Influence of Constant Magnetic Fields on Formation of Polymer Surface Layers in Polymer Matrix Microcomposites

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Abstract

The goal of this work is to find out what interface phenomena give rise to improvement of mechanical properties of Polyvinyl chloride (PVC) composite materials filled with ferrite microparticles. This improvement is reached at sufficiently high filler concentrations through influencing the formation of these microcomposites by constant magnetic fields (CMFs). To overcome the constraint due to the limited performance of modern computers, a computational abstraction is proposed that allows handling the chaotic disposition of the filler particles during calculation of magnetic fields in polymer surface layers of microcomposites near phase transition points. Integrated analysis of laboratory measurements and results of numerical calculations is used as a research tool. On the basis of this analysis, it is argued that magnetic fields improve mechanical properties of the microcomposites at sufficiently high filler concentrations due to the fact that PVC macromolecules situated in the polymer surface layers of these microcomposites are pushed out of regions of high magnetic filed intensity.

Keywords — Composite materials, computational abstraction, Cyber-Physical System, interface phenomena, magnetic particles, phase transition.

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I. INTRODUCTION

The draughts game can not be analyzed in full details due to the limited performance of modern computers. However, there are programs fairly good at this game\(^1\). They are created in the framework of computational thinking. Its essential is generalization of notions. This generalization omits peculiarities of spatial dimensions and durations in time related to the notions. For example, the abstraction of an algorithm is not supposed to produce the desired output within a finite modern processor time frame\(^2\). As for real life problems, analyzing them numerically often assumes parallel computing and is hindered by various scale effects induced by a choice of boundary conditions. These effects become extremely important near phase transition points\(^3\). Hence, computational research needs new methodologies. One of them is a Cyber-Physical System (CPS). In a CPS, computing experiences the lack of resources and is integrated with physical processes. Finding new computational abstractions is important for development of this emerging field\(^4\). For instance, studies of polymer matrix composites (PMCs) filled with magnetic microparticles and synthesized under influence of magnetic fields near phase transitions are limited only to experimental ones\(^5, 6\) due to the chaotic disposition of filler particles in the microcomposite of this type. Therefore, there is only empirical knowledge about these materials. In this work, we present the computational abstraction that allows conducting integrated analysis of numerical modeling of these composites and respective laboratory measurements to understand the physics of the phenomena of the phase transition type observed in the experimental studies\(^5, 6\).

Section 2 explains the value of this research and formulates its goal. In Section 3, we substantiate our models of calculation of magnetic fields in surface layers of polymer composites filled with magnetic microparticles. Section 4 presents solutions of these models. Section 5 is devoted to the integrated analysis of the laboratory measurements\(^5\) and respective numerical calculations. Section 6 contains a brief summary and suggests directions for further research.

II. VALUE OF THIS RESEARCH

Creation of new construction materials stimulates the technical progress. Specifically, viability of new electric devices largely depends on characteristics of magnetic materials they are partially made of\(^7, 8\). Since traditional magnetic substances are fragile, require significant processing efforts, and have high densities; devices containing these materials become cost drivers and bring highly undesirable excessive weight in a bunch of important applications\(^9\). Synthesis of new organic magnets\(^10-14\) can partially satisfy the
need in light magnetic materials. However, their industrial mastering requires significant expenditures\textsuperscript{15}. A material with needed magnetic properties can be obtained through filling a polymer with magnetic microparticles\textsuperscript{9, 16, 17}. Hence, it is much more beneficial to satisfy the above mentioned need with composites containing industrially mastered polymers.

To reach desired magnetic properties of the composite, one often has to increase the filler concentration significantly\textsuperscript{18-28}. Unfortunately, it can cause notable deterioration of mechanical properties of the material\textsuperscript{16, 17, 29}. However, these properties of the microcomposite can be improved through influencing its formation by a constant magnetic field (CMF) if the filler concentration is higher than the one at which the phase transition occurs\textsuperscript{5}. Since properties of polymer matrix composites with fine powder fillers are determined to the great extent by physical and chemical changes of the polymers situated in their polymer surface layers\textsuperscript{15}, it can be explained by the following. Polymer macromolecules are oriented in a CMF. The greater the value of $H^2$ is, the more oriented the macromolecules are. Besides, if the CMF is non-uniform, then they are pushed out of the regions of high values of $H^2$ with the force that is proportional to the value of $H \cdot |\nabla H|$. Thermal motion of these macromolecules opposes both these effects. For macromolecules a polymer matrix composed of, both these effects can be neglected at the temperature of the polymer melting and values of the magnetic field that can be achieved under laboratory conditions\textsuperscript{30}. However, in a polymer surface layer of the composite the interaction of a macromolecule with the magnetic field is influenced not only by the temperature field but also by the aggregative absorption mechanism\textsuperscript{15}. It gives the opportunity to regulate properties of a PMC through influencing the formation of its surface layer structure by a CMF. To figure out which one of two above mentioned interface phenomena causes the improvement of mechanical properties of the polymer matrix microcomposite with sufficiently high concentration of magnetic particles and synthesized under influence of a CMF, one has to know how to calculate the magnetic field in a polymer surface layer of such the PMC near the phase transition. Although the mathematical model of calculation of a magnetic field in the PMC of this type that is valid near the phase transition is presented in the recent research\textsuperscript{5}, it was not determined in the paper\textsuperscript{5} whether the improvement of mechanical properties of the polyvinyl chloride (PVC) composite with sufficiently high concentration of the Fe$_3$O$_4$ fine powder and formed under the influence of the external CMF was caused by the orientation of polymer macromolecules of the surface layers or by their pushing out of regions of high values of $H^2$. The goal of this work is to show that the improvement of mechanical properties of the PMCs with sufficiently high magnetic filler concentrations reached through influencing their formation by CMFs\textsuperscript{5} can be explained by the second effect.

### III. Choice of Models of Calculation of the Magnetic Field in a Surface Layer of the Microcomposite

In the recent research\textsuperscript{7}, to prepare PMCs, PVC was mixed with Fe$_3$O$_4$ fine powder. The mixture was exposed to pressure and temperature as high as respectively 10 MPa and 420 K and to the external magnetic field so strong that all powder particles were in the state of the magnetic saturation. Taylor’s theorem allows us to suppose that calculating the magnetic field in the vicinity of the filler particle situated in the PMC we can neglect the influence of the other Fe$_3$O$_4$ particles. Therefore, in the model \# 1 the calculation is performed for a single spherical Fe$_3$O$_4$ particle with the uniform magnetization density $\mathbf{M}$ placed in the external CMF $\mathbf{H}_{ex}$ (see Fig. 1). However, the size of the surface layer can turn out to be large enough for the other filler particles to influence the magnetic field inside of it significantly. In this case, this problem can not be solved precisely due to randomness of filler particle disposition in a PMC. Therefore, it can be referred to the class of artificial intelligence problems and should be solved using simplifying assumptions. In the recent research\textsuperscript{7}, PMC samples were prepared in the form of cylinders with their diameters equal to $2.5 \cdot 10^{-2}$ m and their heights equal to $5 \cdot 10^{-3}$ m. Since the sample height is 5 times smaller than its diameter, in the model \# 2 the boundary effects are neglected and it is assumed that the Fe$_3$O$_4$ particles create the quasi lattice in the 3-dimensional space as shown on Fig. 2. Calculations according to the model \# 3 are performed to estimate the error of magnetic field calculation according to the model \# 2 that arises due to the substitution of the disposition of filler particles shown on Fig. 2 for the chaotic disposition of filler particles in the PMC in the framework of the model \# 2. Therefore, the filler particle disposition in the model \# 3 is the quasi lattice that can be obtained from the quasi lattice of the model \# 2 through shifting filler particle layers denoted on Fig. 2 by numbers $4 \cdot p - 1$ where $p = 1, \bar{p}$, $\bar{p} = q/2$ if $q$ is even and $\bar{p} = (q-1)/2$ if $q$ is odd (here and below $q$ is the number of horizontal filler particle layers in the quasi lattice of the model \# 2) at the distance equal to the half of the lattice period in the direction of the $x$-axis with subsequent shifting them at the same distance in the direction of the $y$-axis. Such the assumptions about dispositions of filler particles allow applying Fourier’s method to the calculation of the magnetic field in the frameworks of the models \# 2 and \# 3. Since the quasi lattices in these models are different, their periods can be different too if the total mass of the filler in the sample is fixed. Therefore, in what follows $D$ and $\bar{D}$ denote periods of the quasi lattices in the models \# 2 and \# 3 respectively. If all filler particles have a cubical shape, $h$ is the height of the sample and $l$ is the length of the edge of the filler particle; then from Fig. 2 it follows that the numbers of horizontal filler particle layers in the quasi lattices of the models \# 2 and \# 3 are equal to $(h-l)/D+1$ and $(h-l)/\bar{D}+1$ respectively. The quasi lattices of the models \# 2 and \# 3 can be
viewed as sets of cells that are periodically situated in the part of a space bounded by two planes that contain respectively the top base and the bottom one of the sample with the same periods in the directions of the x-, y- and z-axes that are equal to $D$ and $\tilde{D}$ respectively. From Fig. 2, it follows that the volumes of the smallest cells of this type in these quasi lattices are equal to $D^3$ and $2 \cdot \tilde{D}^3$ respectively. In the case of the quasi lattice of the model # 2 and in the case of the quasi lattice of the model # 3, positioning all such the cells along one line does not change the volume of the part of the space they occupy. Therefore, if $V_o$ is the volume of the sample and $N_o$ is the number of magnetic particles in the microcomposite, the periods of these quasi lattices are given by such the expressions: $D = \sqrt[3]{4 \cdot V_o / N_o}$, $\tilde{D} = \sqrt[3]{8 \cdot V_o / 2 / N_o}$. To be able to compare results of calculations in the frameworks of the models # 2 and # 3 with respective results of calculations in the framework of the model # 1, we assume that the volume of the filler particle in the model # 1 is equal to the volume of the filler particle in each one of the models # 2 and # 3. Thus, $R = \sqrt[3]{3 / 4 / \pi \cdot 1}$, see Figs. 1 and 2.

Fig. 1. Set up of the model # 1.

Fig. 2. Filler particle disposition assumed in the model # 2.

### IV. SOLUTIONS OF THE MODEL PROBLEMS

The solution of the model # 2 can be found in the reference\(^a\). As it is known, magnetization density of a medium $\vec{M}$ is related with magnetic field inductance $\vec{B}$ and magnetic field intensity $\vec{H}$ by the following expression

$$\vec{M} = \vec{B} / \mu_0 - \vec{M}$$

(1)

where $\mu_0$ is the permeability of vacuum. Since PVC magnetic properties are much weaker than those of the ferrite filler, we assume that the magnetic particle in the framework of the model # 1 and the ones in the framework of the model # 3 are situated in a medium with $\vec{M}$ equal to the vector which all components equal 0. In the model # 1, the entire space is divided into two domains. The domain # 1 is composed of all the outer points of the magnetic particle, and the domain # 2 is composed of all the inner points of this particle. Therefore, all components of the vector of a magnetization density are equal to zero in the domain # 1, and in the domain # 2 this vector is equal to $(0,0,\vec{M})$ where here and below $\vec{M}$ is the density of the magnetization of the magnetic particle. In its turn, in the model # 3 the entire space is divided into $2 \cdot \tilde{q} + 1$ domains where here and below $\tilde{q}$ is the number of horizontal filler particle layers in the quasi lattice of the model # 3 (see Fig. 2).

Specifically, the domains # 0 and # $2 \cdot \tilde{q}$ are composed of all the points which z-coordinates satisfy respectively $z < 0$ and $z > (\tilde{q} - 1) \cdot \tilde{D} + l$; the domain # $2 \cdot k$ where $k = 1, \tilde{q} - 1$ is composed of all the points which z-coordinates satisfy $l + (k - 1) \cdot \tilde{D} < z < k \cdot \tilde{D}$, and the domain # $2 \cdot k - 1$ where $k = 1, \tilde{q}$ is composed of all the points which z-coordinates satisfy $(k - 1) \cdot \tilde{D} < z < (k - 1) \cdot \tilde{D} + l$. The magnetization density vector is equal to the zero one in the domains with even numbers and equals $(0,0,M_{2k-1}(x,y))$ in the domain # $2 \cdot k - 1$ where $k = 1, \tilde{q}$ and $M_{2k-1}(x,y)$ is a step function that equals $\vec{M}$ which is the absolute value of a filler particle magnetization density in this domain if $(x,y)$ corresponds to the inner point of the filler particle in this domain and equals zero otherwise. Since free currents are absent, from Maxwell’s equations it follows that $\text{curl} \, \vec{H} = \vec{0}$ at any point in the domain # $j$ where $j = 1, 2$ in the model # 1 and $j = 0, 2 \cdot \tilde{q}$ in the model # 3. Therefore, according to the known theorem of mathematical calculus, there are functions $\varphi_j$ and $\psi_s$ that satisfy $\vec{H}_{j,1} = -\nabla \varphi_j$ and $\vec{H}_{s,2} = -\nabla \psi_s$ where $j = 1, 2$; $s = 0, 2 \cdot \tilde{q}$; $\vec{H}_{j,1}$ denotes the vector of magnetic field intensity calculated in the framework of the model # 1 in the domain # $j$, and $\vec{H}_{s,2}$ denotes the vector of the magnetic field intensity calculated in the framework of the model # 2 in the domain # $s$.

From Maxwell’s equations, it follows that the functions $\varphi_j$ and $\psi_s$ where $j = 1, 2$ and $s = 0, 2 \cdot \tilde{q}$ satisfy equations $\Delta \varphi_j = 0$ and
and $\Delta \psi_j = 0$ in the respective domains. From (1) and the definitions of functions $\psi_1$ and $\psi_2$, it follows that the condition of the magnetic field induction normal component continuity on the boundary $r = R$ where here and below $r = \sqrt{x^2 + y^2 + z^2}$ that in the model # 1 separates the domain # 1 from the domain # 2 results in

$$- \partial \psi_1 / \partial r = - \partial \psi_2 / \partial r + M \cdot \cos \theta$$

where here and below $\theta$ is the angle between the radius vector of the point $(x, y, z)$ and the $z$-axis. Similarly, this condition on the boundaries $z = (k-1) \cdot \hat{D}$ and $z = l + (k-1) \cdot \hat{D}$ that in the model # 3 separate respectively the domain # 2 $\cdot k - 1$ from the domain # 2 $\cdot k - 1$ and the domain # 2 $\cdot k - 1$ from the domain # 2 $\cdot k$ results in

$$- \partial \psi_{2k-1} / \partial z = - \partial \psi_{2k+1} / \partial z + M_{2k-1} (x, y),$$

$$- \partial \psi_{2k} / \partial z = - \partial \psi_{2k+2} / \partial z + M_{2k+1} (x, y),$$

where $k = \overline{1,2}$. The condition of the magnetic field intensity tangential component continuity on these boundaries respectively results in

$$- \partial \psi_{2k-1} / \partial \theta = - \partial \psi_{2k} / \partial \theta,$$

$$\partial \psi_{2k+2} / \partial \theta = \partial \psi_{2k+1} / \partial \theta,$$

$$\partial \psi_{2k} / \partial \theta = \partial \psi_{2k+1} / \partial \theta,$$

These conditions should be supplemented with the following ones:

$$\check{\psi}_{\psi_1} \big|_{r=\infty} = \check{\psi}_{\psi_2} \big|_{r=\infty} = 0,$$

$$\check{\psi}_{\psi_0} \big|_{z=\infty} = \check{\psi}_{\psi_0} \big|_{z=\infty} = 0.$$

It should be noted that in the models # 1 and # 3 $\hat{H}_0$ is directed along the $x$- and $y$-axes, we look for the solution of the model # 3 in the form

$$\psi_j (x, y, z) = -H_{ny} \cdot z +$$

$$+ \sum_{l,n=0}^{\infty} \left( \tilde{\psi}_{j,l,0,m} (z) + \bar{\psi}_{j,l,0,m} (z) \right) e^{i \frac{2 \pi q (nx + my)}{D}}$$

where $j = 0, 2 \cdot \hat{q}$, $i$ is the complex unity, the primed summation symbol indicates that in the summation the addend that corresponds to $n = 0$ and $m = 0$ is omitted. As for the functions $\tilde{\psi}_{j,l,0,m} (z)$ present in (12), we look for them in the form

$$\psi_{j,l,4,q(m,n)} (z) = \psi_{j,l,4,q(m,n)} e^{\frac{2 \pi q (nx + my)}{D}}$$

$$\psi_{j,l,3,q(m,n)} (z) = \psi_{j,l,3,q(m,n)} e^{\frac{2 \pi q (nx + my)}{D}}$$

$$\psi_{j,l,2,q(m,n)} (z) = \psi_{j,l,2,q(m,n)} e^{\frac{2 \pi q (nx + my)}{D}}$$

$$\psi_{j,l,1,q(m,n)} (z) = \psi_{j,l,1,q(m,n)} e^{\frac{2 \pi q (nx + my)}{D}}$$

where $p_i = \overline{1, p_1}$, $p_2 = \overline{1, p_2}$, $p_3 = \overline{1, p_3}$, $p_i = \overline{1, p_i}$, $\tilde{p}_1 = (\tilde{q} + 2) / 2$, $\tilde{p}_2 = \tilde{p}_3 = \tilde{q} / 2$ if $\tilde{q}$ is even; and $\tilde{p}_1 = \tilde{p}_2 = \tilde{p}_3 = (\tilde{q} + 1) / 2$, $\tilde{p}_i = (\tilde{q} - 1) / 2$ if $\tilde{q}$ is odd. Substituting the right hand sides of (10), (11) for respectively $\psi_0$, $\psi_2$ in (2), (5) and solving for $B_{1}^{(3)}$, $A_{2}^{(3)}$ where $n$ is non-negative integer we get $A_{2}^{(3)} = B_{4}^{(3)} = 0$ where $k$ is a non-negative integer such that $k \neq 1$, $A_{2}^{(3)} = M/3$, and $B_{4}^{(3)} = R \cdot M/3$. Similarly, substituting the right hand side of (12) for $\psi_j$ in (3), (4), (6), and (7) and solving for $\psi_{j,l,0,m}$ where $j = 0, 2 \cdot \hat{q}$ we get

$$\psi_{0,l,0,m} = 0,$$

$$\psi_{3,l,0,m} = \psi_{3,l,0,m} - \frac{M^{(1)}}{4 \cdot \pi \sqrt{n^2 + m^2}},$$

$$\psi_{2,l,0,m} = \psi_{2,l,0,m} e^{-2 \pi (nx + my)/(D - \hat{D})} + \frac{M^{(1)}}{4 \cdot \pi \sqrt{n^2 + m^2}},$$

$$\psi_{2,l,0,m} = \psi_{2,l,0,m} - \frac{M^{(1)}}{4 \cdot \pi \sqrt{n^2 + m^2}},$$

$$\psi_{2,l,0,m} = \psi_{2,l,0,m} e^{-2 \pi (nx + my)/(D - \hat{D})} + \frac{M^{(2)}}{4 \cdot \pi \sqrt{n^2 + m^2}},$$

$$\psi_{2,l,0,m} = 0,$$

$$\psi_{2,l,0,m} = \psi_{2,l,0,m} e^{-2 \pi (nx + my)/(D - \hat{D})} + \frac{M^{(2)}}{4 \cdot \pi \sqrt{n^2 + m^2}},$$

$$\psi_{2,l,0,m} = 0.$$
\[ \Psi_{4k,3(n,m)}^+ = \Psi_{4k,2(m,0)}^+ e^{-2\left(\pi \Delta + m\right)^2} + \frac{M^{(1)}_{n,m} \cdot D \cdot e^{-2\pi^2 \Delta^2}}{4\pi \sqrt{n^2 + m^2}}, \]  
\[ \Psi_{4k,4(n,m)}^+ = \Psi_{4k,3(m,0)}^+ - \frac{M^{(1)}_{n,m} \cdot D \cdot e^{-2\pi^2 \Delta^2}}{4\pi \sqrt{n^2 + m^2}}, \]  

(24)  
(25)

where \( k_1 = 1, k_2 = 1, k_3 = k = \frac{\tilde{q}}{2} \) if \( \tilde{q} \) is even, and \( k_1 = (\tilde{q}+1)/2, k_2 = (\tilde{q}-1)/2 \) if \( \tilde{q} \) is odd.

\[ M^{(1)}_{n,m} = \begin{cases} 
\frac{e^{-2\pi^2 \Delta^2}}{4\pi \cdot n \cdot D} & \text{if } n \neq 0, \\
\frac{e^{-2\pi^2 \Delta^2}}{2\pi \cdot n \cdot D} & \text{if } n = 0, \\
\frac{e^{-2\pi^2 \Delta^2}}{2\pi \cdot m \cdot D} & \text{if } m \neq 0, \\
\frac{(\pi \cdot m \cdot l - \pi \cdot n \cdot l)}{\pi \cdot n \cdot m} & \text{if } n, m \neq 0, \\
\frac{(\pi \cdot m \cdot l - \pi \cdot n \cdot l)}{\pi \cdot n \cdot m} & \text{if } n \neq 0, \\
\frac{(\pi \cdot m \cdot l - \pi \cdot n \cdot l)}{\pi \cdot m \cdot n} & \text{if } m \neq 0. 
\end{cases} \]

(26)  
(27)  
(28)  
(29)  
(30)  
(31)

V. INTEGRATED ANALYSIS OF LABORATORY MEASUREMENTS AND NUMERICAL CALCULATIONS

The values of \( H \lVert H \rVert \) and \( H^2 \) at the point \( A \) chosen at the center of the surface layer (see Fig. 1) were calculated in the framework of the model # 1. In the frameworks of the models # 2 and # 3, these values were calculated at the points respectively \( B_1 \) and \( B_2 \) that have same coordinates \( z \) and \( y \) as centers of the respective filler particle side faces have and are situated at the centers of the surface layers, and then these values are averaged over all filler particle layers of the respective quasi lattices. Calculations were performed for the samples with the volumetric concentrations of the filler equal to 0.1 %, 1 %, and 10 %. The sizes of the surface layers of these samples are respectively the following: 4.1 \times 10^{-5} m, 2.3 \times 10^{-5} m, and 1.2 \times 10^{-5} m. The values of \( H \lVert H \rVert \) calculated in the frameworks of the models # 1, # 2, and # 3 are presented in Table I in units 10^{-3} \ A^2/m^2. As for values of \( H^2 \) calculated in the frameworks of the models # 1, # 2, and # 3, they are presented in Table II in units 10^{-9} \ A^2/m^2. As it was explained in Section 3, the difference between the respective values of \( H \lVert H \rVert \) calculated in the frameworks of the models # 2 and # 3 can be interpreted as the error bars of the value \( H \lVert H \rVert \) calculated at the center of a surface layer.

<table>
<thead>
<tr>
<th>Model Number</th>
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<tbody>
<tr>
<td>Volumetric Filler Concentration</td>
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<tr>
<td>0.1 %</td>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
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<td>3</td>
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(24)

The calculated values of \( H \lVert H \rVert \) in units 10^{-3} \ A^2/m^2

and the difference between their average value and the respective value of \( H \lVert H \rVert \) calculated in the framework of the model # 1 can be interpreted as the contribution of the filler particles to the value of \( H \lVert H \rVert \) at the center of a surface layer.

From the data presented in Table I, it follows that the value of \( H \lVert H \rVert \) at the center of the surface layer situated in the vicinity of a filler particle is significantly influenced by the other filler particles if the volumetric concentration is equal to 0.1 % and that the ratio of the portion of the value of \( H \lVert H \rVert \) generated by these particles to the uncertainty in the value of \( H \lVert H \rVert \) due to chaos in filler particle disposition in a sample goes to zero as this concentration increases. Similarly, the difference between the respective values of \( H^2 \) calculated in the frameworks of the models # 2 and # 3 can be interpreted as the error bars of the value of \( H^2 \) calculated at the center of a surface layer situated in the vicinity of a filler particle, and the difference between their average value and the respective value of \( H^2 \) calculated in the framework of the model # 1 can be interpreted as the contribution of the filler particles to the value of \( H^2 \) calculated at the center of a surface layer. From the data presented in Table II, it follows that the value of \( H^2 \) calculated at the center of the surface layer situated in the vicinity of a filler particle is influenced by the other filler particles insignificantly, and that the significance of the influence of these particles on this value increases as the filler concentration in a sample increases. Using the experimental data presented in the reference, we formulate the following observations:

1. Young’s modules of the samples of PMCs composed of PVC mixed with a Fe_{3}O_{4} fine powder and created in the presence of an external CMF are notably greater than Young’s modules of the respective samples created in the absence of an external CMF under exactly same the other conditions if the filler concentrations are relatively high.
2. Young’s modules of the samples of PMCs composed of PVC mixed with a Fe$_3$O$_4$ fine powder and created in the presence of an external CMF are slightly lower that Young’s modules of the respective samples created in the absence of an external CMF under exactly same the other conditions if the filler concentrations are relatively low.

3. Poisson’s ratios of samples of PMCs composed of PVC mixed with a Fe$_3$O$_4$ fine powder and created in the presence of an external CMF are only slightly greater than Poisson’s ratios of the respective samples created in the absence of an external CMF under exactly same the other conditions if the filler concentrations are relatively high.

4. Poisson’s ratios of samples of PMCs composed of PVC mixed with a Fe$_3$O$_4$ fine powder and created in the presence of an external CMF are only slightly greater than Poisson’s ratios of the respective samples created in the absence of an external CMF under exactly same the other conditions if the filler concentrations are relatively low.

Thus, we can assert that at some value of the filler concentration the phase transition occurs in the microcomposite synthesized under the influence of a CMF. The first phase of the microcomposite corresponds to relatively low concentrations of the filler whereas the second one corresponds to relatively high concentrations of the magnetic particles. The results of numerical calculations of the value of $H$ at the center of a surface layer in the vicinity of a filler particle in the frameworks of the models # 1, # 2, and # 3 indicate that the contributions of the other filler particles to the value of $H$ is significant at low filler concentrations and can be neglected at high filler concentrations and that such the contributions to the value of $H^2$ are insignificant at all the considered values of filler concentrations. Therefore, we assert that four above mentioned experimental observations can be explained by the following two assumptions:

1. Magnetic fields that can be created under laboratory conditions can significantly alter formations of surface layer friability structures of PMCs with fine powder magnetic fillers.

2. These structures in PMCs with low magnetic filler concentrations formed under the influence of external CMFs are different from these structures in PMCs with high magnetic filler concentrations formed under the influence of external CMFs. This fact explains the above mentioned phase transition.

3. CONCLUSION

Performance of modern computers rarely allows conducting detailed numerical analyses of real life problems. Scale effects induced by a choice of boundary conditions create insuperable obstacles for such the analyses near phase transitions. The fact that with the increase of magnetic filler concentration in a PVC microcomposite synthesized under the influence of a CMF the phase transition is observed explains the absence of numerical studies of composites of this type. In this paper, we present the computational abstraction that allows handling random disposition of the magnetic microparticles inside such the composite during calculation of a CMF in a polymer surface layer of the composite. Having conducted the integrated analysis of the laboratory measurements and respective numerical calculations, we assert that external CMFs significantly influence formations of surface layer friability structures of PVC composites filled with Fe$_3$O$_4$ microparticles. These structures in PMCs formed under the influence of external CMFs with high filler concentrations are different from these structures in PMCs of this type with low filler concentrations, which explains the above mentioned phase transition.

The calculation results presented in Table II indicate that although the value of $H^2$ calculated in a surface layer situated in the vicinity of a filler particle is influenced by the other filler particles insignificantly, the significance of the influence of these particles on this value increases as the filler concentration in a sample increases. Therefore, the mechanical properties of the PMCs with higher Fe$_3$O$_4$ fine powder concentrations should be investigated as well as results of calculations of magnetic fields in their surface layers should be analyzed to check whether a new phase transition occurs.

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