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Properties of Bentonites and Bentonite Mixtures used in Casting Processes

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Abstract

In this work, an assessment and comparison of the quality of selected bentonites and bentonite mixtures was made. The samples consisted of available foundry materials used for bonding green sands. Determining the homogeneity degree and specific surface area of the grains allowed us to compare the examined materials and determine their influence on other parameters. On the basis of a thermal analysis of the bentonites or bentonite mixtures, the changes occurring in the sample during its heating were determined. Determining the potential for ion exchange and montmorillonite content enabled us to assess the binding properties of the materials. The preparation of six green sands with different bentonites or bentonite mixtures gave us the opportunity to assess the changes in apparent density, permeability, compressive strength and friability as a function of humidity, and the impact of different materials on the mentioned parameters. Their charts were analyzed, and the molding sand with the addition of bentonite or a bentonite mixture was selected for which these parameters are favorable. On this basis, the best-presented binding material was assessed and selected.

Keywords: Green Sands, Bentonite, Bentonite Mixture

1. Introduction

Green sands are often used in the foundry industry [1, 2, 3, 8]. They mainly owe their popularity to the cheap readily available materials and satisfactory strength after drying and under damp conditions. They also have their disadvantages, including their low liquidity and inability to be used in the production of cores [1]. Sands with bentonite are not harmful to the environment itself – only the introduction of coal dust or other additives which are its carriers increases the harmfulness of these sands. However, these additives are necessary for obtaining castings without defects and helping them when they are shaken out [4]. Bentonite containing at least 70% montmorillonite is used as the binding material in green sands. The most desirable features are sodium bentonites; these reveal the considerable ability to swell, are more resistant to high temperatures, and have better binding properties

than other bentonites [1]. Sodium bentonite absorbs and retains a significant amount of water. It is a good material for green sand, which requires high hot strength and dry strength [2]. One of the reasons for the use of bentonite in the form of a binder material is the possibility of its repeated use. In practice, only a small part of it undergoes the process of deactivation [5]. In some cases, facing sands are made from new materials [6].

Montmorillonite is the basic component of bentonite and is assigned to the group of hydrated aluminosilicates. The ability for ion exchange results from the presence of ionic bonds between packets. This property is used to carry out the activation process [7]. Activation allows us to obtain more-favorable properties of bentonite. The literature provides information on the influence of various activating agents on bentonites [3]. The characteristics of green sands are also available [8], as are the particular issues including the flowability of green sands [9].

In terms of quality, bentonite is evaluated based on its montmorillonite content, durability, and bond strength. To assess the properties of bentonites, many tests can be carried out (including thermal analysis – DTA) [10]. The bentonite used in foundries has to meet certain requirements; in particular, a high content of montmorillonite and thermal stability are important. In addition, it should be as little sensitive as possible to the introduction of the used sands additives, and it also should not cause changes in it. Bentonite is primarily a bonding material, so it must fulfill its function to the best possible extent, giving green sands the appropriate strength, compactibility, and fluidity. Bentonite should have the least amount of so-called accompanying materials and contain little iron, and it should manifest high cation exchange ability. During storage, good quality bentonite should not lose its quality; this is an additional advantage is its low cost and availability [11].

The continuous striving to improve the efficiency and quality of castings while caring for the environment creates the need to optimize the properties of molding sand. The use of bentonite and good quality additives reduces emissions and waste [10]. The necessity to improve the properties of green sands makes it necessary to conduct research to improve them.

2. Materials and Methods

The qualitative assessment of bentonites and bentonite mixtures required a number of measurements. A sieve analysis of the bentonites and bentonite mixtures using a pneumatic method was carried out in order to determine their parameters. A thermal analysis was also carried out to assess the effect of temperature on the tested material. A derivatograph was used for the research. During the thermal analysis, the samples were heated to a temperature of 1000°C at a constant heating rate of 10°C/min. Using the spectrophotometric method of the Cu (II)-triethylenetetramine complex, the ion exchange capacity and montmorillonite content in the selected materials were determined. A Hach VIS ODYSSEY DR/2500 VIS spectrophotometer with automatic wavelength calibration was used for the study (using a 620-nm wavelength for measurements).

The effect of humidity on various parameters of classic molding sands with different bentonites or bentonite mixtures was also determined. The prepared sands consisted of 100 parts by weight of quartz sand and 8 parts by weight of bentonite according to the guidelines provided in the source [1]. The tests were carried out for six bentonites and bentonite mixtures containing carbon carriers. In order to test the molding sand parameters, three measurements were taken for each of them, and the average was removed. The following designations were adopted: bentonite mixtures (A, B, C), and bentonites (D, E, F). Bentonite D - activated bentonite, Bentonite E – calcium bentonite, Bentonite F – sodium bentonite.

3. Analysis of obtained results

3.1. Sieve analysis

A sieve analysis of the bentonites and bentonite mixtures was carried out using the pneumatic method based on the PN-83/H-11077 standard. Table 1 lists the selected parameters of the bentonites and bentonite mixtures determined on the basis of the sieve analysis. When comparing individual samples, differences were observed between the degree of homogeneity (GG) and the surface area (S_s).

Table 1.
Selected parameters of sieve analysis for individual samples

Sample	Average grain size d_L [mm]	Surface area S_s [m^2/kg]	Degree of homogeneity GG [%]
A	0.04	85.29	59
B	0.04	79.03	51
C	0.04	76.87	48
D	0.03	98.91	81
E	0.03	97.96	78
F	0.03	94.71	75

Based on the obtained results, it was noted that there are no significant differences in the average size of the grains. The most homogeneous material is Bentonite D. The least homogeneous mixture is Bentonite Mixture C. In the analyzed cases, it was observed that a high degree of homogeneity (GG) also revealed a high value of the surface area (S_s).

In summary, Bentonites D, E, and F are materials with higher values of degree of homogeneity (GG) and the surface area (S_s) than Bentonite Mixtures A, B, and C.

3.2. Thermal analysis

Thermal analysis showed similar charts of the TG, DTG, and DTA curves within a range of 0°-300°C for the analyzed materials. The TG curve initially shows a significant loss of mass in the test sample (resulting from the water evaporation process). Within a range of 300°-1000°C, the loss of mass results from the removal of the water contained in the structure of the bentonite and contained in the sample of the organic additives. In the second area, the differences between the individual samples are visible, which means that their compositions are different.

The tests presented a general comparison of different bentonites and bentonite mixtures with carbon-containing additives. The most commonly used additives are: coal dust, resins. Additional tests would allow to determine the composition of the additives included.

The mass loss of samples was compared with each other in two stages: for temperatures 0°-300°C and total loss of mass. In the initial stage, the weight loss of samples for bentonite mixtures A, B, C is about 8-12%, while for bentonites D, E, F: about 6-9%. For bentonite mixtures, the total loss of sample mass is about

twice as high for bentonites. This confirms the occurrence of more carbon-containing additives in bentonite mixtures.

In the case of Bentonite Mixture A (Fig. 1), the maximum mass loss occurs at a temperature of 160°C in the initial stage. During the next stage, the weight loss continues to increase, which might be the result of the removal of the bounded water and the additives present in the bentonite mixture. The maximum value in this range is visible at a temperature of 640°C.

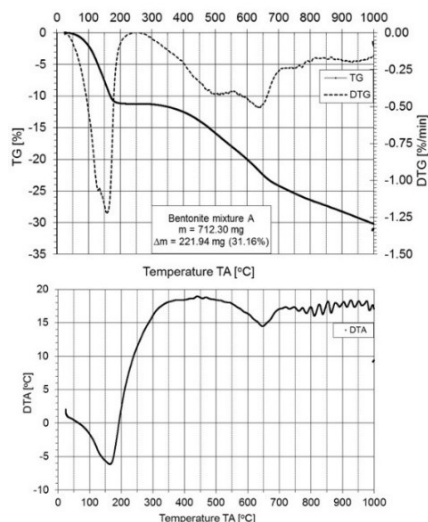


Fig. 1. Results of the derivatographic analysis for Bentonite Mixture A. Sample weight $m=712.30$ mg; weight loss $\Delta m=221.94$ mg (31.16%). Heating speed – $10^\circ\text{C}/\text{min}$

For Bentonite Mixture B (Fig. 2), the maximum value of the loss in mass during the first stage was obtained at a temperature of 150°C. The next maximum was obtained at 530°C. In addition, a peak at 800°C was observed (which was caused by the organic additives).

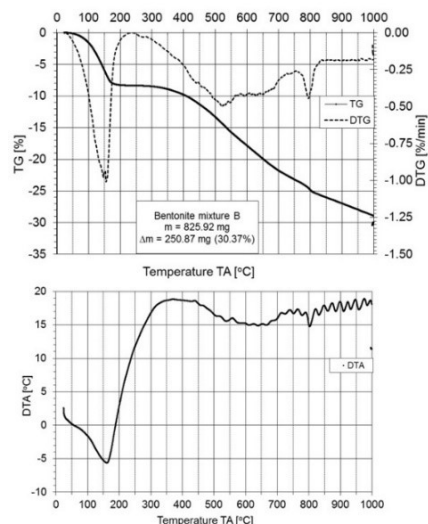


Fig. 2. Results of derivatographic analysis for Bentonite Mixture B. Mass of sample $m=825.92$ mg; weight loss $m=250.87$ mg (30.37%). Heating speed – $10^\circ\text{C}/\text{min}$

During the derivational analysis of Sample C (Figure 3), the occurrence of peaks was observed at temperatures of 140° and 160°C as well as for 530° and 650°C. The peak that occurred at the temperature of 790°C is a result of the presence of the organic additives contained in the bentonite mixture.

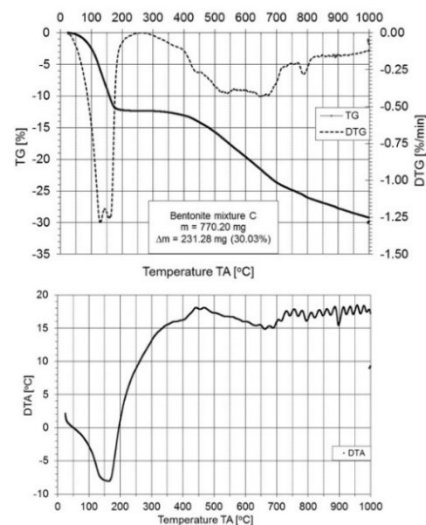


Fig. 3. Results of derivatographic analysis for Bentonite Mixture C. Sample weight $m=770.20$ mg; weight loss $m=231.28$ mg (30.03%). Heating speed – $10^\circ\text{C}/\text{min}$

The first peak of mass loss for Bentonite D (Fig. 4) was observed at 150°C. In the next stage, the maximum occurs at an annealing temperature of approximately 550°C. No additional peaks are visible at temperatures above 700°C, which means that no organic compounds are present.

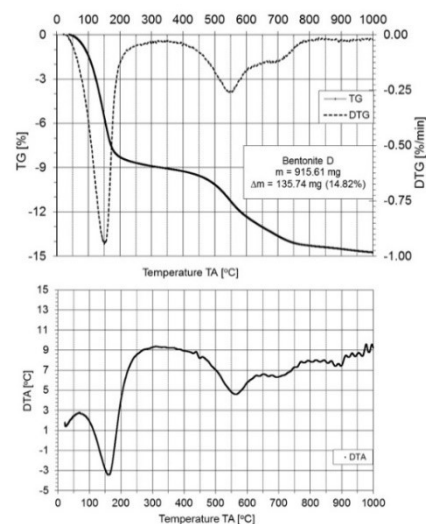


Fig. 4. Results of derivatographic analysis for Bentonite D. Sample weight $m=915.61$ mg; weight loss $m=135.74$ mg (14.82%). Heating speed – $10^\circ\text{C}/\text{min}$

The first peak for Bentonite E appears at 140°C (Fig. 5). The next peaks were observed at 410°, 530°, and 680°C, coming from the process of removing the water and various additives in the sample. Fig. 5 shows that bentonite E is more complex than D and F because there are more peaks in the range 300°-1000°C.

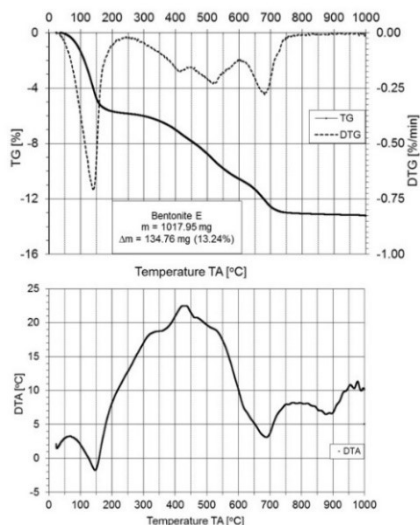


Fig. 5. Results of derivatographic analysis for Bentonite E. Sample mass $m=1017.95$ mg; weight loss $m=134.76$ mg (13.24%). Heating speed – 10°C/min

The first peak for Bentonite F occurs at 150°C (Fig. 6). The next peaks occur at 650° and 750°C (however, the latter is less pronounced). The mass loss for Bentonite F is the lowest of the tested, so it contains the least amount of additives.

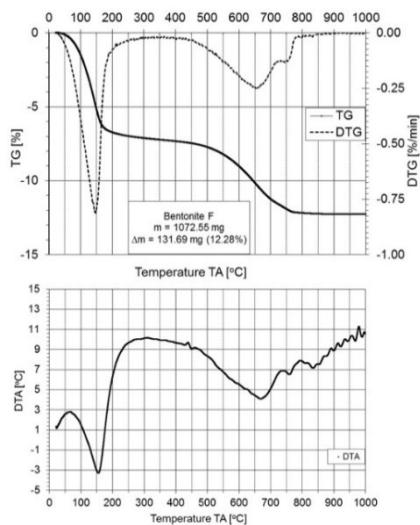


Fig. 6. Results of derivatographic analysis for Bentonite F. Sample weight $m=1072.55$ mg; weight loss $m=131.69$ mg (12.28%). Heating speed – 10°C/min

3.3. Ion exchange capacity and montmorillonite content

Investigations of the ion exchange capacity and montmorillonite content were carried out according to the spectrophotometric method of the Cu (II)-triethylenetetramine complex. Figure 7 shows the values of the ion exchange capacity of the tested materials. In contrast, Figure 8 illustrates the montmorillonite content. The most favorable binding properties were observed in Samples A and F. The highest ion exchange capacity is obtained for Sample A. The high binding properties of Bentonite Mixture A results from the good quality of bentonite and high montmorillonite content. The selected error for the CEC parameter value is $\pm 5\%$.

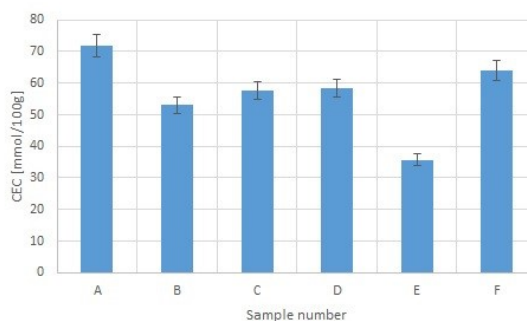


Fig. 7. Ability for ion exchange of tested bentonites and bentonite mixtures

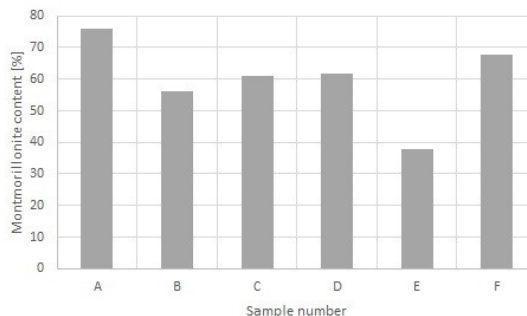


Fig. 8. Montmorillonite content of tested bentonites and bentonite mixtures

The content of montmorillonite in the studied bentonites is low. Taking into account that bentonite should contain at least 75% of montmorillonite, to the consideration should be given accuracy of the montmorillonite content testing. Further testing may include the use of other methods to assess montmorillonite content.

3.4. Apparent density

The change in the apparent density along with the increase in sand moisture content (Fig. 9) is characterized by a similar curve for each of the samples: initially, it decreases, reaches the minimum, and increases. The minimum value of the apparent

density is within a range of 2-3% humidity. Analyzing this range, it was observed that the highest apparent density was obtained from the minimum values of the materials tested for the sand with the addition of Bentonite E (1.5 g/cm^3). The lowest apparent density value was obtained for the sands containing Bentonite Mixture A or C in their compositions (1.47 g/cm^3).

High apparent density values were obtained for the bentonite and bentonite mixture having a high degree of homogeneity. In addition, the bentonites are characterized by a slightly higher apparent density than the bentonite mixtures.

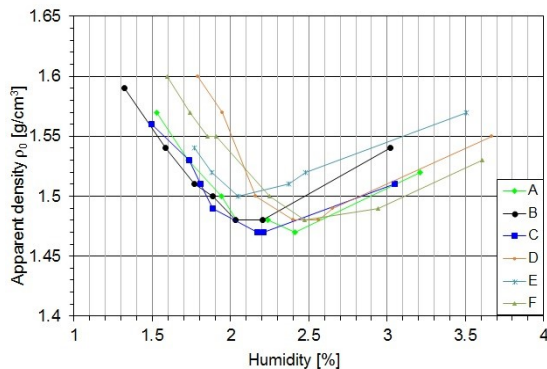


Fig. 9. Influence of humidity on apparent density ρ_0 sands with different bentonites and bentonite mixtures

3.5. Permeability

The permeability measurement was carried out on the LPiR1-type apparatus. Contrary to apparent density, the permeability increases along with humidity, reaches its maximum value within a range of 2-3%, and then decreases (Figure 10). The sand with Bentonite D is characterized by the highest permeability ($530 \times 10^{-8} \text{ m}^2 / \text{Pa} \cdot \text{s}$), while the lowest parameter value was obtained for the sand with Bentonite Mixture B ($316.67 \times 10^{-8} \text{ m}^2 / \text{Pa} \cdot \text{s}$). In the case of the sands with bentonite mixtures (which were characterized by the lowest apparent density value), the lowest permeability values were obtained. In contrast, significant differences were noted in the permeability values for the sands with the bentonites.

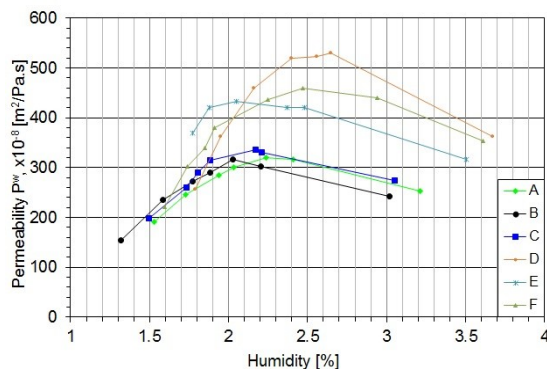


Fig. 10. Influence of humidity on permeability P^w of sands with various bentonites and bentonite mixtures

3.6. Compressive strength

In order to determine the compressive strength, an LRu-2e-type universal strength measuring device was used. The compressive strength increases with increasing humidity in each sand; it reaches its maximum value and then decreases (Fig. 11). The maximum parameter measurements were obtained within a range of 1.5-2% humidity. The mass with Bentonite F showed the highest compressive strength (0.196 MPa at 1.85% humidity). The lowest compressive strength was obtained for the sand with Bentonite E (0.096 MPa at 1.88% humidity). The highest values of compressive strength were characterized by the samples from sands bonded by bentonites with high montmorillonite content.

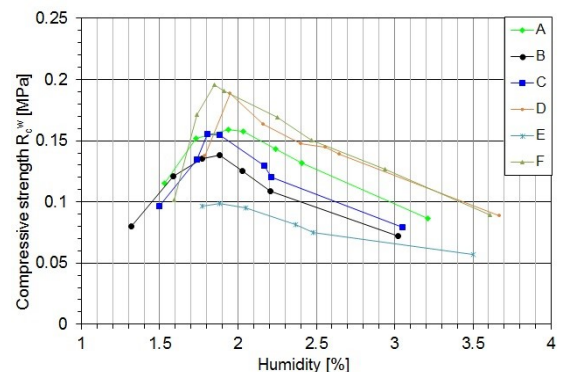


Fig. 11. Influence of humidity on compressive strength of sands with various bentonites and bentonite mixtures

3.7. Friability

The measurement of friability was carried out on an LS-type apparatus. For each tested material, the friability of the molding sand decreases with increasing humidity (Fig. 12). The parameter value is not significantly different for individual samples; therefore, one of the humidity values was selected for comparison. At 2.5% humidity, the lowest values of friability were obtained for Bentonite Mixtures B and Bentonite E. For the same moisture content, the sand with Bentonite D has the highest friability. This parameter is related to the amount of water contained in the molding sand as well as the mechanism in which the binding takes place. The comparison of the results was based on the basis of the points obtained and the chart changes made on their basis.

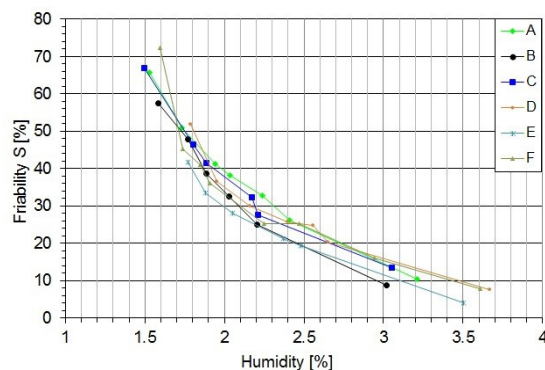


Fig. 12. Effect of humidity on friability S of sands with different bentonites and bentonite mixtures

4. Conclusion

The conducted research allowed us to state the following:

- Bentonites are characterized by greater homogeneity and specific surface area than bentonite mixtures, which may result from the addition of carbon-containing additives.
- The carried-out thermal analysis allowed us to find more than double the loss of sample mass for bentonite mixtures than for bentonites during heating. This results from the introduced carbon-forming additives in the bentonite mixtures.
- The highest ion exchange capacity and montmorillonite content among the bentonite mixtures are represented by Sample A, while for the bentonites – Sample F. The best bentonite has worse parameters when compared to the best bentonite mixture.
- The sands with bentonites were characterized by a slightly higher apparent density as compared to sands with bentonite mixtures.
- The permeability of the molding sand reached higher values for bentonites. The maximum parameter value was reached within a range of 2-3% humidity.
- The highest values of compressive strength were obtained for the samples from sands with high-montmorillonite-content bentonite. • On the basis of the carried-out tests, it was found that the type of bentonite or bentonite mixture does not have a significant impact on the friability of the molding sand.

- Summing up the obtained properties for each of the tested materials, the most favorable is Bentonite F, showing the lowest loss of mass during heating, a high ion exchange capacity, and a high montmorillonite content. The sand made with the addition of Bentonite F has the highest compressive strength and high permeability.

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