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Enhancing mechanical properties of fused silica composites by introducing well-dispersed boron nitride nanosheets

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ABSTRACT

Well-dispersed boron nitride nanosheets (BNNSs) reinforced fused silica composites were successfully fabricated by surface modification assisted flocculation method. Surface modification can enhance the performance of flocculation process. BNNSs were homogeneously mixed with fused silica through the electrostatic interaction between hydroxylated BNNSs with negative charge and amino-modified fused silica with positive charge. The BNNSs can act as excellent nanofillers for enhancing the mechanical properties of fused silica composites. Approximately 74% and 48% increases in flexure strength and fracture toughness can be achieved for the 1.5 wt % BNNSs/fused silica composite, respectively. The toughening mechanisms were analyzed by microstructural characterization, especially for pull-out mechanism.

1. Introduction

Two-dimensional materials, graphene and boron nitride nanosheets (BNNSs), have been attracting great interest due to their unique properties and promising applications [1,2]. Owing to the superior mechanical properties, graphene has been utilized to improve the mechanical properties of different matrixes, including polymers, ceramics, and metals [3–6]. Compared with graphene-based nanofillers, BNNSs can be regarded as a promising candidate because it possesses comparable mechanical strength and thermal conductivity with graphene [7–9], higher thermal and chemical inertness [10], excellent dielectric properties, and better biocompatibility [11]. Therefore, BNNSs have the potential to be used as efficient reinforcement for composites applied at some special environment.

BNNSs with its outstanding mechanical properties, such as high Young's modulus (0.865 ± 0.073 TPa) and high fracture strength (70.5 ± 5.5 GPa) [9], have attracted attention as reinforcement for polymers and ceramics [12–16]. In comparison to original matrixes, the related composites exhibited enhanced mechanical properties. Homogeneous dispersion is essential to enhancing the reinforcing efficiency of BNNSs. However, uniform dispersion of BNNSs in matrix is difficult to achieve because of weak interactions between BNNSs and dispersion medium [17,18], which hinders the further improvement of mechanical properties.

Recent studies have proven that flocculation (or heterocoagulation) method, which is caused by the electrostatic interactions between particles with opposed zeta potential [19], is an efficient method to obtain relatively well-dispersed graphene in the alumina ceramic [20,21]. Due to the geometric and structural analogy, flocculation could be an effective way to obtain the dispersive BNNSs in matrix. To sufficiently take advantage of the flocculation method, two homogenized colloidal suspensions, with high absolute values of zeta potential as well as opposite zeta potential, should be achieved. However, there is still a great challenge to achieve these two factors within a common pH range at the same time.

Deionized water is a common and green solvent for flocculation method. For the BNNSs dispersion systems, the high hydrophobicity results in extremely poor solubility of the BNNSs in aqueous media [22], which makes them difficult to form stable colloidal suspension with high absolute value of zeta potential. This obstacle hinders the homogeneous incorporation of BNNSs through flocculation process. Surface modification with available functional sites is effective method of manipulating the hydrophilicity of nanomaterials and improving their aqueous dispersions [23,24]. Furthermore, the introduction of functional sites can enhance the electrostatic repulsion between them [24], which conduces to form stable colloidal suspensions. It has been demonstrated that the hydrophilicity of BNNSs can be improved by introducing hydroxyl functional groups onto their surface [25,26]. Expectantly, hydroxylated BNNSs (OH-BNNSs) can enable a more homogeneous incorporation into matrices.

Fused silica and hexagonal boron nitride are important functional materials with low and stable dielectric constant. Therefore, BNNSs-reinforced fused silica composites can be used as an attractive candidate material for high temperature wave-transparent applications. In this article, we report a surface modification assisted flocculation method to

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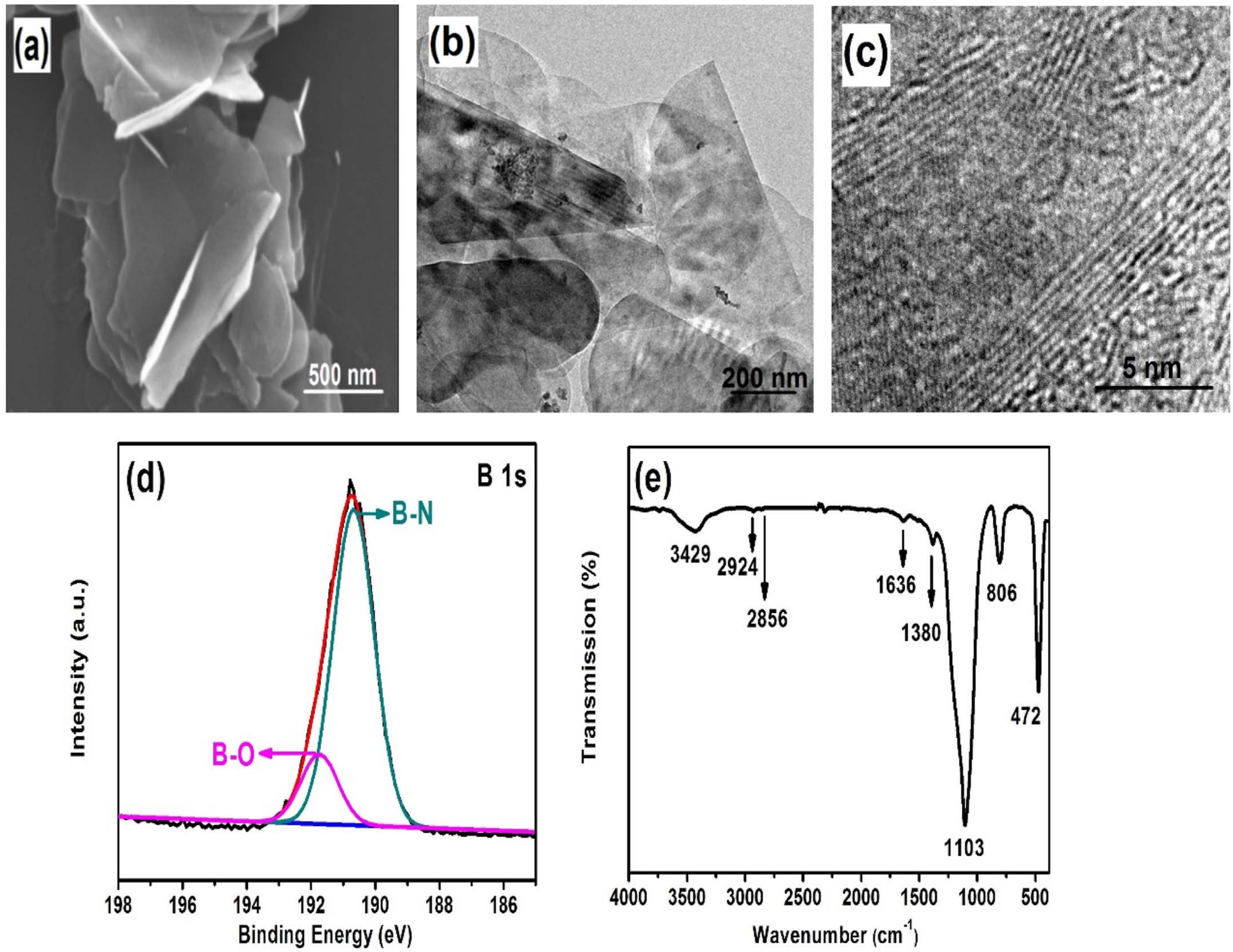

Fig. 1. (a) FESEM image of OH-BNNSs. (b, c) TEM images of the OH-BNNSs. (d) XPS spectrum of OH-BNNSs (B1s). (e) FTIR spectrum of NH_2-FS.

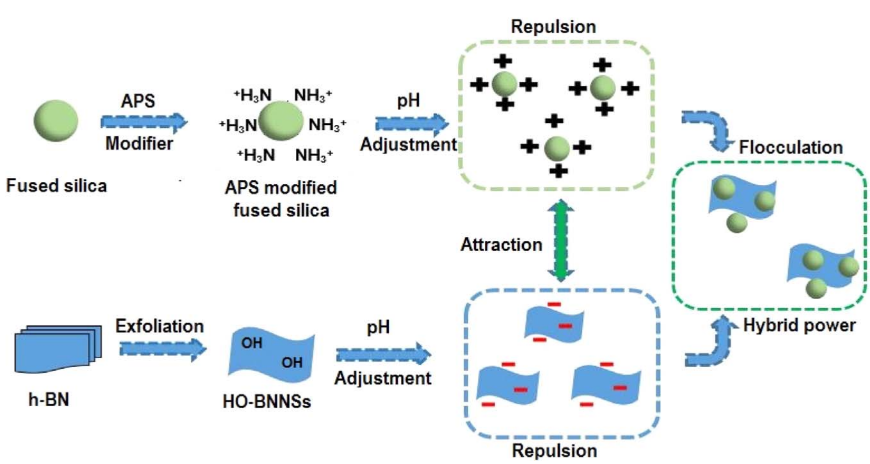

Fig. 2. Schematic illustration of the synthetic procedures of BNNSs/fused silica composite powders.