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Effect of Bentonite Clay Addition on the Thermal and Mechanical Properties of Conventional Moulding Sands

J. Kamińska *, S. Puzio, M. Angrecki
ŁUKASIEWICZ Research Network - Foundry Research Institute,
Zakopianska 73, 30-418 Cracow, Poland
* Corresponding author. E-mail address: jadwiga.kaminska@iod.krakow.pl

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Abstract

Bentonites and clays are included in the group of drilling fluids materials. The raw materials are mainly clay minerals, which are divided into several groups, like montmorillonite, kaolinite, illite, biotite, muscovite, nontronite, anorthoclase, microcline, sanidine or rutile, differing in chemical composition and crystal lattice structure. Clay minerals have a layered structure forming sheet units. The layers merge into sheets that build up to form the structure of the mineral.
The aim of the studies carried out in the ŁUKASIEWICZ Research Network - Foundry Research Institute is to explore the possibility of using minerals coming from Polish deposits.
The article outlines the basic properties of hybrid bentonites, which are a mixture of bentonite clay called beidellite, originating from overburden deposits of the Turoszów Mine, and foundry bentonite from one of the Slovak deposits.
As part of the physico-chemical tests of minerals, measurements included in the PN-85/H-11003 standard, i.e. montmorillonite content, water content and swelling index, were carried out. Additionally, the loss on ignition and pH chemical reaction were determined.
Based on the thermal analysis of raw materials, carried out in the temperature range from 0 to 1000^{o}C, changes occurring in these materials during heating, i.e. thermal stability in contact with liquid metal, were determined.
Examinations of the sand mixture based on pure clay and bentonite and of the sand mixture based on hybrid bentonites enabled tracing changes in permeability, compressive strength and tensile strength in the transformation zone as well as compactability referred to the clay content in sand mixture. Selected technological and strength parameters of synthetic sands are crucial for the foundry, because they significantly affect the quality of the finished casting.
Based on the analysis of the results, the optimal composition of hybrid bentonite was selected.

Keywords: Bentonite, Bentonite clay, Moulding sand, Montmorillonite, Strength properties

1. Introduction

The current state of foundry industry and development trends clearly indicate that both now and in the future the basic materials for disposable foundry moulds will be synthetic sands with bentonites. Statistical data shows that over 75% of the world production of iron alloy castings is made in conventional moulding sands with bentonite [1-5].

Bentonite moulding sands are commonly used in foundry industry to make green sand moulds [6, 7]. The versatility of their application is mainly due to the low cost of materials used in these sand mixtures. Further reduction in the cost of moulding sand with bentonite results from the possibility of its multiple use. After each casting knocking out operation, the used moulding sands are subjected to the rebonding process by adding an appropriate amount of fresh moulding materials such as sand and bentonite. Rebonding is one of the final steps in the process of preparing the sand mixtures for further use [8, 9].

In Poland, the bentonite deposits occur in very small quantities. The exploitation of bentonites is carried out only in the Krzeniów deposit, where they constitute a mineral accompanying basalt. Much more common are bentonite clays containing in addition to smectites also a large amount of other clay minerals [10].

Polish demand for raw bentonite materials is almost entirely satisfied by imports from Slovakia, Turkey, Italy, Germany and the Czech Republic, in order of import size. The total import of bentonite amounts to over 122 thousand tons per year. At the same time, Poland exports this raw material, among others, to Russia, Germany and Belarus in the amount of about 23 thousand tons [11, 12].

2. Test materials and methods

As part of physical and chemical tests, measurements of montmorillonite content, swelling index, loss on ignition and pH chemical reaction of clay and bentonite and of the resulting hybrid bentonite were made. The bentonite clay came from a Polish mine, while foundry bentonite from Slovak deposits.

The content of montmorillonite was determined by two methods, i.e. adsorption of methylene blue (BM) and a modern spectrophotometric method of adsorption of Cu (II) copper - triethylenetetramine (Cu-TET) complex. The examination of the sand loss on ignition (LOI), which consisted in heating the previously dried sample of the sand, was carried out in a CZYLOK high-temperature chamber furnace, model FCF 4/160M, at a temperature of 900°C for 2 hours. The swelling index was determined by standard procedure.

Thermal analysis was carried out to assess the effect of temperature on the tested materials. The STA 449F3 Jupiter thermal analyzer coupled with QMS 403C Aëolos for the study of TG-DTA-DSC-Cp curves was used for the tests. During thermal analysis, the samples were heated to 1000°C at a constant heating rate of 10°C/min.

The effect of clay content on several parameters of conventional moulding sands with various bonding materials was also determined. Moulding mixtures were prepared using medium silica sand with the main fraction 0.32/0.20/0.16 supplied by Sibelco. Before preparation of sand mixtures, both clay materials and base silica sand were subjected to the drying process carried out at 105°C. In accordance with the guidelines given in [13], the tested conventional sand mixtures were composed of 100 parts by weight of silica sand and 7 parts by weight of bentonite. The tests were carried out for the four assumed sand moisture contents, i.e. 2,5; 3,0; 3,5 and 4,0%. The determination of moisture content in the sand mixture showed that the values obtained in practice did not deviate from the assumed values by more than ± 0.1%. Six bentonites with different clay binders were used in the tests.

The following designations were adopted: Bentonite - pure sodium bentonite; Clay - pure bentonite clay; 90/10, 85/15, 80/20, 70/30 - blends of hybrid bentonites containing 10, 15, 20 and 30% of bentonite clay, respectively.

3. Test results and discussion

3.1. Physical and chemical tests

Table 1 summarizes the basic properties of clays and bentonites.

Compared to bentonite, the bentonite clay is characterized by a much lower content of montmorillonite. The standard assumes that bentonite should contain at least 75% of montmorillonite, but products currently available on the market often contain 65% of montmorillonite, and therefore a 70/30 mixture containing 74% of montmorillonite was also selected for further studies.

Greater ability to swell freely indicates higher sorption capacity, i.e. the amount of water that can be absorbed by bentonite between sheet units. Increasing the amount of clay in hybrid bentonite causes gradual decrease in its swelling index.

Table 1.
Basic physico - chemical properties of the tested minerals

Bentonite/ clay ratio	Montmorillonite content, %	Swelling index, ml/2g	LOI, %	pH	W, %
100 Bentonite	87.3	38	9.23	10.39	2.34
90/10	79.3	25	9.42	10.61	5.08
85/15	78.7	24	9.61	10.33	5.03
80/20	75.6	23	9.76	10.70	4.93
70/30	74.0	19	9.84	10.24	4.72
100 Clay	65.8	6	10.32	10.55	1.87

3.2. Thermal analysis

Derivatographic studies allowed the thermal and differential thermogravimetric analyses to be conducted simultaneously. Changes occurring in the samples during heating were recorded in the form of two curves:

- TG curve showing changes in the temperature of the sample as a function of the heating time,
- DTG differential plot showing loss of sample mass on heating.

The obtained waveforms correspond to the typical course of changes occurring in bentonites [14, 15].

For all materials tested, the thermal analysis carried out showed similar course of the TG, DTG and DTA curves in the range of 0°-300°C. The TG curves initially show a significant loss of sample mass, which is the result of the water evaporation process. In the range of 300-1000°C, the loss of mass results from the removal of water contained in the bentonite structure (interlayer water) along with the small amount of organic additives. In this temperature range, the differences between individual samples are already well visible, which indicates some differences in their chemical composition.

In the case of Bentonite (Fig. 1), the maximum loss of sample mass took place at a temperature of approximately 140°C. In the next stage, the loss of sample mass was increasing, which was due to the removal of bound water and probably the low content of organic impurities. In this range, the maximum value was recorded at 680°C. The mass loss in Bentonite was the highest among all the tested materials, which means that it contained the largest amount of organic additives.

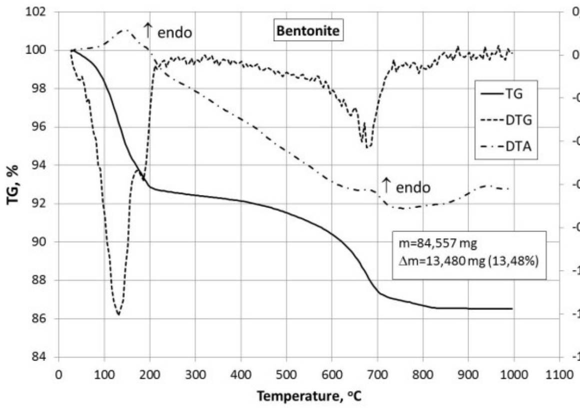

Fig. 1. The results of derivatographic analysis for Bentonite. Sample weight m = 84.555 mg; weight loss Δm = 13.480 mg (13.48%). Heating speed - 10°C/min

In the case of Clay (Fig. 2), the maximum loss of mass in the first stage was obtained at a temperature of 140°C. The next maximum was obtained at 500°C.

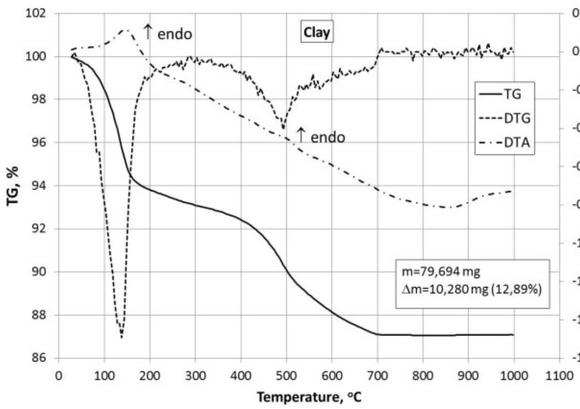

Fig. 2. The results of derivatographic analysis for Clay. Sample weight m = 79.694 mg; weight loss Δm = 10,208 mg (12.89%). Heating speed - 10°C/min

In the analysis of 90/10 hybrid bentonite (Fig. 3), the occurrence of peaks responsible for water evaporation was observed at 130°C and 190°C. The peak that occurred at 680°C was due to the presence of organic substances.

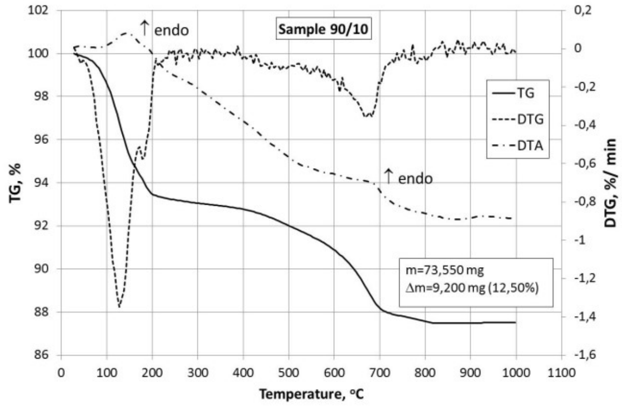

Fig. 3. The results of derivatographic analysis for 90/10 hybrid bentonite. Sample weight m = 73.550 mg; weight loss Δm = 9.220 mg (12.50%). Heating speed - 10°C/min

The first peaks of the loss of sample mass in 85/15 hybrid bentonite (Fig. 4) appeared at 130°C and 190°C. In the next stage, the maximum has occurred at a baking temperature of approximately 660-680°C.

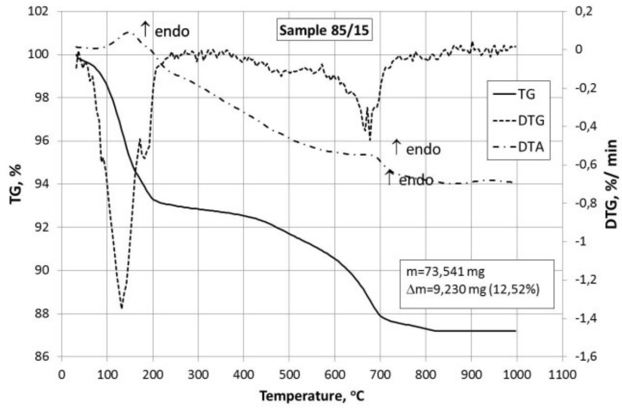

Fig. 4.The results of derivatographic analysis for 85/15 hybrid bentonite. Sample weight m = 73.541 mg; weight loss Δm = 9.230 mg (12.52%). Heating speed - 10°C/min

The first peaks associated with water evaporation in 80/20 hybrid bentonite appeared at 105°C, 120°C and 190°C (Fig. 5). The next peak derived from the process of removing bound water and various organic additives was observed at a temperature of about 680°C.

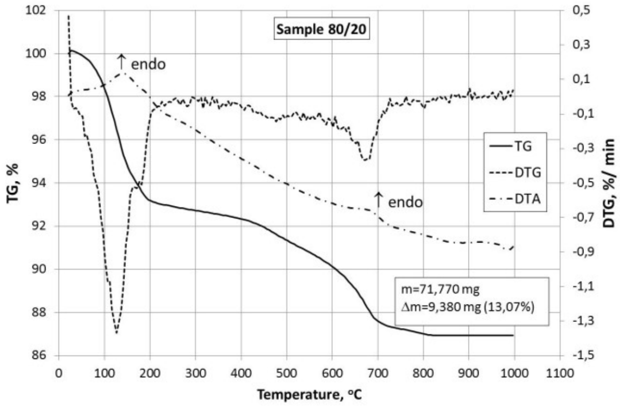

Fig. 5. The results of derivatographic analysis for 80/20 hybrid bentonite. Sample weight m = 71.770 mg; weight loss Δm = 9.380 mg (13.07%). Heating speed - 10°C/min

The first peaks of the loss of sample mass in 70/30 hybrid bentonite appeared at 130°C and 195°C (Fig. 6). The next intense peak occurred at 680°C. The mass loss in 70/30 bentonite was the lowest among all the tested materials, which means that it contained the smallest amount of additives.

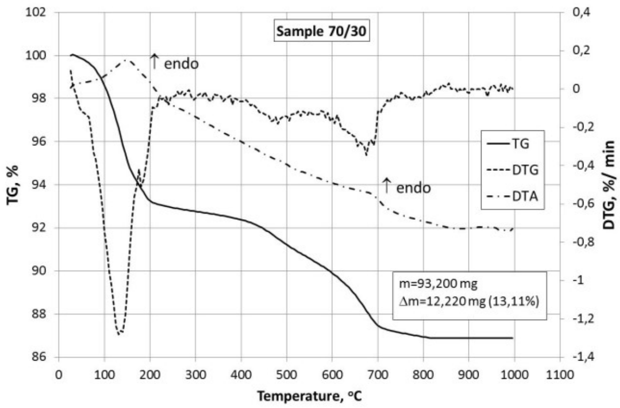

Fig. 6. The results of derivatographic analysis for 70/30 hybrid bentonite. Sample weight m = 93 200 mg; weight loss Δm = 12.220 mg (13.11%). Heating speed - 10°C/min

3.3. Permeability

The permeability was measured on an LPiR-3e type apparatus. With increasing moisture content, the permeability value was decreasing (Fig. 7). The sand mixture based on pure clay was characterized by the highest permeability of 395 x 10-8m^2/Pa·s at a moisture content of 2.5%. The lowest value of this parameter was obtained for the sand mixture based on 70/30 hybrid bentonite (211 x 10-8m^2/Pa·s at a 4.0% moisture content). The data presented in the graph are the arithmetic mean of three measurements with values not deviating from the mean by more than ± 5%.

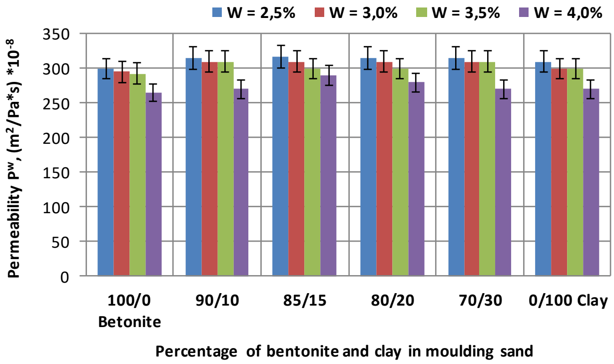

Fig. 7. The effect of clay content on the permeability P^w of the tested sand mixtures

3.4. Compressive strength

The green compressive strength was tested on standard cylindrical specimens using a universal LRu-2e strength measuring device. In the examined range of moisture content values, the compressive strength of the sand mixtures was decreasing with increasing moisture content (Fig. 8). The highest green compressive strength for all the tested compositions was obtained in the sand mixtures with a moisture content of 2.5%. The sand mixture based on pure bentonite has reached the highest compressive strength value (above 0.09 MPa at a 2.5% moisture content). Despite the low content of montmorillonite in clay (68.5%), the sand mixtures prepared with this clay have also reached a high value of the strength. The data presented in the graph are the arithmetic mean of five measurements with values not deviating from the mean by more than ± 5%.

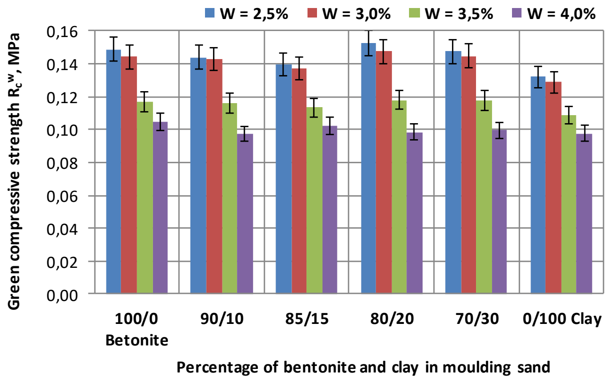

Fig. 8. The effect of clay content on the compressive strength R_c^w of the tested sand mixtures

3.5. Tensile strength in the transformation zone

The measurement of tensile strength in the transformation zone was performed for 20 seconds at 310°C using an LRP device. The test consisted in heating a flat surface of the green moulding sand, which caused water evaporation and movement inside the sand. Water vapour condensed on the sand layers with a temperature of less than 100°C forming a transformation zone. The tensile strength in this zone was characterized by a relationship inverse to compressive strength (Fig. 9). With moisture content increasing in the sand mixture, the value of the tensile strength in the transformation zone was also increasing. For all the adopted moisture content values, the sand mixture based on 80/20 hybrid bentonite had the highest strength values. The maximum has occurred at a moisture content of 4.0% and amounted to 528 N/cm^2. The data presented in the graph are the arithmetic mean of five measurements with values not deviating from the mean by more than ± 5%.

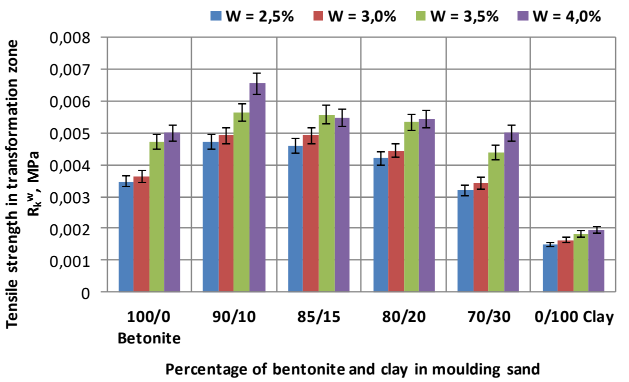

Fig. 9. The effect of clay content on the tensile strength in the transformation zone R_k^w of the tested sand mixtures

3.6. Compactability

The measurement of compactability was performed on an LPr-2e apparatus. For all tested compositions, the compactability of sand mixtures was increasing with the increase in moisture content (Fig. 10). The values of compactability obtained for the sand mixtures based on hybrid bentonites were comparable with the values of this parameter obtained for the sand mixtures based on pure bentonite. The data presented in the graph are the arithmetic mean of three measurements with values not deviating from the mean by more than ± 5%.

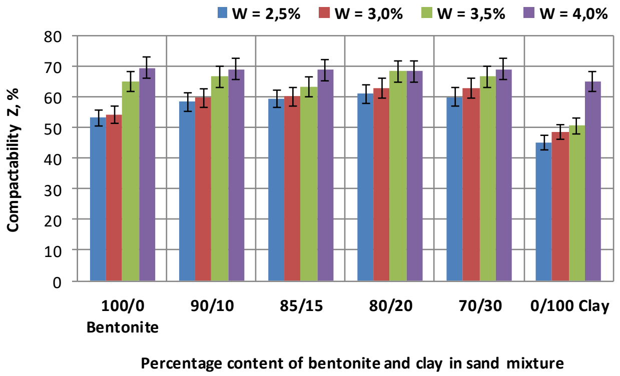

Fig. 10. The effect of clay content on the compactability Z of the tested sand mixtures

4. Conclusions

The research carried out allowed drawing the following conclusions:

- Bentonite is characterized by a much higher content of montmorillonite, increased binding capacity, greater swelling capacity and resistance to the temperature of liquid metal. Increasing the amount of clay in hybrid bentonites causes gradual decrease in montmorillonite content and swelling index.
- The conducted thermal analysis showed that the obtained waveforms correspond to the typical course of changes occurring in bentonites. In the case of clay, the temperature of the characteristic second peak, related to the removal of bound water and the content of organic pollutants, is shifted to a lower temperature of about 500°C. The loss of mass for bentonite is the highest among all the tested materials, which means that it contains the largest amount of organic additives.
- The content of montmorillonite and the obtained green compressive strength values allowed the first two of the prepared hybrid bentonites with a bentonite-to-clay percentage ratio of 90/10 and 85/15 to be classified as grade I according to PN-85/H-11003.
- Among all the tested hybrid bentonites, the sand mixtures based on bentonites with the percentage composition of 85/15 and 80/20 were characterized by the most favourable strength properties and technological parameters.

The results of the studies confirm that it is possible to use some of the domestic bentonite clays and process them into a high-value clay binder intended for the foundry industry.

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