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The Influence of Mineral Fillers on Mechanical Properties of Polyvinyl Chloride Composites

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Abstract: The paper reports the investigation results of tensile stress-strain properties of filled PVC composite during static and low cycle testing. The distinctive features of composite mechanical behavior depending on the content of dispersed mineral fillers which are basically industrial waste are established. It is revealed that small filler additives have a strong influence on the structural behavior that manifest itself as their abnormal change depending on the filler content. The experimental data obtained are explained based on the modern ideas about structural morphological model of base polymer structure.

Key words: Polyvinyl chloride · Fillers · Composites · Mechanical properties

INTRODUCTION

The advances in the field of development of polyvinyl chloride (PVC) composites with better mechanical properties broadens their application in modern technology to manufacture structural products. Today PVC composites provide 70% of structural plastic market [1]. The most efficient and simple method to improve the mechanical properties of PVC materials is to modify them by incorporating the different target additives, including fillers, into their content. That's why, during development of PVC composites it is important to find the available and cheap fillers among which waste products are of the greatest interest [2]. The purpose of this paper is to study the influence of mineral fillers on tensile stress-strain properties of rigid PVC composites during static and low cycle testing.

Main Part: The investigation object was PVC suspension of PVKh-C7059-7058M grade which was stabilized with the mixture of calcium stearate and dibasic lead silicate (3 mass fractions per 100 mass fractions of polymer). The mineral fillers were chalk of MMC-2 grade and investment casting waste products (ICWP). ICWP consists, mainly, of refractory electrolytically produced corundum, hydrolyzed ethyl silicate solution as binder, quartz sand as dusting. The filler content in the composites was changed from 1 to 30 mass fractions. The chalk was used as delivered without additional dispersion, filler particle size was maximum 2 μm. ICWP was first subjected to mechanical milling followed by final dispersion with planetary mill Activator-2SL, dispersion time varied from two to five hours. The particle size distribution was determined using laser analyzer Analizette-22. ICWP particle size varied from 20 to 5 μm depending on milling time. PVC composites were made by mixing specific combinations and ratios of polymer, stabilizers and fillers in the laboratory blender. Then the mixtures were heat softened in the friction mills in the optimum temperature-time conditions depending on the composite content.

In order to determine the tensile stress-strain properties of composites the specimens were tested in Shimadzu universal multifunctional testing machine AGS-X. The static tests were made on the standard spatula-like specimens cut out of the films at speed of stretching 50 mm/min. During testing the tensile strength and elongation modulus were automatically recorded. The low cycle testing was made on the spatula-like specimens at different tensions and travel speed of gripping device 50 mm/min. The loads for low cycle testing were chosen with regard to the static testing results of the composites. For the first low cycle test each composite got the coefficient 0.8 of tensile strength obtained from static testing.

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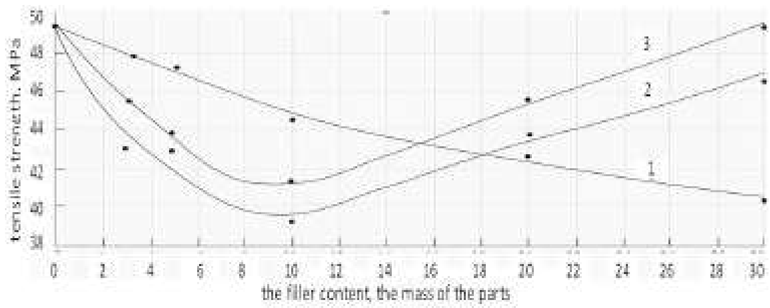

Fig. 1: The plot of the composite strength limit versus chalk (plot 1) and ICWP (plots 2 and 3) content. ICWP milling time is 2 and 5 hours respectively.

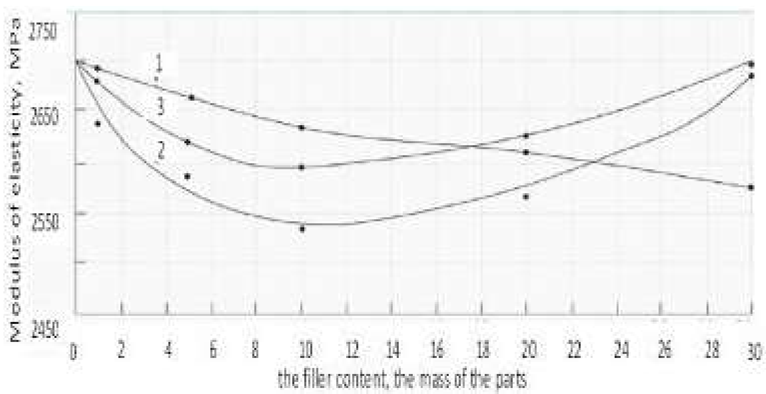

Fig. 2: The plot of the composite elongation modulus versus chalk (plot 1) and ICWP (plots 2 and 3) content. ICWP milling time is 2 and 5 hours respectively. C

For subsequent low cycle tests each composite got the coefficient higher or lower than 0.8 depending on the durability value obtained during the testing of the first specimen.

Figures 1 and 2 show the plots of the tensile strength and elongation modulus of the investigated composites versus mineral filler content. It is seen that the tensile strength and elongation modulus decrease monotonously in the composites filled with PVC-inert chalk through all the range of its content (plot 1). In the ICWP-filled composites (plots 2 and 3) the extreme nature of tensile stress-strain change is observed as the concentration increases. The decrease in strength and elongation modulus is observed in the area of comparatively small filler content (up to 10-15 mass fractions) and as the additive concentration further increases the opposite effect is observed: strength and modulus increase. Besides, for the ICWP-filled composites as the milling time increases, i.e. particle size decreases from 20 to 5 Mm, the nature of tensile stress-strain behavior does not change, only the absolute values change. As the particle fineness increases (plots 3) the increase in the composite strength and elongation modulus is observed through all the range of ICWP content. Moreover, if the content exceeds 20 mass fractions the tensile stress-strain properties of ICWP-filled composites are much better than those of the composites filled with inert chalk.

According to the modern ideas about structural morphological model of PVC structure the polymer supermolecular structure consists of spherical features and their fragments interconnected by passing chains. One of the determining factors having a great impact on the properties, including tensile stress-strain ones, of filled systems is boundary layers formed during the adsorption of polymer macromolecules on the filler surface. Herewith, the properties of filled composites change significantly in comparison to the properties of original polymer as a consequence of molecular interaction and structure transformations in the interface: polymer – filler [3-5].

The tensile stress-strain behavior of the investigated composites can be explained using the concept about the core role maintained in the melt of PVC structurally nonuniform microheterogeneous globular structure and the effects appeared on the component interface. During stretching of the specimens the globular textural features interconnected by passing chains slide interdependently in PVC structure.

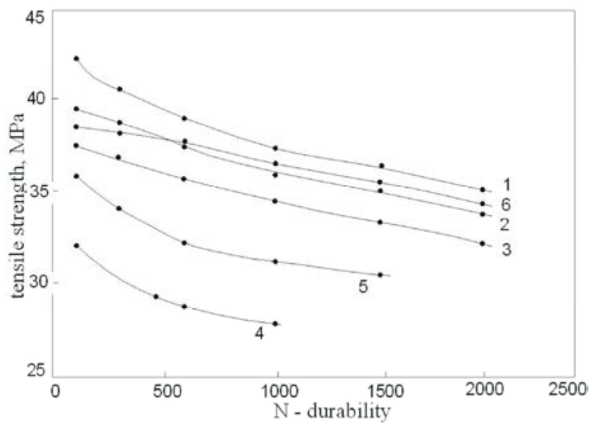

Fig. 3: The plot of fatigue strength of PVC composites versus ICWP content. Plots 1, 2, 3, 4, 5, 6 correspond to the composites with content 0, 3, 5, 10, 20, 30 mass fractions of filler.

Moreover, sliding is followed by bond breaking, mostly, in the globular boundaries and increase in their mobility that leads to natural decrease in tensile stress-strain properties. Decrease in tensile stress-strain properties of composites filled with PVC-inert chalk seems to be the consequence of reduction of the distances between filler particles, overlapping of the interfacial areas due to the squeezing effects which have difficulties in sliding interdependently in the direction of external force impact along the matrix interlayers.

The increase in composite strength with large ICWP content can be also explained using the above mentioned ideas about PVC structure taking into account the adsorption interaction between the components included in the composite, i.e. taking into account the criterion of phase linking. The incorporation of the comparatively large amount of filler in the form of ICWP leads to increase in adsorption interaction due to increase of contact surfaces of dispersion medium and dispersed phase. Herewith, the filler particles (dispersed phase) form the additional cross-links leading to increase in the composite tensile stress-strain properties which corresponds to modern theory of strengthening of particle filled polymer composites [6-9].

The experience in application of composite products is a reason to study the degradation processes not only under static loads but also under cycle loads. It is known that the specific character of fatigue failure of particle filled polymer composites is related, mainly, to relaxation, self-heating and interaction of minidestructions. The progress of these processes depends, mainly, on the state of composite structure which has as one of the main characteristics the filler loading capacity which at the same time serves as a criterion of material cost effectiveness evaluation [5, 10].

Figure 3 show the results of low cycle testing of filled PVC composites. According to the analysis of the experimental data, as ICWP content increases as during static testing the extreme nature of fatigue strength change is observed. When the filler loading capacity is comparatively small (up to 10 mass fractions) the fatigue strength decreases in comparison with that of non-filled polymer and for the composites filled with 20 and 30 mass fractions of filler the increase in this characteristic is observed.

Using the experimental data obtained the conclusion can be made that in case of the same durability the composites with comparatively small filler content (10 mass fractions) are recommended for products used at medium loads; and the composites with maximum filler content (20-30 mass fractions)-for products used at higher loads.

CONCLUSION

As a result, the established concentration dependencies of tensile stress-strain properties of filled PVC composites make it possible to choose the effective compositions to manufacture structural parts.

Summary: The results of static and cyclic testing made it possible to identify the distinctive features of tensile stress-strain behavior of filled PVC composites. The identified distinctive features of tensile stress-strain behavior are explained using the modern ideas of structural-morphological model of PVC structure and effects appeared on the interface: polymer-filler.

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