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Voigt-based swelling water model for super water absorbency of expanded perlite and sodium polyacrylate resin composite materials

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Abstract: Polyacrylate resin composite materials with the mineral exhibit super water absorbency and good degradation ability. In this work, expanded perlite and sodium polyacrylate resin composite materials have been prepared with ceric ammonium nitrate (CAN), N,N'-methylene bisacrylamide (MBA), tapioca starch, and expanded perlite. Fourier transform infrared spectroscopy (FT-IR) and field emission scanning electron microscopy (SEM) are used to characterize the bonds absorption peaks and morphologies. The results suggest that the expanded perlite can graft on sodium polyacrylate resin, and the optimal distilled water and 0.9% NaCl absorbency are 1079 and 253 g/g when the expanded perlite content is 8 wt%, respectively. The swelling water model of the composite materials is firstly simulated to be Voigt-based model. In addition, the composite materials absorbency that is influenced by special characteristics of the expanded perlite has been shown.

Keywords: expanded perlite; sodium polyacrylate; composite materials; swelling model; super water absorbency

1 Introduction

Polyacrylate resin is one of the important superabsorbent polymers (SAPs) because of their broad sources and super solution absorbency, which have the potential water absorbency of hundreds times that of their own weight with three-dimensionally net structure, and they can be always used in agriculture (i.e., water retention, soil nutrient reserves, and low soil compaction), sanitary products, food and drug preservation (1,2). However, the traditional polyacrylate resin has some drawbacks, such as not very fast swelling rates, weak mechanical properties, and poor degradation ability, which hinder their application in the field of agriculture distinctly (3). Therefore, many researchers had focused on polyacrylate resin composite materials with clay, montmorillonite, or kieselguhr mineral to overcome their disadvantages in recent years (4-6). Additionally, the starch could graft on polyacrylate resin by chains with their quantities of –OH for the three-dimensionally net structure, resulting in the super water absorbency and good degradation ability (1,7-9).

Expanded perlite, possessing a similar aluminosilicate structure like the other mineral, features two-dimensional layered and three-dimensional pore structure with through holes and thin walls (10). The expanded perlite and polyacrylate resin composite materials were seldom reported, although they might have potential larger water absorbency than the other mineral composite materials (~600 g/g) (4-6,11). Further, Voigt model was used to simulate creep process of superpolymer, but it was seldom fitted with the mineral and sodium polyacrylate resin composite materials, because the composite materials not featured linear viscoelastic behavior basically (12). Though the composite materials swelling water model was essential for their actual application, the Voigt-based model was rarely reported before (13).

In this paper, the expanded perlite and sodium polyacrylate resin composite materials were reported. The influences of various contents of expanded perlite on composite materials structure and solution absorbency were fully discussed. Moreover, the swelling water model was simulated under the swelling rate of composite materials with the optimum formula, which would give guidance on environmental friendly agricultural application.

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2 Experimental

2.1 Preparation

The expanded perlite and sodium polyacrylate resin composite materials were synthesized by solution polymerization. The expanded perlite was prepared with perlite mineral by an expanded process under 1180°C, which was mined in Shangtianti, Xinyang, P. R. China. The starting raw materials were crylic acid monomer, ceric ammonium nitrate (CAN) initiator, N,N'-methylene bisacrylamide (MBA) cross-linking agent, grafted tapioca starch, NaOH neutralizer, and expanded perlite. Firstly, 62% neutralization of crylic acid was achieved by NaOH solution under –12°C. Secondly, the polycondensation of sodium acrylate was prepared with 0.10 wt% CAN, 1.6 wt% MBA, and 7 wt% tapioca starch under 25°C for 1 h, and then various contents of the expanded perlite (2–12 wt%; 200 mesh) were added into the aforementioned polycondensation under 65°C for 2.5 h in a container under a pressure of ~0.5 bar. Thirdly, the composite materials particles were obtained by shredding and drying process.

2.2 Characterization

The phase of the expanded perlite was characterized by X-ray powder diffraction (XRD; X'Pert PRO) under a 2θ scanning rate of 0.05°/s with Cu-Kα radiation at room temperature. Field emission scanning electron microscopy (SEM; S-4800) was used to detect the composite materials fracture and surface morphologies. The FT-IR (Nicolet IS-50) spectra were investigated the bonds absorption peaks of the materials using KBr pellets. The solution absorbency (Q, g/g) was calculated by the equation, i.e., $Q = (m_2 - m_1)/m_1$, here m_1 is the weight of dried composite materials particles, m_2 represents the weight of the swelled solution samples after draining for 5 min, all the absorbency results were tested for 5 times in this study.

3 Results and discussion

Figure 1 shows XRD pattern of the expanded perlite. It could be observed the majority phase of the expanded perlite main peaks was SiO_2 with hexagonal phase, which was in line with the information of PDF # 79-1910. The impurity phases in the figure were speculated as aluminosilicate compounds in the structure. The expanded perlite fracture SEM image is displayed in Figure 1a. It could be seen, the expanded perlite possessed through holes and thin wall characteristics. The special characteristics and phase implied the expanded perlite could elevate the sodium polyacrylate resin water absorbency and enhance mechanic strength after grafting reaction (14).

FT-IR spectra of the expanded perlite, sodium polyacrylate resin, and composite materials are given in the Figure 2. From the figure, the characteristic of –OH bond absorbed around 3748 and 2924 cm^{-1}, suggesting all the samples had a capacity for dehydration condensation with –COOH. The absorption peaks around 1541 and 1675 cm^{-1} indicated the existence of C=O bond in the resin and

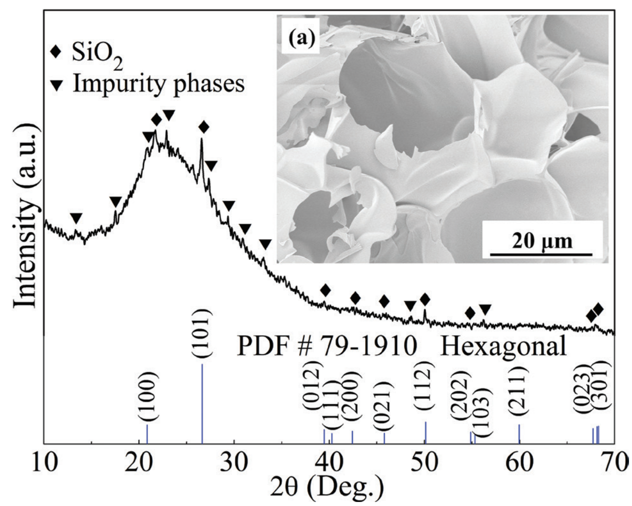

Figure 1: XRD pattern of the expanded perlite. The inset (a) is SEM image of the expanded perlite fracture.

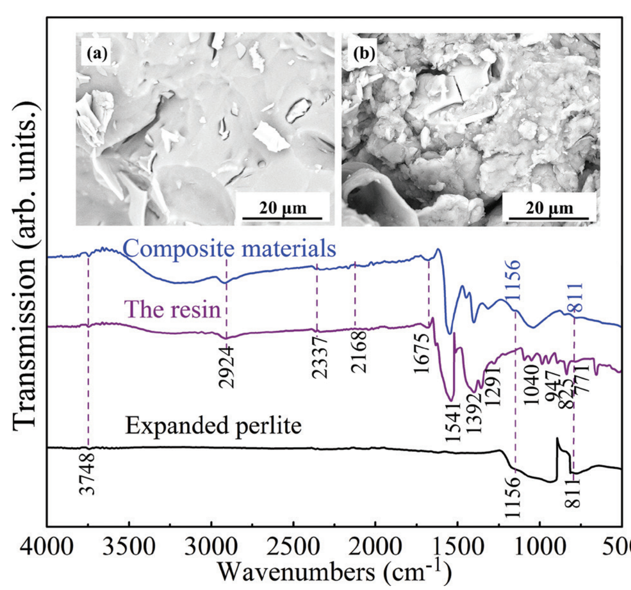

Figure 2: FT-IR patterns of the expanded perlite, sodium polyacrylate resin, and composite materials. SEM images for the inset (a) the composite materials surface and (b) fracture surface.

composite materials. The absorption peaks around 771, 852, and 1040 cm^{-1} revealed the unique cyclical glucose units in the structure (7,15). In addition, the unique Si–O bonds absorption peaks could be observed around 811 and 1156 cm^{-1} in the expanded perlite and composite materials. Figures 2a and b show SEM images for the composite materials surface and fracture surface, respectively. It could be observed the expanded perlite was tightly sealed with the resin in the Figure 2a, the holes were highly filled with the resin and two sides of thin walls were also bonded with the resin in the Figure 2b. All the detected bonds reaction information and microstructure message implied the expanded perlite grafted on sodium polyacrylate resin, which was in agreement with literature report (15).

Figure 3 shows solution absorbency (g/g) of the composite materials under various contents of expanded perlite. The distilled water and 0.9% NaCl absorbency firstly elevated and then decreased with increasing addition of expanded perlite. The optimal distilled water absorbency was 1079 g/g, and the 0.9% NaCl absorbency was 253 g/g when the expanded perlite was 8 wt%. The reason for the varying absorbency was attributed to the varied osmotic pressure in different solution. The elevated solution absorbency of the composite materials with a small addition of expanded perlite was due to its porous structure and their bonding reactions (15). However, the decreased solution absorbency was attributed to the inadequate filled resin in the through holes, formed cracks, or punched channels in the structure of the composite materials.

The composite materials were prepared with the expanded perlite content was 8 wt%, and their swelling rate (g/g) of the composite materials in distilled water is shown in Figure 4. It could be observed the swelling rate initially exponential growth, and then basically unchanged (1079 g/g) with increasing addition of expanded perlite. The detected swelling property was firstly simulated to be Voigt-based swelling model, the equation and some meanings of the parameters are displayed in the Figure 4, the water swelling rate (S; g/g) of the composite materials water absorbency (P, g/g) at a certain time was also calculated by the solution absorbency in the Experimental section (16). The Voigt-based swelling model of the composite materials could provide guidance on their practical application in swelling and plugging process.

4 Conclusions

The super water and 0.9% NaCl absorbency composite materials were successfully synthesized by solution polymerization with expanded perlite and sodium polyacrylate resin. The composite materials solution absorbency initially enhanced and then deteriorated with increasing expanded perlite contents, and the optimal solution absorbency (i.e., distilled water: 1079 g/g; 0.9% NaCl: 253 g/g) was obtained when the expanded perlite content was 8 wt%, showing a more excellent absorbability than the mineral composite materials. FT-IR and SEM results indicated the expanded perlite could graft on sodium polyacrylate resin for the composite materials. Under the optimum formula, the swelling water model of expanded perlite and sodium polyacrylate resin composite materials was firstly simulated to be Voigt-based model, which could provide guidance in their practical application.

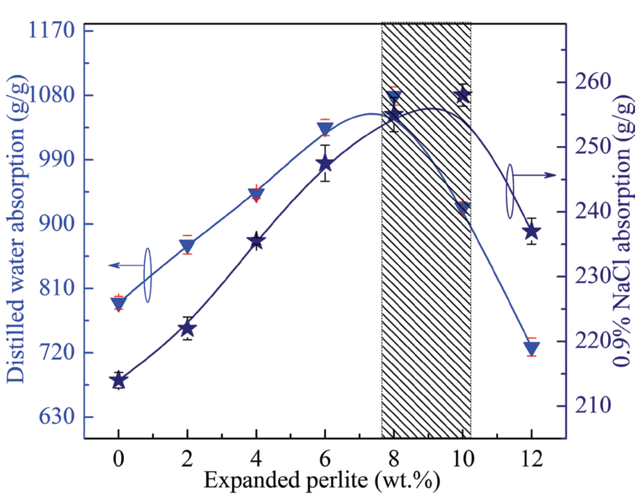

Figure 3: Distilled water and 0.9% NaCl absorbency (g/g) of the composite materials with varying contents of expanded perlite.

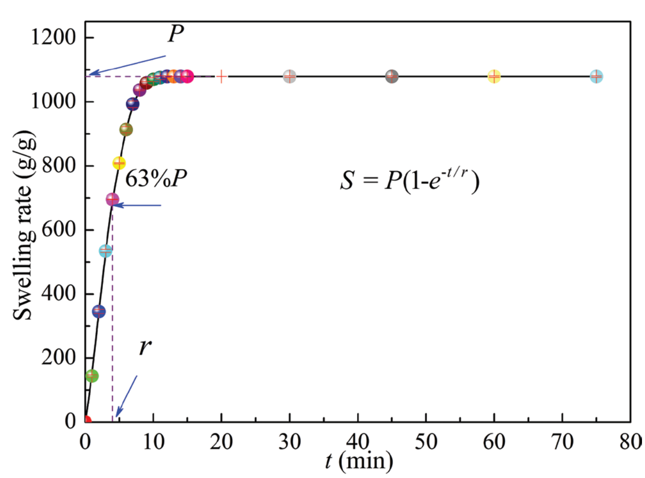

Figure 4: The swelling rate (g/g) of the composite materials in distilled water with expanded perlite content was 8 wt%.

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