

Reinforcement of bone china by the addition of sepiolite nano-fibers



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ABSTRACT

The work attempts to investigate the effect of sepiolite nano-fibers addition on mechanical properties of bone china bodies. Compared with the traditional toughening fibers, the sepiolite nano-fiber has two main advantages: One is that the chemical composition of sepiolite mineral and the chemical composition of bone china raw materials are similar. So it can be used as one of the main components of bone china formulations directly. The other is that the sepiolite is a kind of cheap mineral resources, which will decrease the cost of the toughening ceramics. The flexural strength and fracture toughness were tested by three point bending method and single edge notched beam method, and the microstructure of the bone china was studied by scanning electron microscopy (SEM), X-ray diffraction (XRD) and transmission electron microscope (TEM). The results showed that 2 wt% sepiolite fiber addition could increase the bending strength of the ceramic bodies. There were two toughening mechanisms in the reinforced ceramic. One was the fiber pull-out. The other was the weak interface mechanism. Plenty of micro-cracks came into being at the weak interface to consume most of the elastic strain energy to prevent main crack from spreading.

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1. Introduction

Bone china is a kind of unique material in terms of appearance, exceptionally white and translucent which make it the most expensive tableware around the world [1]. The main raw materials of the ceramic are various kinds of clay minerals, which have a very wide range of sources [2]. However its large brittleness and small toughness limit the application in larger fields [3]. So how to increase the toughness of bone china becomes a hot research topic all over the world.

Traditionally, several methods have been used to toughen the bone china, such as transformation toughening, dispersed ductile/brittle (micro cracking toughening) particle toughening, and fiber/whisker toughening, which can lead to crack bridging and deflection upon crack propagation [4,5]. The most commonly used method is to add nano-fibers to reinforce the bone china [6]. The current development fibers are mainly zirconia fiber, quartz fiber, carbon fiber and SiC whisker [7–10]. However, high cost and health hazard of nano-fibers preparation could hinder its application. Another method to improve strength is to add aluminum or magnesium in the ingredients, so as to form mullite or other

crystal phase in sintered samples at high temperature [11].

Sepiolite is a natural hydrated magnesium silicate clay mineral with a micro fibrous morphology and good sorptive property. Sepiolite belongs to the structural family of 2:1 phyllosilicates, which is a hydrous magnesium silicate with $(\text{Si}_{12}\text{Mg}_8\text{O}_{30})(\text{OH})_4(\text{OH}_2)_4 \cdot 8\text{H}_2\text{O}$ as the theoretical unit cell formula and the sepiolite includes a tubular channel, which section size is $0.37 \times 1.06 \text{ nm}$ [12,13]. When the sepiolite is observed under transmission electron microscope and the scanning electron microscopy, the form of sepiolite is mostly fibrous or fiber bundle [14,15]. And thus it finds applications in a variety of industries including cosmetics, ceramics, detergents, paper and paint [16–22]. Also the nano-fibrous structure of sepiolite gives it a good foundation to become a toughening material [23–26]. The chemical composition of sepiolite mineral and the chemical composition of ceramic raw materials are similar. So it can be used as one of the main components of ceramic formulations directly. And the sepiolite fiber bundle, which is aggregated by the needle-like particles is easily dispersed in water or a polar solvent and form an interpenetrating network regularly. Thereby it can form a better flow denaturing high viscosity of the suspension. Especially, the sepiolite is a kind of cheap mineral resources, which will decrease the cost of the toughening ceramics.

In this research, sepiolite mineral nano-fibers processed in our laboratory were added in the matrixes of bone china by simple mechanical mixing. The mechanical properties and the

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Table 1.
The chemical compositions of raw materials for producing bone china (wt%).

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	K ₂ O	Na ₂ O	P ₂ O ₅	Other
Bone dust	0.74	–	–	–	61.11	7.32	–	–	30.3	0.29
Laiyang soil	71.42	14.91	0.7	0.06	1.77	3.18	1.22	0.55	–	6.69
Albite	73.45	16.54	0.25	–	0.34	0.16	0.5	8.84	–	0.36
Datong soil	45.6	37.77	0.21	0.45	0.27	0.13	–	–	–	15.46
Longyan soil	47.03	37.23	0.06	0.01	0.38	0.23	1.35	0.02	–	13.22
Fangzi soil	51.37	29.2	1.28	–	1.46	0.6	2.32	0.29	–	12.76
Sepiolite	54.36	–	1.36	–	5.67	35.56	–	–	–	3.05

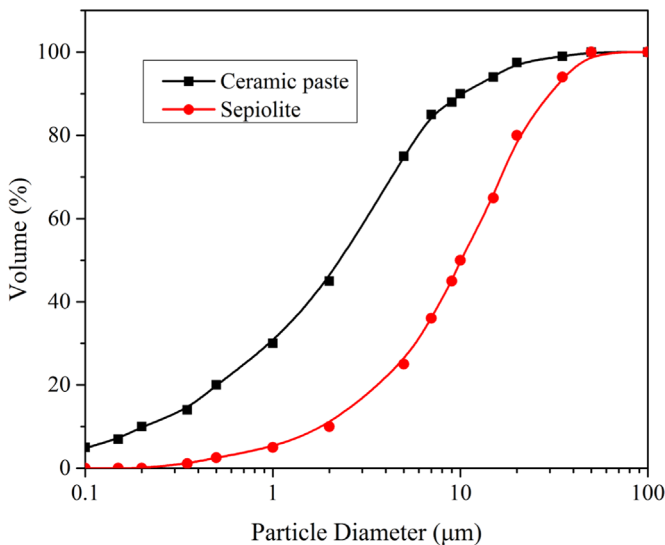


Fig. 1. Particle size distributions of raw materials, a is ceramic paste and b is sepiolite.

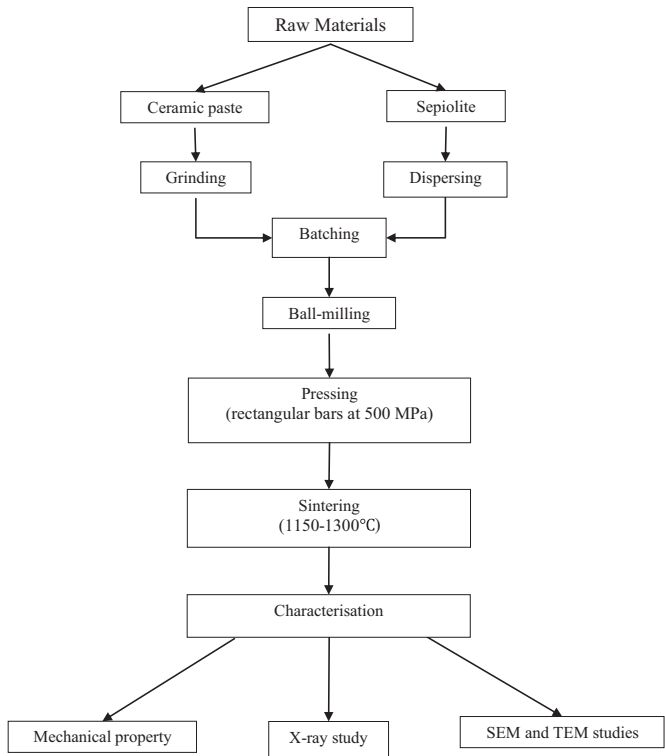


Fig. 2. Flow chart for the processing and characterization of sepiolite fiber reinforced ceramic.

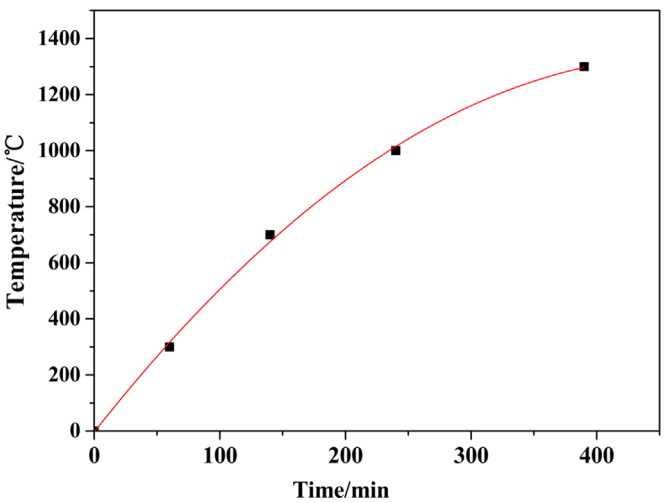


Fig. 3. The sintering system curve.

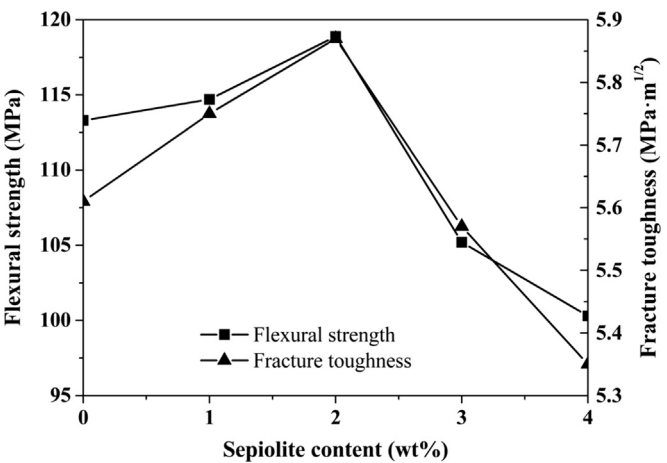


Fig. 4. Effect of sepiolite mineral nano-fiber on the flexural strength and fracture toughness of bone china.

microstructure of the bone china reinforced by sepiolite mineral nano-fiber were systematically investigated.

2. Experimental

The raw materials used to make a sepiolite fiber reinforced ceramic, with a typical chemical analysis as given in Table 1, were Bone dust, Laiyang soil, albite, Datong soil, Longyan soil, Fangzi soil and sepiolite. In previous studies [27,28], it was found to be necessary to add magnesium to the raw materials to produce fired materials that would easily vitrify and become densified. It was added in the form of sepiolite whose chemical formula was (Si₁₂)₂(Mg₈)O₃₀(OH)₄(OH₂)₄·8H₂O.

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