The Effect of Bentonite (BNTN) Nanoclays with Multiple Weight Proportions on the Mechanical Properties of Polyacrylamide (PAM) Composites

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Abstract

The research includes studying the mechanical properties of BNTN/PAM nanocomposites under static and dynamic conditions. The BNTN/PAM nanocomposites were prepared with different weight fractions (0, 20%, 40%, 50%, and 60%) by utilizing the ball milling technique. Tensile strength, Charpy impact, and Shore A hardness were performed to verify any improvements in these mechanical properties of nanocomposites. The results showed significant improvements in tensile, Charpy impact, Shore A hardness properties of nanocomposites at 50% weight fraction by approximately 335%, 1422%, 63% respectively. These results started decreasing after the addition of 60% of nanoclays content to PAM composites. This mechanism indicates that the percentage of weight content of BNTN could affect the mechanical properties of nanocomposites.

Keywords: Polyacrylamide (PAM), Nanoclays, Nanocomposites, Weight Content, Strength Measurements.

تأثير البنتونايت (BNTN) النانوي بنسب وزن متعددة على الخواص الميكانيكية لمركبات البولي أكريلاميد (PAM)

رغد حامد هلال

الخلاصة:

يتضمن البحث دراسة الخصائص الميكانيكية للمركبات النانوية BNTN / PAM في ظل ظروف ثابتة وديناميكية. تم تحضير المركبات النانوية BNTN / PAM بأجزاء مختلفة من الوزن (٠ ، ٢٠٪ ، ٤٠٪ ، ٥٠٪ و ٦٠٪) باستخدام تقنية طحن الكرة. تم إجراء مقاومة الشد وتأثير Charpy وصلابة Shore A للتحقق من أي تحسينات في هذه الخصائص الميكانيكية للمركبات النانوية. أظهرت النتائج تحسنًا معنويًا في خصائص مقاومة الشد وتأثير Charpy و Shore A للمركبات النانوية بنسبة ٥٠٪ نسبة وزن بحوالي ٣٣٥٪ ، ١٤٢٢٪ ، ٦٣٪ على التوالي. بدأت هذه النتائج في التناقص بعد إضافة ٦٠٪ من محتوى النانو إلى مركبات PAM. تشير هذه الآلية إلى أن النسبة المئوية لمحتوى الوزن من BNTN يمكن أن تؤثر على الخواص الميكانيكية للمركبات النانوية.

1. Introduction

Polymeric materials supported by nanomaterials are important nanocomposites, due to their many applications in medicine, engineering, and industry [1]. The properties of nanocomposites such as mechanical, thermal, electrical, and optical properties depend on many factors (e.g., type of polymer or nanomaterials, geometric structure of nanomaterials, uniform dispersion, weight fractions, interface regions between polymers and nanomaterials, and other factors). The interface strength between polymer and nanomaterial can be affected by these factors [2]. The brittleness or ductility of polymers materials could also be affected by these factors [3]. Polyacrylamide (PAM) is a synthetic polymer that could be soluble in water and has beneficial properties such as good adhesion, suitable moisture, hydrophobicity as well as nontoxicity [4, 5]. Due to these benefits, PAM has been utilized with multiple types of nanoclays (e.g., montmorillonite, bentonite, kaolinite, hectorite, and halloysite) to reinforce the mechanical properties of polymer composites. These nanomaterials possess high mechanical and physical properties and are cheap. However, these types of

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nanomaterials showed high improvements in the mechanical properties of PAM nanocomposites and other polymer nanocomposites. Here are some examples: ShiNengLi et al. (2019), improved the mechanical properties of polyacrylamide/chitosan (PCH) hydrogels, the resulting hydrogels also showed an impressive strain-resisting ability to withstand cyclic compression tests [6]. Guorong Gao et al. (2015), have studied the nanocomposites hydrogels with unprecedented stretchability, toughness, and self-healing. These have been developed by in situ polymerization of acrylamide with the presence of exfoliated montmorillonite (MMT) layers as non-covalent cross-linkers. Uniaxial tensile tests showed a very high fracture elongation up to 11 800% and a fracture toughness up to 10.1 MJ m^{-2} [7]. Peng Li et al. (2009), studied the influence of varying clay contents (25–43%), pH (2–11) buffer solutions of (polyacrylamide – laponite) nanocomposite hydrogels. This study occurred in the absence of polyelectrolyte. The results showed that the swelling ratio reached the maximum value at pH 11. In addition to the ionic strength can weaken the swelling abilities of the nanocomposite hydrogels considerably [8]. Anfeng Zhu et al. (2012), have used polyacrylamide/ MWNT- NC) as a nanocomposite conducting hydrogel, the mechanical properties and electrical conductivity tests were performed for the nanocomposites. The results observed that mechanical strength and electrical conductivity increase with increasing the content of MWNT. In contrast, both properties decrease with increasing the content of water [9]. Ekmel Helvacıoğlu et al. (2011), have used in situ free radical polymerization method to prepare a series of polyacrylamide-montmorillonite (MMT)/ nanocomposite hydrogels. Mechanical tests were performed under uniaxial compression loads. The outcomes indicated that exfoliated PAM/nanocomposites at 0.5% OrgMMT had both the maximum equilibrium swelling in water and compression strength [10]. Mahmood M. Barbooti et al. (2018), studied the mechanical properties of polyacrylamide- Kaolin composites. The main purpose of this study was to improve the mechanical capability to be a sorbent for the removal of heavy metals from water. The results appeared an improvement in the mechanical properties (e.g., tensile strength, impact, Shore A hardness) after increasing the kaolin ratio [11].

A.G. Supri et al. (2008), have prepared polyacrylic acid- low density polyethylene ((PAA) – NC/ nanocomposites by melt intercalation method. The main goal of this study was to improve the mechanical properties of the nanocomposite. The results showed good improvements in tensile strength and elasticity modulus after the addition of 2.5 phr and 5.0 phr from nanoclay (NC) to PAA [12]. Shivraj Pugga et al. (2015), studied the effect of montmorillonite (MMT) on the mechanical properties of the epoxy matrix. Both tensile strength and hardness increased with increasing the clay amount in the epoxy [13]. Ali I. AlMosawi, (2009), studied the effect of weight fraction of fibers on the mechanical properties of conbextra epoxy resin (EP-10). Mechanical measurements were performed such as impact resistance, tensile strength, flexural strength, and stiffness of the epoxy composites reinforced with biaxial Kevlar fibers [0°, 45°]. The results observed that the mechanical properties of the polymer improved after strengthening it with three-directions Kevlar fibers, and the values of these properties increased with the increase in the percentage of added fibers [14]. Kusmonon et al. (2013), have illustrated the effect of clay loading on the morphological and tensile, flexural, un-notched Charpy impact and fracture toughness tests of unsaturated polyester/glass fiber composites. The tensile strength, flexural strength, and flexural modulus of the composites were increased in the presence of clay. The suitable loading of clay in the UP/glass fiber composites. At 2 wt% of clay, values of tensile strength, flexural strength, and flexural modulus were nearly13, 21, and 11%, respectively. While the highest impact toughness and fracture toughness values were noticed at 4 wt% of clay [15]. Gerald Okwuchi Onyedika et al. (2020) have prepared low density polyethylene reinforced with slurry at various weight contents. The mechanical properties increased with increasing the clay content into the matrix, but the stress resistance at fracture and shear strength decreased with the increasing proportion of clay [16]. Omar AboMadyan et al. (2016), studied the development of the composition of robust clay aerogels by clay aerogel with different natural and synthetic polymers [17]. Odette F. Ngasoh et al. (2021), have performed experimental and theoretical studies of the interfacial and mechanical properties of epoxy/clay nanocomposites. The measured mechanical properties showed an increase with the increasing weight ratio of clay [18]. Zahra Khalid Hamdan et al. (2021), used waste natural composite materials as base materials to manufacture a novel composite. The purpose of this study is to improve the mechanical properties of the novel composite. The results showed that the elastic modulus of polyester/ composite increased after adding 10% waste natural composite [19]. Amir Eshraghi et al. (2016), prepared polyethylene composite materials enhanced with wood flour and nanoclays at different weight concentrations. The physical and mechanical properties were studied before and after weathering. The results showed that the stages of weathering led to reducing the modulus of elasticity, moreover, the good dispersion of nanoclays contributed to decreasing somewhat in the modulus of elasticity values. [20].

2. Experimental work

2.1 Materials:

Polyacrylamide powder with the formula (-$CH_2CHCONH_2$-), was supplied from (Interchimiques SA France) as a white powder. The powder was directly used to prepare the composite materials as the base, Nanoclay (bentonite) was supplied from (Iraq Geological Survey) and deionized water.

2.2 Preparation of nanocomposites:

In the first stage, the bentonite stone was crushed into small sizes using the Jaw crusher model (BB200). The grinding process was performed using the ball milling technique (model PM200) to obtain fine bentonite powder with different granular sizes as the second stage. Different weight ratios of the composite material were prepared to manufacture BNNT/PAM nanocomposites dissolved in deionized water at ratios (0:10, 2:8, 4:6, 5:5, and 6:4). The blends were mixed well using the magnetic stirrer (Daihan Labtech Co. Ltd) at 800rpm and 60±2°C. The time required was nearly (2-3h) to obtain a homogeneous dense solution. The mixtures were poured into the molds to prepare the samples. The samples were then left for the curing process for 24 hrs to dry. A standard layer of nanocomposites was obtained. The layers were then placed in an electric oven at 80°C to remove the remaining water. The samples were cut into the standard dimensions of the tensile strength, compressive strength, and Shore A hardness tests as the final stage.

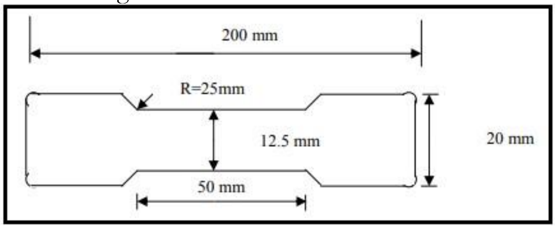

Figure (1): Schematic diagram of the tensile specimen as per standard ASTM, VOL (03.01), 103.02 EBM

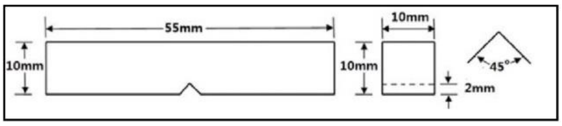

Figure (2): Schematic diagram of impact specimen as per standard ASTM-E8M-89b.

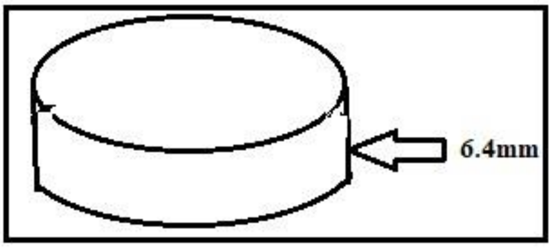

Figure (3): Schematic diagram of (shore- A) specimen as per standard ASTM-D2240.

3. Results and Discussion:

3.1 Tensile strength properties:

The typical tensile strain-stress curves for BNTN/PAM nanocomposites at multiple weight contents are shown in Fig.4. The level of improvements of tensile tests shows that the strength values increase with the increase in the proportion of BNTN into the resin as shown in Fig.5. The maximum improvement is 335% at weight content 50%. This improvement could be due to a good diffusion for clay particles in the PAM matrix without happening agglomerations [21-23]. While the tensile strength properties decrease with an increase in weight content of nanoclay in particular at 60%. The reasons behind this could be that the polymer began to lose its polymeric properties as well as the adhesion force between the clay particles and polymer decreases, which makes the sample break and begin to disintegrate [22,24].

3.2Charpy impact properties:

Fig. 6 shows that the addition of nanoclay to the PAM composite could be increased the property of impact significantly by 1422 % at a weight content of 50 % in comparison to pure PAM composite. The values start to decrease at high weight content. This increase may affect the amorphous polymer due to the increase the viscosity. This could also affect the dispersion of nanoparticles into the PAM matrix [25].

3.3 Hardness properties:

Fig.7 shows that the hardness properties of BNTN/PAM nanocomposites increase with the increase in the weight content of particles. The level of improvement was 63% in comparison to the pure PAM composite. While the hardness value begins the decrease with increasing of weight content such as at 60%. The reason could be due to the pores created in the sample during manufacturing processes or heterogeneous dispersion, particularly at the high weight content of particles. However, the present results are rather close to the results in comparison to previous res [12].

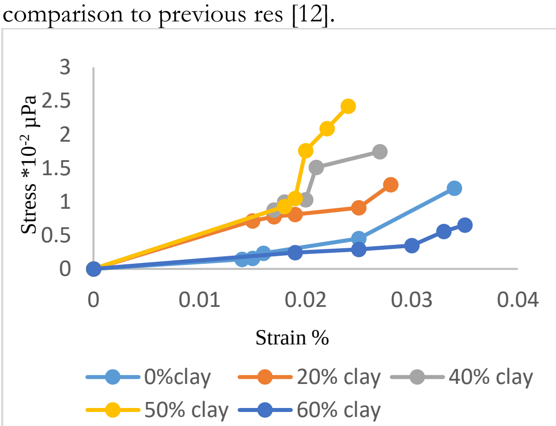

Figure (4): The typical stress-strain curves of BNTN/PAM nanocomposites at various weight content of BNTN nanomaterial

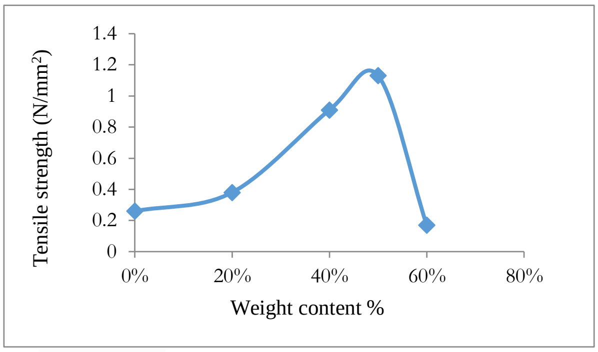

Figure (5): Tensile properties of BNTN/PAM nanocomposites at various weight content of BNTN nanomaterial

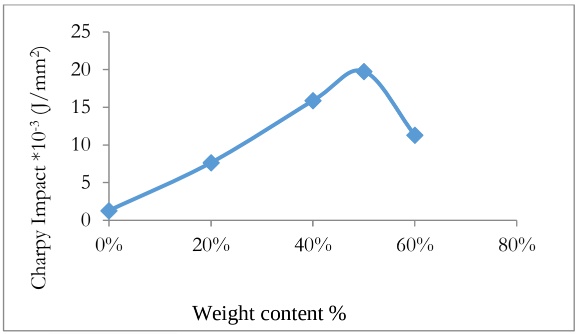

Figure (6): Charpy impact of BNTN/PAM nanocomposites at various weight content of BNTN nanomaterial

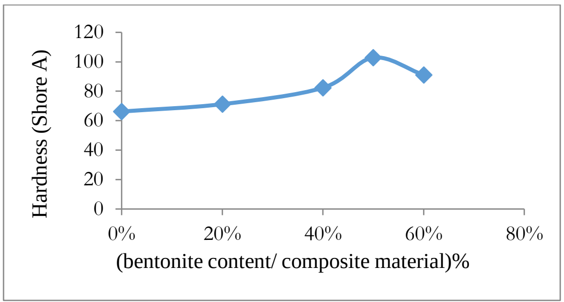

Figure (7): Hardness properties of BNTN/PAM nanocomposites at various weight content of BNTN nanomaterial

4. Conclusion:

The BNTN/PAM nanocomposites have been successfully prepared to utilize practical techniques (e.g., ball milling, magnetic stirrer). The novel type of BNTN nanoclays dispersed into the PAM matrix showed high improvement in mechanical properties of nanocomposites at different weight concentrations, especially at 50%. The maximum improvements in tensile strength, impact, hardness were 335%, 1422%, 63% respectively. The present results were rather close to previous experimental research.

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