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THE MATERIALS RESISTANT TO HIGH TEMPERATURES OBTAINED FROM POST-PRODUCTION FIBROUS WASTE

This paper describes preparation methodology and research results of newly developed materials from post-production fibrous waste that are resistant to high temperatures. Widely available raw materials were used for this purpose. Such approach has significant impact on the technological feasibility and preparation costs. Obtained materials were verified via applying of various tests including characterization of shrinkage, porosity, density and water absorption as well as X-ray analysis (XRD), followed by mechanical bending and compressive strength determination.

Based on the research results, the possible applications of materials as thermal insulators were indicated.

Keywords: waste, thermal insulation, ceramic, porosity, fibers

1. Introduction

Thermally-insulating materials are still one of the most significant aspects in the area of materials engineering [1-3]. The development of this field leads to the design of modern and mechanically and thermally durable materials. The improvement of such properties can reduce dimensions of thermal insulation that highlights the following statement: the development of a product fabricated from post-production fibrous waste which is resistant to high temperatures might increase its competitiveness compared to commonly-applied commercial products.

Due to availability of natural resources and simple technological process to fabricate products from post-production waste and because of good mechanical and thermo-insulating properties, it is predicted that both in Poland as well as in the entire Europe such a product may find its niche market as well as customers willing to get the license for this technology.

The materials with high mechanical and thermal durability, and high quality are continually sought. Hence, the technology presented in the paper and the type of the obtained material perfectly fit current trends.

Based on the available literature [4-7], suggesting the possibility of changing the properties of materials through the use of appropriate raw materials and additives, two types of thermal insulation materials that could be used in industry, were developed.

Thermal insulations, used in high-temperature conditions, are materials and their systems that, in direct or indirect contact with hot media (flames, gases, liquids, solid materials, melts, etc.) reduce the heat emission from the source to the environment or the neighboring area. For this reason, they are applied as thermal barriers between various media in the wide range of temperatures.

Due to this property, to describe them the term of "high-temperature insulation" is used.

However, based on the raw material applied, thermal insulation materials are classified into two fundamental groups: organic and inorganic.

Organic materials have lower strength and they are less useful in exploitation because they are more hygroscopic and more susceptible to the destructive effects of moisture. Also they are insufficiently resistant to high temperatures (up to 100ºC). Inorganic materials do not have these disadvantages. They operate well in very high temperatures.

In terms of a structure, the following products can be divided into:

- fibrous,
- porous (foamed, cellular),
- granular (including cellular structure) [8].

The available literature shows limited examples of the use of fibrous waste materials, intended for thermal insulation applications.

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2. Experiment

The main goal of the work were technology and examine the properties of the new materials obtained from fibrous waste.

2.1. Materials

In this paper, the basic component applied as a post-production waste is ceramic nonwoven fabric (mainly SiO_2 compounds) - newly developed product. Additionally, to form the composite material, another ingredients were added to the mixture in the amount of a few percent that include: bentonite, calcium oxide, water glass, cationic starch, orthophosphoric acid, silica in colloidal form and demineralized water.

3. Research methodology, results and discussion

3.1. Technology

The obtained samples marked as TC1 and TC2, differing mainly the content of bentonite, starch, and orthophosphoric acid, were thoroughly mixed in a ceramic mortar during 25 minutes, by adding plasticizing agents. Commonly available raw materials were used for the preparation.

The samples were prepared in the form of bars using hydraulic press and applying pressure of 25-30 kG/cm^2.

Drying and sintering temperatures of samples were experimentally selected based on the literature [9,10] and previous own experience [11]. After drying all samples were sintered using Nabertherm high-temperature furnace at the temperature of 830°C, 1050°C, 1200°C and 1320°C (Fig. 1).

3.2. XRD method analysis

Diffractometric studies of structure composition (XRD) were performed on samples of newly obtained materials to determine the main phases in the materials. The analysis was performed by a DRON + 2 powder diffractometer by step-registered method Co radiation with Fe filtration. The identification of crystalline phases was carried out based on PDF (Powder Diffraction Files) file data, which consists of comparing interplanar distances and reflection intensities.

Based on the diffractometric analysis, it was found that the obtained materials were mainly SiO_2 compounds (hydrated silicate – opal $SiO_2 \cdot H_2O$, cristobalite (silicon dioxide) and CaO calcium compounds). The diffraction spectra of the examined samples do not differ significantly – there are large amounts of weak reflections with similar angular positions. Examples of diffractograms of obtained materials are presented in Fig. 2 and Fig. 3.

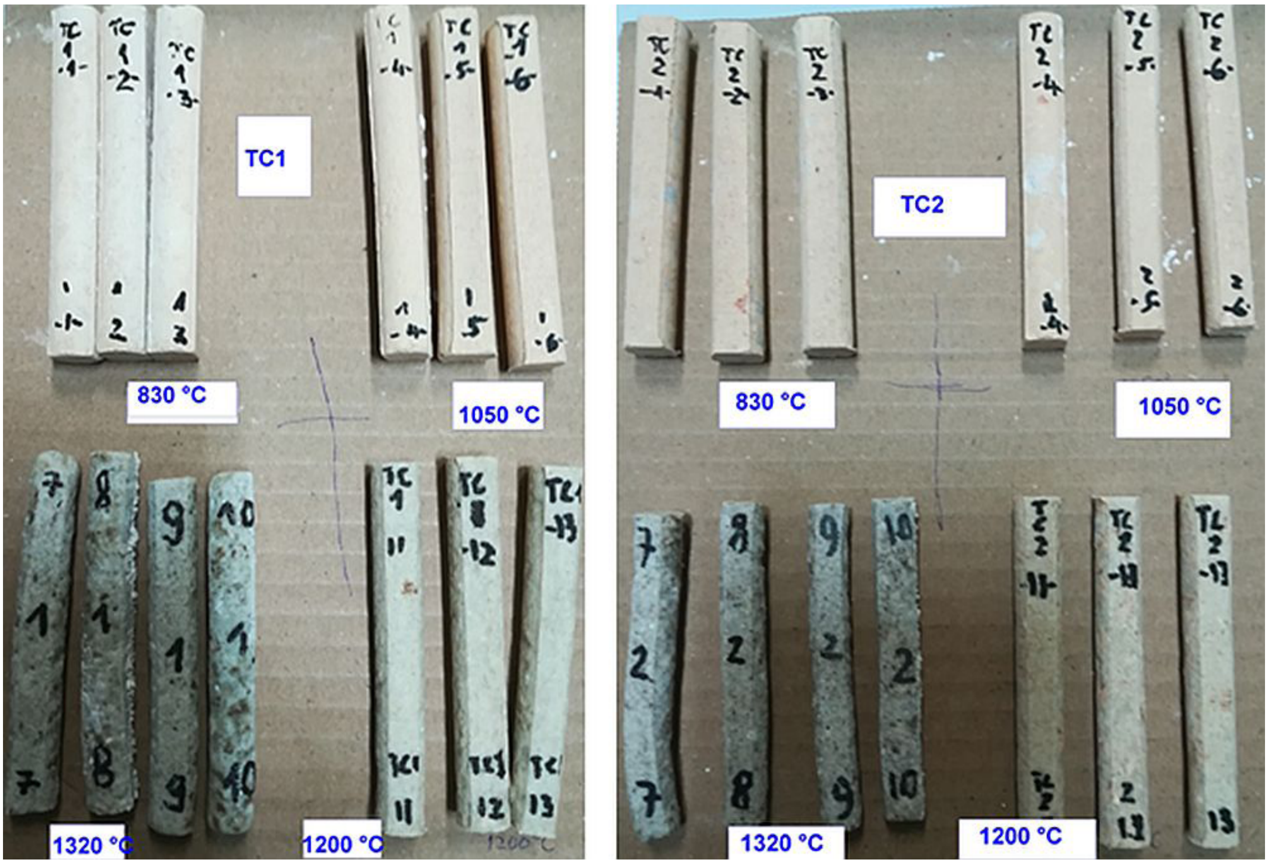
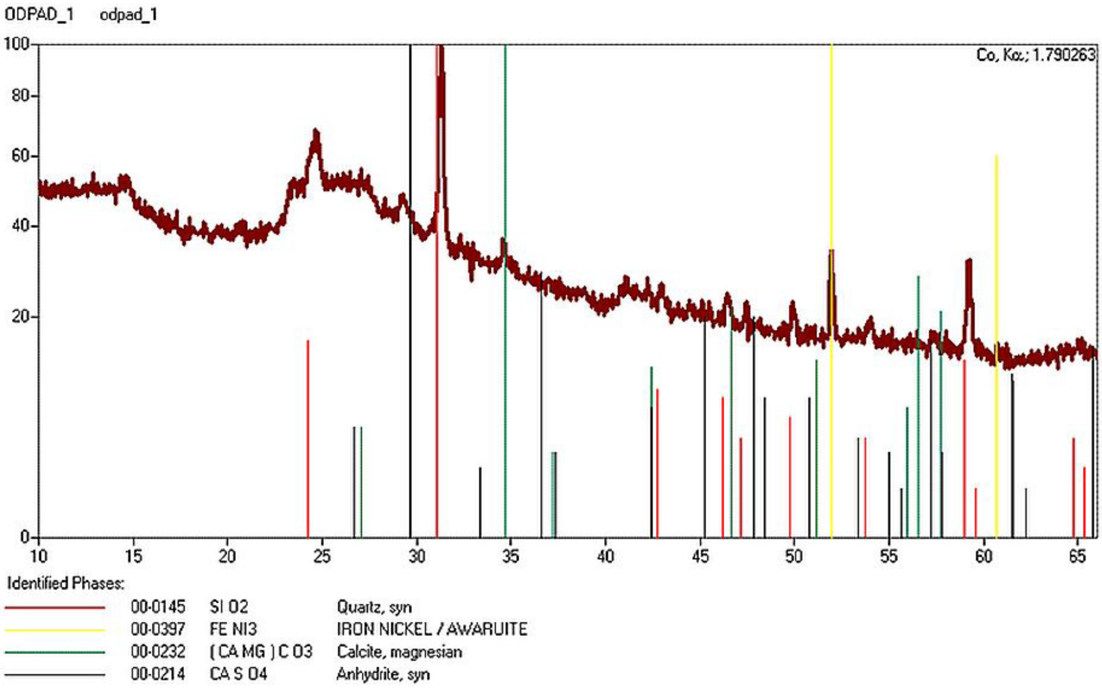
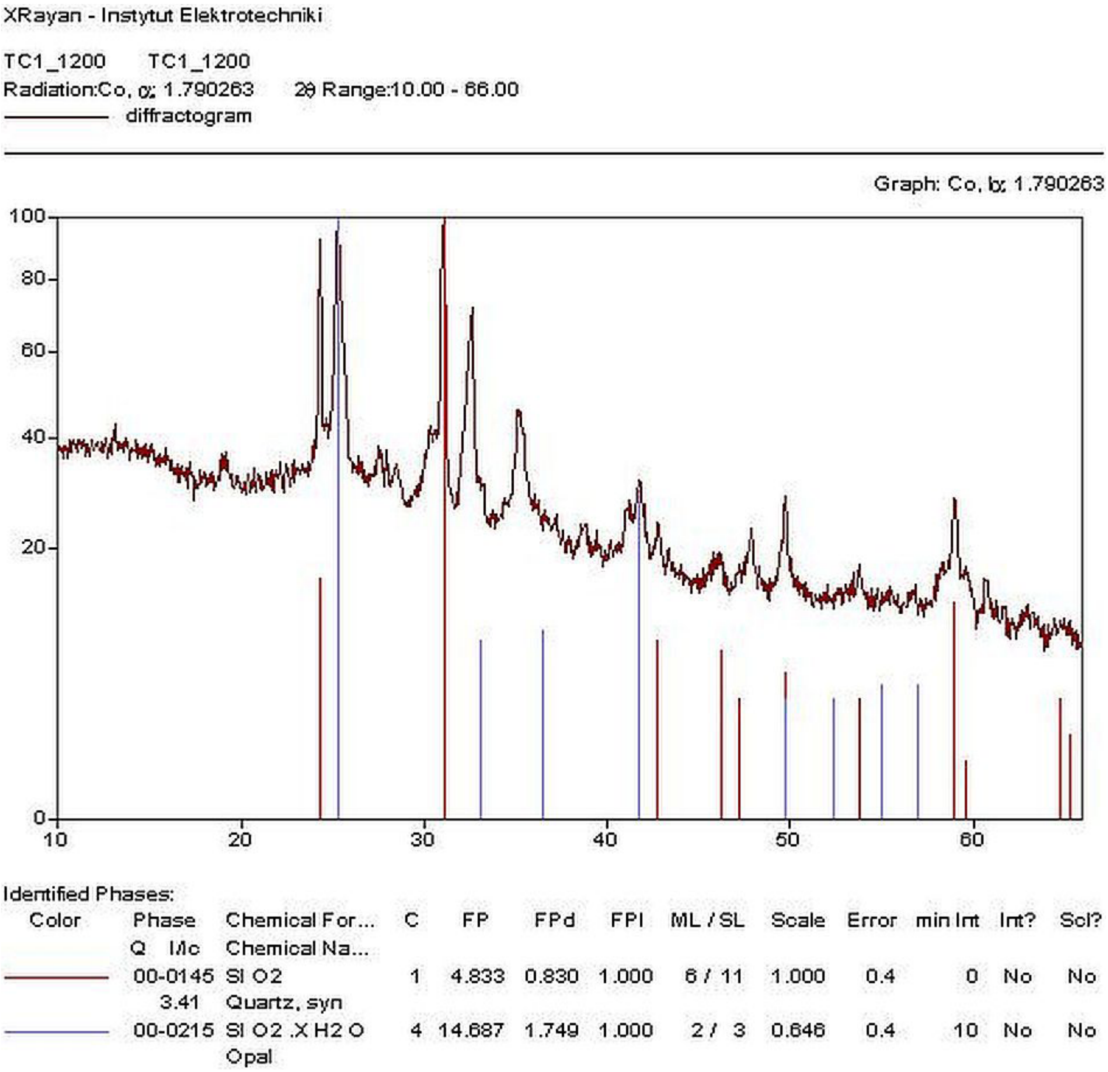


Fig. 1. The examples of particular samples after sintering at the following temperatures: 830°C, 1050°C, 1200°C and 1320°C, a) mass TC1 b) mass TC2



—	00-0145	SI O2	Quartz, syn
—	00-0397	FE NI3	IRON NICKEL / AWARUITE
—	00-0232	(CA MG) C O3	Calcite, magnesian
—	00-0214	CA S O4	Anhydrite, syn

Fig. 2. Diffractometric analysis of waste (raw) material



Color	Phase Q I/Mc	Chemical For... Chemical Na...	C	FP	FPd	FPI	ML / SL	Scale	Error	min Int	Int?	Scl?
—	00-0145 3.41	SI O2 Quartz, syn	1	4.833	0.830	1.000	6 / 11	1.000	0.4	0	No	No
—	00-0215	SI O2 .X H2 O Opal	4	14.687	1.749	1.000	2 / 3	0.646	0.4	10	No	No

Fig. 3. Diffractometric analysis of material marked as TC1 sintered at 1200°C

3.3. Weight loss and shrinkage

The lowest weight loss values were measured for TC1 sample sintered at 1200°C. The weight loss value was ~12%. The highest weight loss values were measured for material marked as TC2 sintered at 1050°C (~22%).

Shrinkage of the obtained material marked as TC1, depending on sintering temperature, was from 1% (for 830°C) to 8% (for 1200°C).

Interestingly, in the case of sintering at 1320°C, an increase in volume was observed. It probably results from the adhesion of the alumina ballast.

Additionally, an impact on these phenomena had the growth of grains and gassing, which was caused by the reaction of one of the components of the obtained material.

For the material labeled as TC2, shrinkage was ranged from 3% (for 830°C) – 8% (for 1320°C). Samples of TC2 material did not show any increase in size or grain growth after sintering at 1320°C.

3.4. Physico-chemical properties

Density, open porosity, and absorbability of the obtained materials were determined by the hydrostatic weighing method. The results of the measurements are presented in Fig. 4 and Fig. 5.

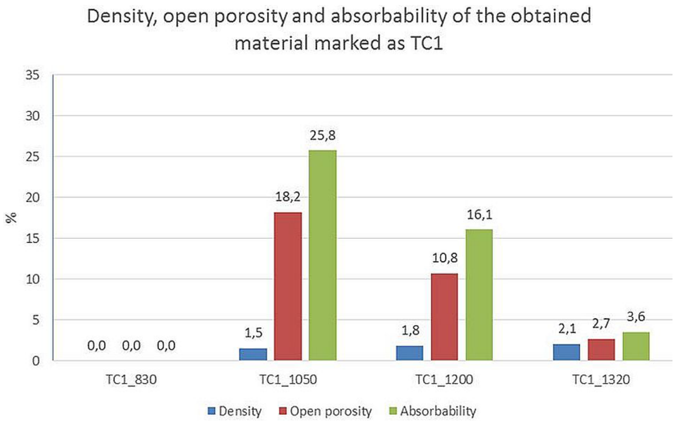


Fig. 4. Density, open porosity and absorbability of the obtained material marked as TC1

For both tested materials – TC1 and TC2 – subjected to thermal treatment at 830°C, the density, open porosity, and absorbability could not be determined – the samples were damaged/crushed (the samples were saturated with water during cooking. The sample of TC2 material sintered at the highest temperature at 1320°C was characterized by the highest density (2.2 Mg/m^3), and therefore the lowest porosity (0.8%) and water absorption (1.1%). The open porosity and water absorption of the TC2 material in the temperature range of 1050°C-1200°C are lower than that of TC1 material. At the sintering temperature of 1320°C, the situation is opposite. The density measurement shows an upward trend as the sintering temperature increases.

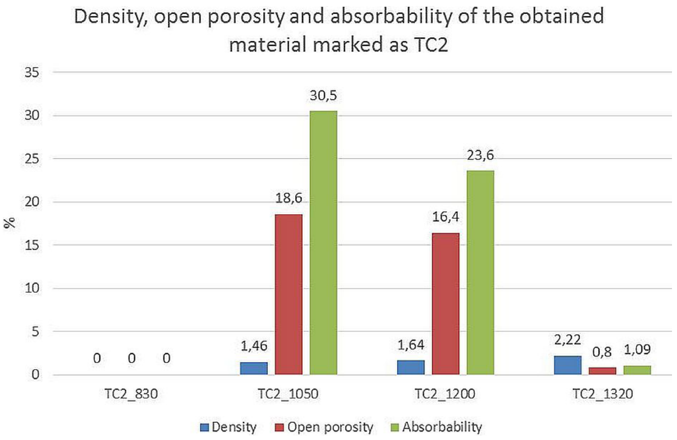


Fig. 5. Density, open porosity and absorbability of the obtained material marked as TC2

After cutting the samples, large pores are visible inside the materials (Fig. 6). This is an advantage of thermal insulation applications. The pores in the material act as thermal insulation and with inorganic raw materials there is an additional advantage: non-flammability.

However, high open porosity can significantly affect the mechanical properties, therefore in the next step, mechanical strength tests were performed.

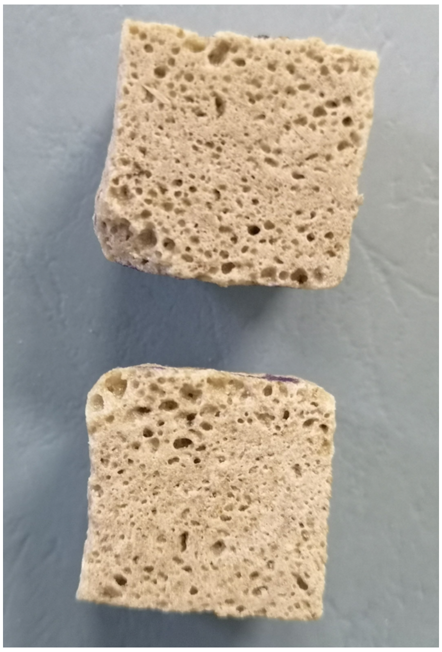


Fig. 6. Large pores of TC1 material sintered at 1290°C

3.5. Mechanical bending strength

The mechanical bending strength was measured for 5 samples of each type of obtained material, sintered at different temperatures. Measurements were carried out on samples in the form of bars of ca. 10 mm in diameter and 75 mm long. To perform these tests, the Rauenstein mechanical strength machine was used. The test results are shown in Fig. 7.

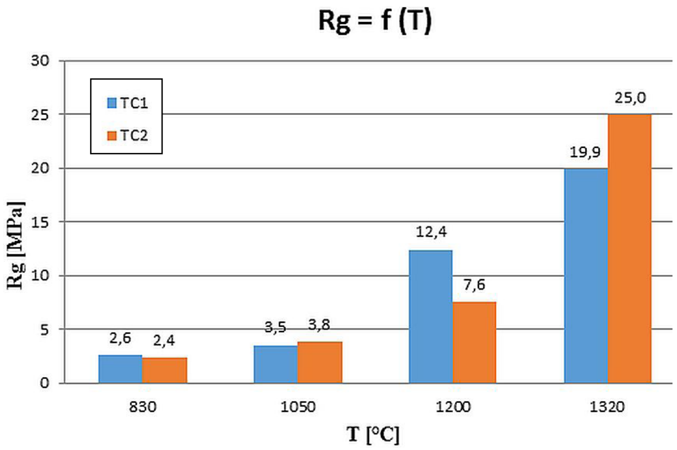


Fig. 7. Mechanical bending strength *Rg* of the samples versus temperature of sintering

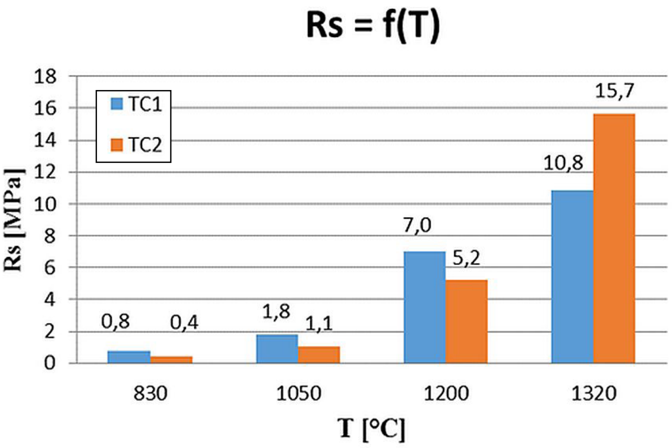


Fig. 8. The results of mechanical strength *Rs* of the examined samples

It was found that the samples marked as TC1 and TC2 sintered at temperature of 1320°C were characterized by the highest mechanical bending strength (*Rg* = 19.9 MPa and 25.0 MPa, respectively). High mechanical bending strength has also the TC1 sample sintered at 1200°C (*Rg* = 12.4 MPa).

In the tested samples (both types), an upward trend occurs at higher sintering temperatures. This is due to an increase in density and a decrease in the porosity of the samples. This is typical behavior for ceramic materials [12]. The largest increase in mechanical strength in the case of samples marked as TC1 was observed when the sintering temperature increased from 1050°C to 1200°C. This increase (*Rg*) was about 3.5 times. Another increase in the sintering temperature did not give such a significant change in mechanical strength.

For the samples of the TC2 material, the improvement of mechanical bending strength was observed by almost 4 times when the sintering temperature was scaled up from 1200°C to 1320°C.

With reference to TC1 material, the highest strength value determined for samples sintered at 1320°C is about 20% higher.

3.6. Mechanical compressive strength

The mechanical compressive strength was measured for 5 samples of each type of obtained material sintered at different temperatures. Measurements were carried out on samples in the form of bars of ca. 10 mm in diameter and 20 mm high. To realize these tests, the Raunstein mechanical strength machine was used. The results are shown in Fig. 8.

Compressive strength of thermal insulation materials is within the limits of 0.1-1.5 MPa, occasionally reaching 5.0 MPa however only in a few cases it exceeds 5.0 MPa [13]. In our case, most of the studied materials were within the 0.1-1.5 MPa limit. The highest values of mechanical compressive strength are obtained by using heat treatment as a processing method in this case.

At a sintering temperature of 1320°C for TC1 and TC2 samples and additionally for TC1 sample sintered at lower temperature of 1200°C, the results of experiment revealed very high values of compressive mechanical strength. The largest increase (more than 3-times) of mechanical strength Rs was observed for TC1 when the temperature was elevated from 1050°C to 1200°C. Relevant phenomenon was also detected for TC2 samples, however in this case the temperature was scaled up from 1200°C to 1320°C (*Rs* from 5.2 to 15.7 MPa). With regard to TC1 material, the highest strength value determined for samples sintered at 1320°C is 30% higher (*Rs* TC1 = 10.8 MPa, *Rs* TC2 = 15.7 MPa).

Additionally preliminary abrasion tests (kinematic coefficient of friction) were carried out using the CEZAMET machine. The results are interesting because the material could not be ripped like other abrasives. This is the promising outcome for the future study.

4. Conclusions

A new technology of high temperature insulating material based on the fibrous waste was established.

In this work the physicochemical and mechanical tests of newly obtained materials based on waste ceramic nonwoven fabric were presented.

Technological simplicity and the results of the analysis is optimistic in terms of various possible applications of materials.

It is interesting that these materials are characterized by high porosity thus they could be applied as thermal insulation. The air trapped in the pores creates additional thermal insulation.

The materials do not contain organic compounds, which is an additional advantage – their non-flammability.

The performed mechanical analysis allows to conclude that despite the high porosity and low specific weight of the samples after heat treatment, they are characterized by high mechanical strength – taking into account this type of material.

Additionally preliminary abrasion tests (kinematic coefficient of friction) were carried out using the CEZAMET machine.

The results were surprising. The material could not be ripped like other abrasives. The materials were very resistant to such activities.

This, in turn, allows the application of the obtained material as a product for the fabrication of elements in the form of, for instance, furnace linings or as building construction materials for special applications (filling switchgear, etc.), and materials used in special buildings exposed to fire.

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