fe-Mn alloy, and Fe iron (type MT-212). Based on the images from electron microscope scanning (Fig. 2), it can be observed that they are diverse in terms of geometry. They are mostly irregular polyhedral shapes, showing differences in the size of the total contact surface of the filler with the polymer matrix, which can significantly affect the resultant effect of the mechanical strength of the final-result composite.

As a lubricant for reducing motion resistance and wear, flake graphite M15-99 has been used, and its microscopic image is presented in Figure 2d. The primary fibre filler for the composite is organic polyaramid fibre (Kevlar pulp type 1F651) shown in Fig. 2e.

Preliminary tests, experiments, and publication data formed the basis for setting the weight participation for basic metallic fillers at 300 parts by weight (pbw), for polyaramid fibres at 2 pbw, and lubricant additives at 10 pbw, for 100 parts by weight of the modified epoxy matrix. The production the composites consisted in exact mixing of the liquid matrix the fillers using a laboratory Z homogeniser. Since these composites are intended for regeneration layers in friction connections, it was necessary to examine other strength properties such as hardness, compressive strength affecting wear, pressure limits transferred in the friction node, and a very important parameter – the peel strength, which indirectly indicates layer adhesion of the regenerating polymer composite to metal substrate. These properties were studied based on the norms for plastics (PN-EN ISO 2039-1: 2004, PN-EN ISO 179-1: 2004, PN-EN ISO 604: 2004).

Table 2 shows the influence of metallic fillers on mechanical properties of regenerating polymeric composites.

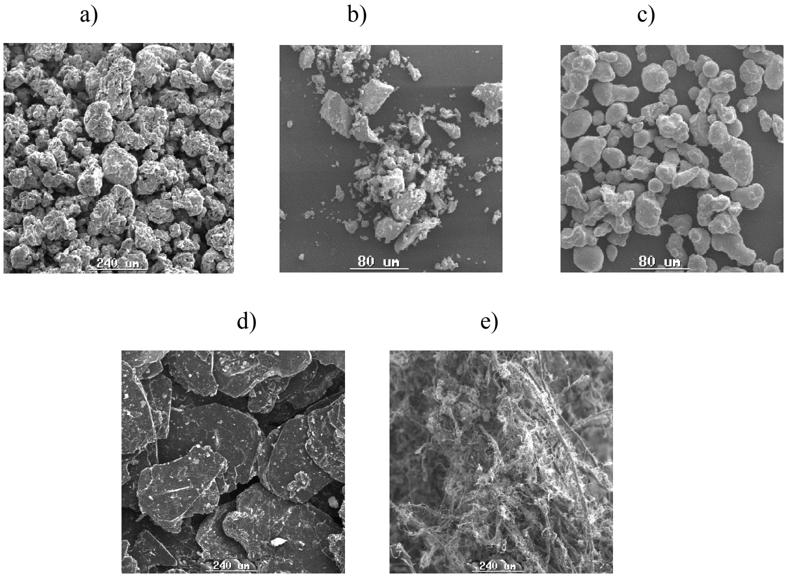

Fig. 2. Microscopic images of polymer composite fillers: a) iron powder Fe NC 100.24, b) powder iron-manganese Fe-Mn, c) iron powder Mt 212, d) graphite, e) aramid fibres

Table 2. Strength properties of polymeric composites

Type of metallic filler	Impact strength [kJ/m^2]	Stress [MPa]	Strain	Hardness [MPa]	Compressive strength [MPa]	Peel strength [MPa]
Iron powder NC 100.24	4.2	78.6	0.022	254	105	19.2
Iron powder MT 212	3.1	62.2	0.016	222	89	18.4
Iron-manganese powder	3.2	63.5	0.016	239	100	22.0

The data presented in Table 2 indicates that the type of the applied metallic filler affects mechanical properties of composites. This effect is caused by filler morphology and its surface properties. The best results were obtained for the composite with iron powder NC 100.24, which it is characterized by the highest hardness, resistance to dynamic impact, high resistance to compression, and adhesion to a steel substrate. A comparison of microscopic images of fillers indicates that iron powder NC 100.24 has more irregular shapes and thus provides greater surface area than the other fillers. This makes it easier to dampen the filler with the liquid matrix, and it increases the adhesion effects between the matrix and the filler.

Apart from mechanical properties, the key properties of polymer composites that determine their applicability in regeneration of worn machine components as a result of friction are tribological properties. The composite selected for the wear and friction in depth testing was the composite with a modified epoxy resin matrix and with metallic iron powder filler – NC 100.24. To determine the tribological characteristics, the T-05 tester was used with roll--and-block in staggered contact. A model friction node of this device is a representation of a sliding bearing. Figure 3 shows an example of a temperature change process and a friction coefficient of composite contact: polymer – bearing alloy (bronze).

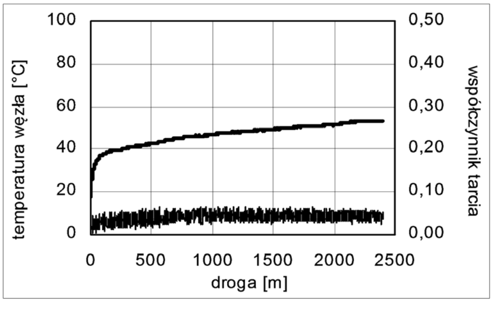

Fig. 3. An example of temperature change process and the friction coefficient of the polymer – bearing alloy (p = 3 MPa, v = 0.3 m/s) contact

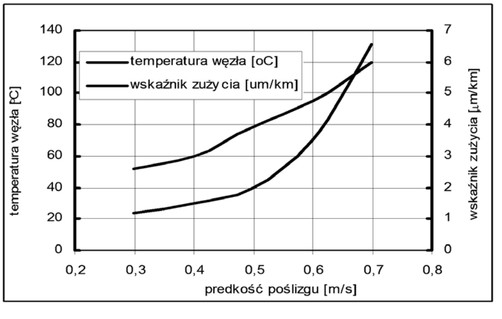

Fig. 4. The relationship between wear indicator and the temperature of the node on the one hand, and the sliding velocity on the other, for the composite – bearing alloy contact, for pressure 3 MPa

The obtained results in the friction coefficient and temperature changes in the friction node for the polymer composite-bronze contact show a monotonic process throughout the entire range of the friction path. This shows stable friction cooperation and a low motion resistance in the developed polymer composite with the bearing alloy. Figure 4 shows the influence of rubbing velocity on the wear and the temperature indicator of the polymer composite-bronze contact. This indicates that with a rubbing velocity of up to 0.5 m/s, the wear indicator changes are small. A noticeable increase of this parameter can be observed for velocities above 0.5 m/s, and the increase of rubbing velocity by about 0.2 m/s doubles the increase of this parameter. It is related to a significant increase in the temperature in the contact area and the thermal destruction of the polymer composite.

4. Examples of applications

Due to the ease of forming and coating the surfaces of different configurations, high strength characteristics and adhesion to metal substrates, the specialised polymeric composites have been used in many technical applications. They are used, for example, for the regeneration of the roller bearing pins and slide bearing pins (Fig. 5a) while maintaining certain restrictions on the values of load and rubbing velocity.

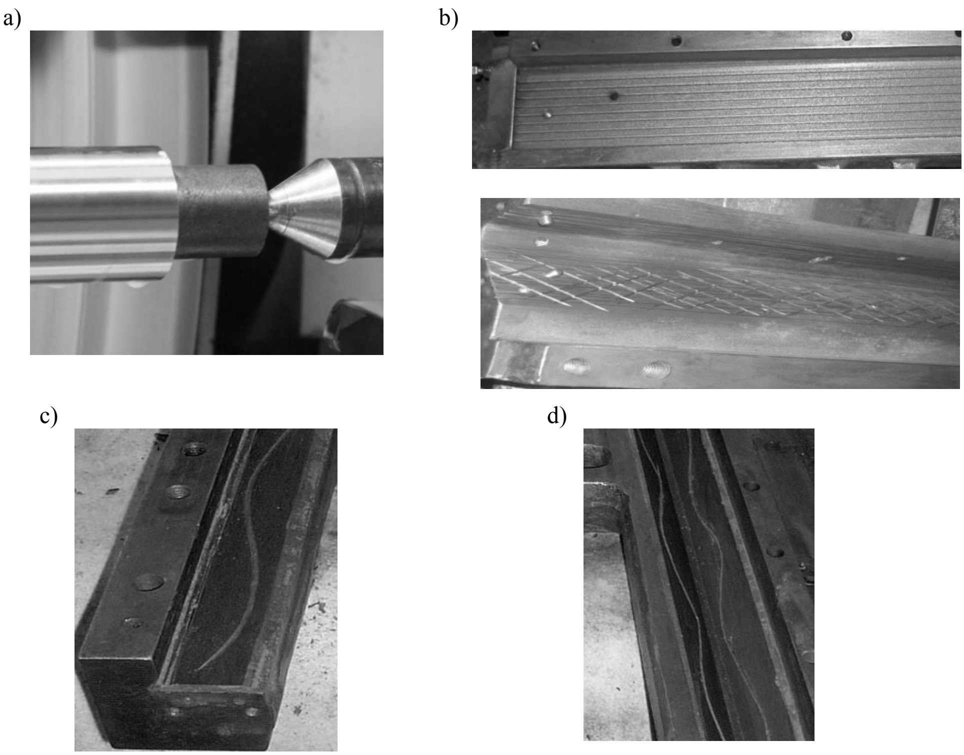

Fig. 5. Finishing machining slide bearing pin (a), machine tool guide with lengthwise and crosswise scoring prepared for regeneration of (b), composite polymer regenerated flat guides (c), triangular guides (d) with lubrication grooves

Due to a lower static friction coefficient in comparison to steel and a minimum tendency for the stick-slip effect (self-excited frictional oscillation), the composite-steel contact is widely used for the regeneration of guide systems for cutting machines (Figs. 5 b, c, d). A valuable advantage of this regeneration process is its uncomplicated technology, using an imaging method independent of the geometric accuracy of the guides. The final stage of the regeneration process is making lubrication grooves.

Summary

The interpenetrating polymer networks (IPN) composed of two polymers – epoxy resin and polyurethane – used as a matrix have made it possible to create a specialized polymer composite with satisfactory performance parameters. This polymer composite may act as a surface layer for different types of friction contacts. It is characterized by good mechanical, heat, and tribological properties. The universal properties of the specialised polymer composite are such that it can be used to regenerate not only the lubrication elements of slide bearings, but also used in friction contacts of different materials working in the conditions of boundary friction (machine tool guides). Moreover, another positive feature of this method is the ease of the process of regeneration and the possibility to carry it out without the need for a complicated and energy-consuming apparatus, as is the case in galvanising or welding.

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Specjalistyczne kompozyty polimerowe przeznaczone do regeneracji elementów maszyn

Słowa kluczowe

Żywica epoksydowa, poliuretan, przenikające sieci polimerowe, kompozyty polimerowe, regeneracja, właściwości mechaniczne, zużycie, współczynnik tarcia, układy prowadnicowe obrabiarek.

Streszczenie

Współczesne urządzenia i maszyny przemysłowe charakteryzują się zaawansowaną konstrukcją, która pozwala na realizację skomplikowanych procesów wytwórczych. Złożoność konstrukcyjna maszyn powoduje wysokie koszty wymiany zużytych elementów, jednak w wielu przypadkach ich stan pozwala na regenerację z wykorzystaniem nowoczesnych materiałów kompozytowych gwarantujących uzyskanie odpowiednich parametrów użytkowych zregenerowanego elementu. W artykule przedstawiono wyniki prac nad opracowaniem specjalnych chemoutwardzalnych kompozytów polimerowych przeznaczonych do regeneracji elementów maszyn i urządzeń. Osnowę kompozytów stanowiła modyfikowana żywica epoksydowa. Jako modyfikatory polimeryczne zastosowano żywice poliestrowe oraz poliuretan, które tworzą z osnową epoksydową przenikające sieci polimerowe (IPN – *Interpenetrating Polymer Network*). Podstawowymi napełniaczami kompozytów były proszki metaliczne o określonym składzie chemicznym i granulometrycznym oraz smary stałe o spójności anizotropowej. Zbadano właściwości eksploatacyjne opracowanych kompozytów z wykorzystaniem nowoczesnej aparatury badawczej. Opracowane kompozyty polimerowe zastosowano do regeneracji warstw wierzchnich zużytych elementów. Stwierdzono, że gwarantują one uzyskanie odpowiednich właściwości użytkowych zregenerowanych elementów. Omówiono przykładowe aplikacje.