DOI 10.1007/s11148-023-00752-x
Refractories and Industrial Ceramics *Vol. 63, No. 5, January, 2023*

RAW MATERIALS

PROSPECTS FOR USING MINERAL MATERIALS FOR THERMAL INSULATION OF SANDWICH CHIMNEYS

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Translated from *Novye Ogneupory*, No. 10, pp. 16 – 20, October, 2022.

Original article submitted July 11, 2022.

The problem of increased fire danger in residential and administrative areas can be solved by reducing the flammability of building materials and structures. In this paper, we investigate the possibility of using a magnesium-containing mineral to protect sandwich chimneys from excessive heating and, in general, to increase the fire safety of furnace heating. The mineral considered in this work is an inorganic combustion inhibitor, currently used for neutralization of acidic waste waters and removal of heavy metal ions. The conducted experiments confirmed its applicability as a material for thermal insulation in sandwich chimneys. The obtained results expand the range of inorganic flame retardants obtained from Russian raw materials. The use of the studied material reduces the risk of overheating of roof elements due to its specific physical and chemical properties. This study can contribute to reducing the use of chemical inhibitors of combustion, adversely affecting human health and the environment. This material can be used to protect the wooden elements of roof structures.

Keywords: thermal resistance, magnesium-containing element, chemical fire inhibitors, sandwich chimney.

INTRODUCTION

A large part of building constructions in eastern Russia (Tuva Republic, Zabaykalsky Krai, Buryatia) are not equipped with central heating. According to the state regulations, furnace heating can be used in administrative and public buildings no more than two stories in height, as well as in the private sector, which, according to statistics, is characterized by an increased level of fire danger [1]. A high fire risk is associated with stove chimneys.

In order to eliminate condensation in a chimney, the temperature of chimney smoke must be at least 250°C. At the same time, the thermal degradation of wooden elements in the roof truss construction (purlins, struts) starts at a temperature of about 170°C [2]. Therefore, building constructions equipped with a chimney stove are exposed to a high fire risk, particularly when temperatures in wooden roof elements exceed their critical values.

The fire-resistance properties of wooden structures can be improved using flame retardant compositions, whose physical and chemical properties inhibit combustion [3–5]. However, flame retardants, although reducing the probability of ignition and combustion, cannot not protect wooden elements from reaching elevated temperatures. In addition, flame retardants frequently contain antimony, halogens, and phosphorus organic compounds that are highly toxic to human health and the environment. Compounds released during thermal decomposition of such flame retardants can cause more damage than flames, sparks, and elevated temperatures [6].

Taking the abovementioned into account, fire prevention measures in buildings equipped with furnace heating should be aimed not only at protecting roof wooden structures from fire, but also at reducing the negative impact of elevated temperatures. This can be achieved by chimney insulation in order to maintain the temperature of the surrounding materials below 50°C. In this respect, sandwich chimneys are currently gaining in popularity. In comparison with conventional de-

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signs, such chimneys consist of internal and external steel parts, between which either a heat-insulating material or a heating element to improve the draught is installed [7 – 10].

Mineral-based materials are increasingly being used for chimney insulation purposes [11], largely due to their affordable cost and relevant properties, as well as the availability of starting products. The possibility of using mineral wool as a flame retardant was discussed in [12].

Materials based on cement, limestone, basalt minerals, dolomite, and vermiculite can also be used for thermal insulation. Vermiculite contains about 8 – 18% Al_2O_3, up to 5% K_2O, and (in some modifications) up to 11% NiO. Vermiculite belongs to minerals from the group of hydrous mica, which has a layered structure. This mineral can be successfully used for thermal insulation and fire-retarding barriers [13]. Vermiculite products exhibit good water absorption, which further reduces fire risk in various structural units [14].

A large number of reagents derived from natural raw materials are currently used for environmental protection. Their properties are yet to be investigated from the standpoint of passive fire protection. Thus, the possibility of using red mud, a by-product generated in the Bayer process of obtaining aluminum hydroxide from bauxite, as a halogen-free combustion retardant was studied in [15].

Therefore, a research study into the possibility of using mineral materials containing hydroxides and various oxides as a basis for heat-insulating materials with flame retardant properties seems highly relevant. This study can expand the range of non-toxic, low-cost, and effective materials for thermal protection of roof structures in building constructions equipped with furnace heating.

Materials consisting of magnesium hydroxide include brucite, a mineral whose largest deposits are found in Maly Khingan, Russia. Although this mineral is widely applied in the production of flame retardants, no information is available about its use as a basis for thermal insulation in sandwich chimneys.

In this work, we investigate the behavior of a magnesium-containing material obtained from brucite under heat exposure to determine its applicability as a basis for thermal insulation in sandwich chimneys.

RESEARCH OBJECT

In this work, we investigate a magnesium-containing material produced by grinding brucite. Brucite is a natural mineral used in environmental engineering for wastewater treatment, including for neutralization of acidic wastewater and removal of heavy metal ions [16]. The material consists largely of magnesium compounds (90 – 92%) in the form of magnesium carbonate and hydroxide. The material is a white solid substance of a layered structure, gray on chips with grain sizes from 5 to 10 mm (Fig. 1).

Fig. 1. A magnesium-containing material obtained by grinding brucite.

Fig. 2. Jupiter 449 Synchronous Thermal Analyzer (Netzsch).

RESEARCH METHODS

Experiments were conducted using a Jupiter 449 (Netzsch) thermal analyzer [17] and a FTIR spectrometer (Fig. 2) at the facilities of the Department of Fire Safety, Civil Defence Academy of the Ministry of Emergency Situations of Russia. The following experimental conditions were

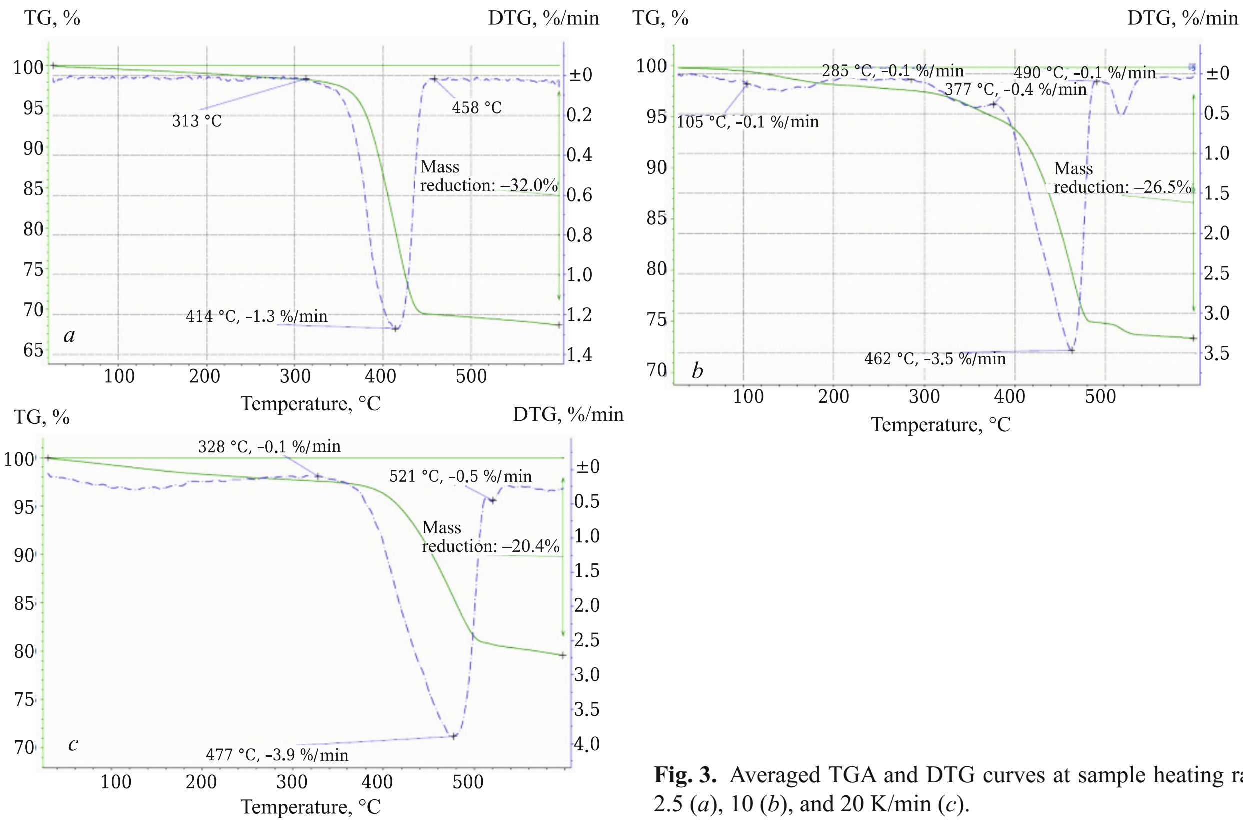

Fig. 3. Averaged TGA and DTG curves at sample heating rates of 2.5 (*a*), 10 (*b*), and 20 K/min (*c*).

used: a sample weight of 30 mg; heating to 600°C; heating rates of 2.5, 10, and 20 K/min; air atmosphere in the furnace. For each heating rate, three tests were carried. Computer processing was used to obtain average values of thermal analysis data. As a result, the following curves were derived:

– curves reflecting the reduction in sample mass as a function of temperature (TGA curves);

– differential-scanning calorimetry curves reflecting the thermal effects arising in the material upon heating (DSC curves);

– derivatives of the mass reduction curves reflecting the mass reduction rate as a function of temperature (DTG curves);

– IR spectra of thermal analysis products corresponding to the maximum rate of mass reduction.

RESULTS

In order to identify the material composition and determine the mechanism of thermal oxidative decomposition, IR spectra of both the source material and the thermal decomposition products were obtained with an IR spectrometer. The averaged TGA and DTG curves obtained at different rates of heating a sample are shown in Fig. 3. The interpretation of the TGA and DTG curves is given in Table 1.

It can be seen that, when heated to 600°C, the sample loses from 20.4 to 32 wt.% depending on the heating rate. The maximum rate of sample mass reduction corresponds to the range of 313 – 521°C, comprising from 1.3%/min when heated at a rate of 2.5 K/min to 3.9%/min when heated at a rate of 20 K/min. Sample mass reduction is accompanied by various endothermic effects, which are reflected by DSC

TABLE 1. Results of thermal analysis of the studied mineral at different heating rates

Heating rate, K/min	Temperature, °C			Maximum rate of sample mass reduction %/min	Total mass reduction, %
	at the onset of intense sample mass reduction	upon completion of intense sample mass reduction	of sample mass reduction at the maximum rate		
2.5	313	458	414	1.3	32.0
10	377	490	462	3.5	26.5
20	390	521	477	3.9	20.4

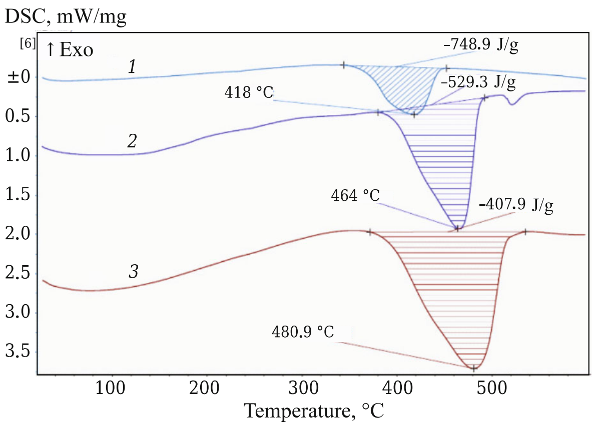

Fig. 4. DSC curves at different heating rates: *1*) 2.5 K/min; *2*) 10 K/min; *3*) 20 K/min.

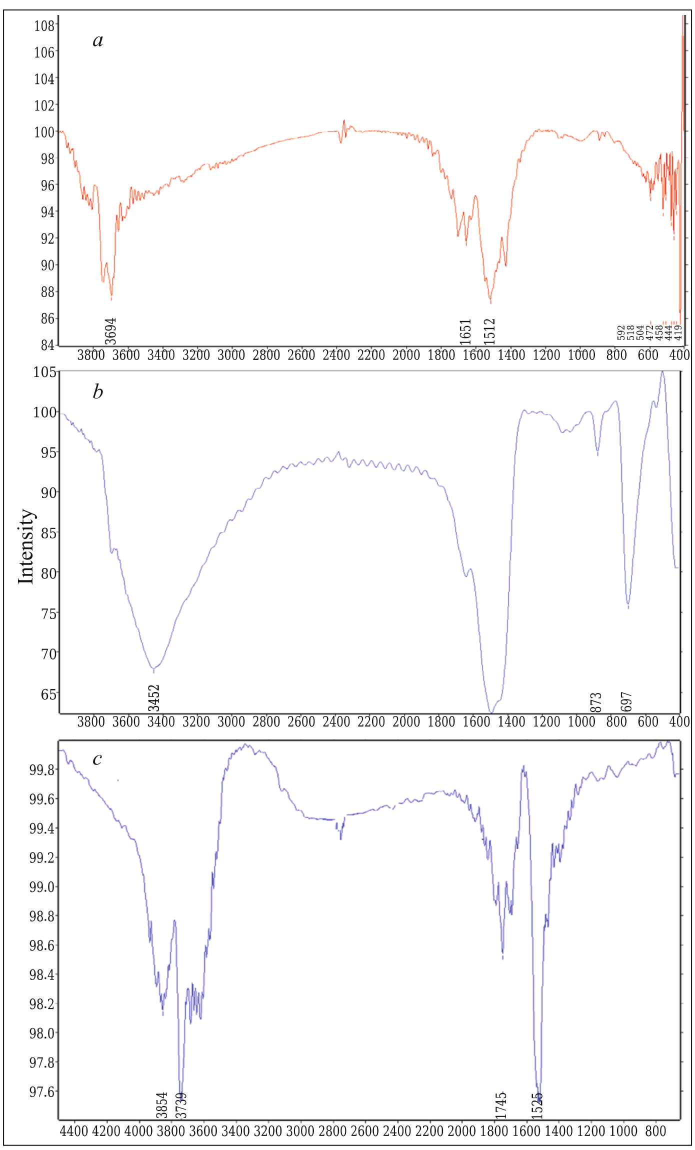

Fig. 5. Infrared absorption spectra from 400 to 4400 cm^{-1}: *a*) source mineral; *b*) solid residue after thermal exposure; *c*) gaseous products of thermolysis at 426°C.

curves. The averaged DSC curves at different heating rates are shown in Fig. 4.

Figure 4 shows that the minima of the endothermic effects accompanying sample mass reduction approximately coincide with the temperature of mass reduction at the maximum rate for the corresponding heating rate (see Table 1). The value of energy absorbed by the studied material upon heating ranges from – 407.9 kJ/kg (when heated at a rate of 20 K/min) to 748.9 kJ/kg (when heated at a rate of 2.5 K/min). Therefore, the material under study exhibits thermal resistance when heated to elevated temperatures and is capable of absorbing heat. These properties make the material promising for use as a filler in sandwich chimneys.

In order to assess possible toxic effects of the studied mineral on human health and the environment, IR spectroscopy analysis was carried out to study the composition of the source mineral, gaseous products of its thermolysis, and solid products after thermal exposure. Figure 5 presents infrared absorption spectra in the range from 400 to 4400 cm^{-1} of the source material (see Fig. 5*a*), thermal exposure products in the form of pressed KBr tablets (see Fig. 5*b*), and gaseous thermolysis products at 426°C (see Fig. 5*c*), a temperature of the most intensive mass reduction at heating rates.

The absorption spectral bands of 419 – 592, 1512, and 1651 cm^{-1} for the source mineral correspond to the mineral components of samples. The absorption band at 459 cm^{-1} can be attributed to the deformation vibrations of Si–O–Mg^{2+} (VI). The region of intensive absorption at 1512 – 1643 cm^{-1} may belong to the deformation vibrations of adsorbed water molecules, while the 3693 cm^{-1} absorption band may refer to oscillations of hydroxyl groups (see Fig. 5*a*) [18]. These assumptions are confirmed by a decreased intensity and blurring of the absorption region of the bands corresponding to the vibrations of water molecules remained after thermal exposure (see Fig. 5*b*).

The conducted spectroscopic analysis of gaseous thermal products (see Fig. 5*c*) demonstrates the presence of water molecules (3799 – 3854 and 1525 cm^{-1}). The 1745 cm^{-1} absorption band, which was absent in the spectrum of the source material, may correspond to CO_2 likely to have been formed during decomposition of the $MgCO_3$ crystals.

According to the obtained FTIR data, the mineral under study emits no highly toxic compounds during thermal decomposition. The gaseous products of its thermolysis exhibit properties not only preventing flame propagation, but also producing cooling effects.

CONCLUSION

According to the conducted experiments, the magnesium-containing material produced by grinding brucite exhibits properties typical of inorganic heat insulators, including heat absorption upon elevated temperatures and the absence of toxic emissions upon thermal decomposition. The studied mineral has good prospects for use as a filler in sandwich chimneys due to its low cost and wide availability in Russia.

The obtained results may be useful when designing furnace heating systems in administrative, public, and private buildings, as well as when developing thermal insulation for surfaces heated in operation above 60°C.

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