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The Dependence of Castings Quality Produced in Clay Moulding Mixtures from the Properties of Binder Based on a Montmorillonite

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Abstract

Casting quality depends on many factors including the quality of the input materials, technology, material securing and last but not least, the mould into which the casting is casted. By pouring into a single-shot mould, based mainly on 1st generation binders, is a very important factor. Basically, a bentonite mixture represents either a three- or four-component system, but each component of the system is a heterogeneous substance. This heterogeneity punctuates mainly a non-stationary heat field, presented throughout the whole process of the casting production. The most important component is a binder and in the case of first generation binders mostly bentonites are used - clays that contain minimum of 80% of montmorillonite.

Keywords: Casting quality, Clay moulding mixture, Bentonite, Montmorillonite

1. Introduction

Bentonite clays, their composition, structure and properties influence the properties of moulding mixtures which influences also the inner quality of castings. The quality of bentonites, their availability and price determine the performance and profitability of foundries. Even in Slovakia there is an effort to use the products of Slovak origin. The aim of the presented work, which resulted from praxis requirement, is to examine the properties of Slovak bentonite and its suitability for usage for foundry purposes and compare them with a selected bentonite of high quality standard.

2. Theoretical part

Besides the new tendency of increase in production processes, used for mould production for pouring, the mould production

processes on the bentonite base will have in the future a dominant role. The predominant advantages of these moulding mixtures in processes of mould production are the following:

- high joining and plasticity of bentonite binder is reached with low amount of free water, what ensures pouring of the metal into raw mould
- relatively low costs for moulding mixture, related to relatively low costs for material
- high degree of regeneration of moulding mixture (cca 95 - 98%), low specific consumption of moulding mixture on ton of sound casting (0,1 - 0,3 t/t of sound castings)
- possibility of creation of closed material circulation
- high productivity of used production technique, enabling control and regulating the grade of moulding mixtures
- high and stable grade of castings (quality surface, stable accuracy, castings without defects) assured with modern ways of compression
- hygienic and ecological advantages

Nowadays, also modern methods of mould production count on a bentonite moulding mixture, which brings a lot of technical and economical advantages but mainly ecological.

3. Experimental part, results, discussion

The work was focused on two types of bentonite clays. The first was of non-slovak bentonite was marked A and considered as being of high quality. The second examined clay binder was bentonite of a slovak location – in the paper marked as B. Basic physical-chemical characteristics were set:

- specific surface,
- comprehensive chemical analysis,
- X-ray analysis, focused on montmorillonite content,
- Content of active bentonite,
- pH and electrical conductivity of the suspension,
- differential thermal analysis (DTA, TG).

The BET method was used to measure the size of the specific surface, which is most suitable for the measurement of powders with high specific surface area, mainly fine. It is based on the adsorption of gases on the surface of powder elements. According to the BET method there are no big differences in the size of specific surfaces, slightly higher specific surface was measured in bentonite A - 50,216 m²/g opposite to sample B - 46,6077 m²/g. The higher specific surface is probably related to the higher quality of connective capabilities of bentonite that affect the technological properties of bentonite moulding mixtures.

Tab. 1 shows the results of chemical analysis of bentonite A and B. From comparison of results is seen the higher content of SiO₂ and lower content of Al₂O₃ in bentonite sample B. The consequence of this is a significant difference in the ratio of SiO₂ to Al₂O₃, namely A = 3,23 and sample B = 4,85. The different value probably indicates a different montmorillonite ratio to other minerals in the bentonite. Based on the higher ratio of SiO₂ to Al₂O₃ in bentonite B, we can conclude that it contains more impurities containing SiO₂. From the genetic point of view this means, the higher this ratio, the more SiO₂ in the bentonite, and the given montmorillonite was created during the conversion of acidic vulcanoclastics rocks. All slovak deposits were created by the weathering of acidic vulcanoclastics, unlike for example the locations in northern Czech republic, which were created by the weathering of basic rocks. With chemical analysis we cannot get mineralogical composition of clays and also no technological properties, but it is a valuable addition for evaluation of clay binders. The aims of attention are adverse oxides, mainly oxides of alkali metals (Na₂O and K₂O) and metals of alkali earth (CaO and MgO) [1]. These basic oxides react by higher temperatures with SiO₂ and create easy-melttable silicates, decreasing the heat resistance.

Table 1.
Chemical analysis of bentonite samples A, B

Sample	SiO ₂	Fe cell.	CaO	MgO	Fe ₂ O ₃	Al ₂ O ₃	MnO	FeO	Na ₂ O	K ₂ O	SiO ₂ /Al ₂ O ₃
A	59,75	3,90	2,31	6,09	4,08	18,48	0,021	0,431	2,00	1,66	3,23
B	65,92	2,79	2,29	7,15	2,08	13,58	0,085	0,287	1,43	1,66	4,85

Also some pictures of the structure of individual samples were taken using a microscope SEM Olympus OLS 300 LEXT and Nikon SMZ 15000.

Practically, the only objective qualitative and quantitative determination of clay minerals is X-ray analysis. Diffraction analysis was done at the workplace of Stat Geological Survey of Dionyz Štur (ŠGÚDŠ), Regional Center – Department of Applied Technology of minerals (ATNS), in Košice.

Qualitative mineralogical analysis was made from the grist of X-ray samples using diffraction analysis on the device Dron – UM 1 under the following conditions: radiation CuKα, Ni – filter, accelerating voltage 30 kV, current intensity 20 mA, time constant T – 2, aperture 2 – 2 and 2 – 0,5, the shift arm goniometer 2°/minute. Evaluation of X-ray results was done according to conventional ASTM tables using a special program computer technique[3].

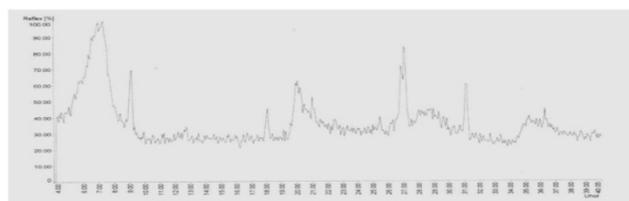


Fig. 1. RTG analysis - sample A

Graphical record of X-ray analysis of sample A is shown on Fig. 1 and the record of X-ray analysis of sample B is shown on Fig. 2.

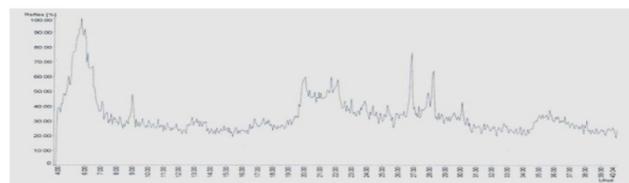


Fig. 2. RTG analysis - sample B

With the research method – X-ray diffraction analysis found the following qualitative mineral composition of the tested samples:

Sample A:

Major minerals (> 15%): smectite
Secondary minerals (3 to 15%): sericite, plagioclase, quartz, dolomite

Sample B:

Major minerals (> 15%): smectite, amorphous phase
Secondary minerals (3 to 15%): cristobalit, plagioclase, quartz

On the basis of ion exchange the following results were achieved:

Sample A: total exchange VKA (mol/kg) – 0,69. The exchange of different ions (mekv/100g): Na – 15,85; Mg – 22,98; Ca – 11,21; K – 1,99. With conversion was determined the content of smectite (montmorillonite) to 75,8%. By exchange of individual

ions it can be assumed that it is natrified calcium – magnesium montmorillonite. Proportional representation of the ion is 82,2%. This fact highlights the value of basic basal reflex $d = 1,22$ to $1,28$ nm determined by X-ray diffraction analysis.

Sample B: total exchange VKA (mol/kg) – 0,35. The exchange of different ions (mekv/100g): Na – 53,3; Mg – 5,88; Ca – 5,00; K – 0,66. With conversion was determined the content of smectite (montmorillonite) to 38,5%. By exchange of individual ions it can be assumed that it is less natrified calcium – magnesium montmorillonite. Proportional representation of the ions Ca + Mg is 81,3%. The value of basic basal reflex is $d = 1,47$ to $1,54$ nm determined by X-ray diffraction analysis.

The difference in the montmorillonite content is significant, in sample A it is nearly twice the value compared to sample B. A higher content of montmorillonite points to higher ability of the binder to swell, resulting in better jacketing of the binder at the grains of the opening material, and more technology and foundry characteristics.

Microscopic analysis of clay minerals and other components of clays is very difficult and deadlocked by the high fineness of elements and platelet composition, where between two silicate tetrahedron is gibbsite octahedron. As part of the grid, there is free and grid water. The main component of bentonite A (Fig. 3) is montmorillonite, forming aggregates, well distributed in the rock, the space between aggregates is filled with amorphous matter. Also appears the weak admixture of organics and probably feldspars in an accessory amount.

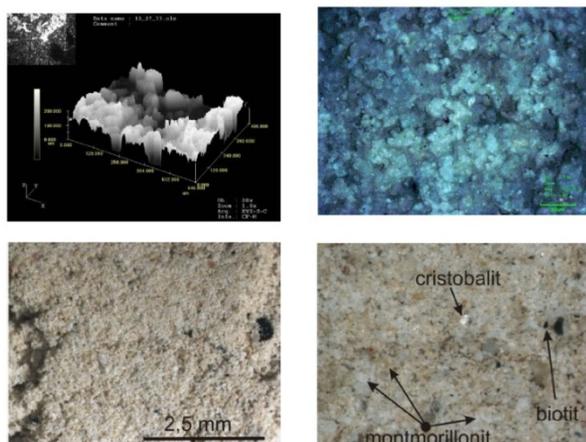


Fig. 3. Microscopic pictures of bentonite A

In bentonite B (Fig. 4), the montmorillonite is flaky, forming aggregates, the space between aggregates is filled with amorphous matter with very small impurities of Fe (limonite, hematite), quartz is also present and α cristobalit (about 20 volume %). Furthermore, there is mica – biotite (bigger dark grains, it also occurs baueritized, small dark matter is organic and the lightest unit are feldspars, probably part of the grains are already caolitized.

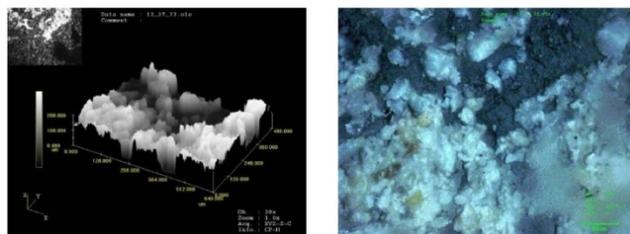


Fig. 4. Microscopic pictures of bentonite B

Also the thermal analysis of the raw samples was carried out, even when annealed to 550°C . In bentonite A, the annealing to 550°C resulted mainly in the total weight loss of TG. This shows that the temperature is low for a loss of total dehydroxylation. A similar fact has also reflected in the bentonite of slovak provenience[4]. At the temperature 540°C - 550°C occurs mild dehydroxylation, almost no loss and next endotherm at 680 - 690°C is probably caused by decomposition of carbonates, especially MgCO_3 .

While the previous tests were realized on pure binder clays A and B, the properties of moulding mixtures were tested on moulding mixtures. The aim of the tests was to compare the basic properties of bentonite mixtures with both types of bentonite, two binders were assessed in a raw state – both in terms of thermostability, annealed at three temperatures – 350 , 450 and $550^{\circ}\text{C} / 1$ hour.

For preparation of investigated bentonite moulding mixtures was used the classical laboratory paddle mixer MK 00 (Poland). Investigated moulding mixtures were prepared with the same composition and mixed for 8 minutes:

- 100 weight % of quartz opening material Š32ŠH, d_{50} 0,35 mm
- 8 weight % of bentonite binder – in original and annealed state
- x weight % of water – to achieve compactibility 46 – 48%
- For all mixtures were determined, except moisture and compactibility, tensile strength of the raw – the severity, the strength of the graft, tenacity blends based on the ratio of graft strength and compressive strength, tensile condensing zone, breathability and temperature effect of graded exposure to temperature on the properties. All results listed in Tab. 2 are obtained from at least 5 measurements.

Table 2. Measuring average data of bentonite mixtures technological characteristics

Sample	Green strength [kPa]	Shear strength [kPa]	Shear compressive strength ratio	Permeability [j.p.SI]	Condensati on zone strength [kPa]
A	130	33	0,25	73,5	0,52
B	96	27	0,28	71,8	0,38
Dif	-34	-6	+0,03	-1,7	-0,14
%	-26	-18	+0,12	-2,3	27

Determination of thermal stability of bentonites is important in terms of knowledge of its connective abilities. Part of the three-layer structure of bentonite is molecule (free) water, and mesh (in the form of OH-groups) as part of the crystal grid[5]. Free water

is removed at 100 ° C, the process is perfectly reversible. At higher temperatures, approximately 400 to 600 ° C, tightly bound water is removing, bentonite is irreversibly damaged, is no longer able to bind water and degradation occurs. This dehydroxylation temperature varies, depending on the material deposit and determines the thermostability of bentonites.

In order to find and compare the thermal stability of the bentonites, different bentonites samples were annealed at three temperatures graduated after one hour. Comparison of thermal stability of both bentonites covered in the evaluation of technological properties of bentonite mixtures, annealed at temperatures of 350°C, 450°C and 550°C for one hour.

Dependences of the strength of the pressure at raw and strength of the graft on temperature exposure bentonites at different temperatures for both bentonites are shown in Fig. 5.

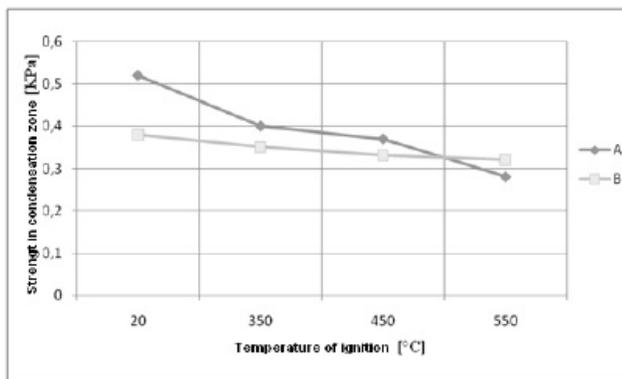


Fig. 5. Influence of thermal stability on strength properties of bentonite moulding mixtures

Test of strength in the condensing zone belongs to the most sensitive test for evaluation of bentonite mixtures. In Fig. 6 are given dependences of the strength in condensing zone on the degree of degradation of bentonite after exposure to heat. Generally, a decrease in the strength of the condensation zone in mixtures signals for example imperfect mixing, decrease of moisture, tearing forms during dismantling or higher content of core sand in the mixture. The result is an increased tendency to development of drop send holes and expansion scabs.

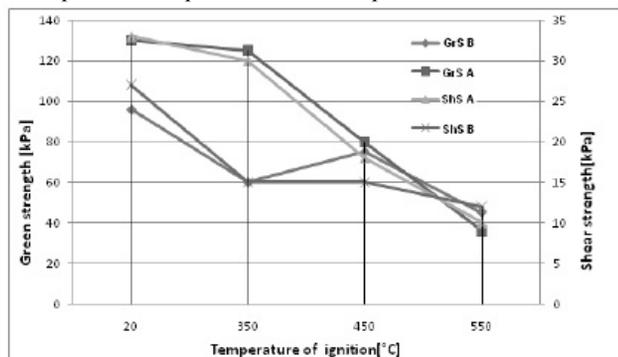


Fig. 6. The influence of degradation degree of bentonite after annealing exposure in condensation zone of water

As shown in Fig. 6, to the annealing temperature of 450°C a mixture of bentonite A has higher values, but when annealed at the temperature 550°C per hour, bentonite B begins to prevail. This confirms the higher thermal stability of the Slovak bentonite.

In mixtures with bentonite A, B were realized test of interaction of mixtures with poured metal to verify the actual measured technological properties of bentonites and bentonite mixtures through pouring technological test, which characterizes the predisposition of mixture to the creation of surface defects on castings, expansion scabs.

Expansion scabs are surface defects of castings which mainly arise during pouring to raw bentonite moulds where silica opening material is used.

In Fig. 7, the model pattern used in this test is shown. To find out the predisposition to expansion scabs, three model mixtures with tested bentonites with given composition (tab. 3) were prepared.

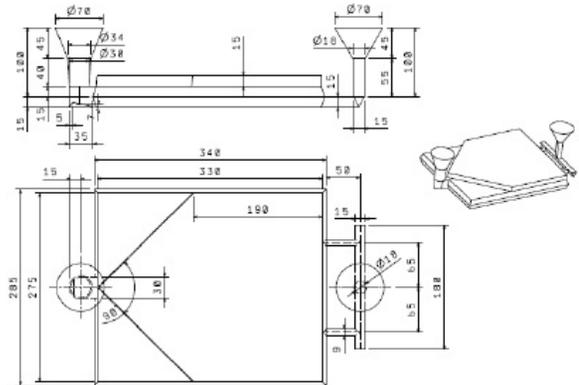


Fig. 7. Sample castings of expansion scabs test according to Patterson and Bonisch

Table 3.

The composition of bentonite mixtures to the expansion scabs test

Mixtere	Brand of bentonite	Amount of bentonite [hm. %]
1	A	8
2	B	8
3	B	4

In order to model the creation of expansion scabs on a casting, the amount of bentonite B (mixture 3) was decreased.

Expansion scabs arise mainly in heat stressed places or close to ingates. When this surface defect occurs on other places it means that moulding mixture has low quality; there is less activated bentonite to assure optimal properties of moulding mixture, it is not enough nitrified.

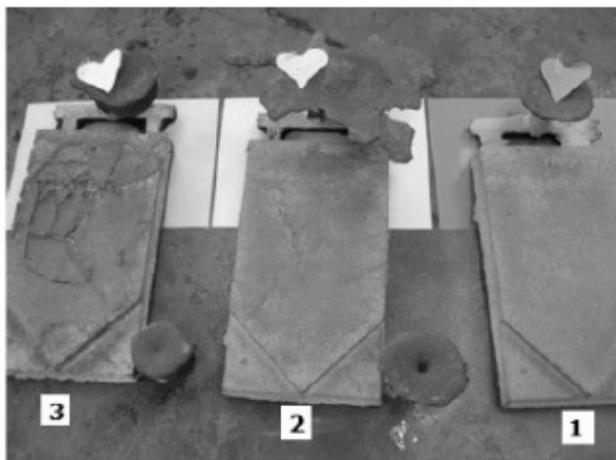


Fig. 8. Sample castings of expansion scabs test according to Patterson and Bonisch

Fig. 8 shows sample castings, in which the model mixtures were used. When using the mixture 1, the creation of expansion scabs did not shown, the small burning ins and drop sand holes can be seen.

When using the modelling mixture 2, the classic expansion scabs did not shown on the surface, but the top part of the mould got heat stroke and it came to first phase of its creation, which was expressed in roughness in casting surface and fine prominences – fig. 9.



Fig. 9. Test casting - pattern mixture 2

Modelling sample mixture 3 – decreased amount of bentonite B was prepared in order to model the creation of classic expansion scabs, when it comes to unstuck the surface layer[6].



Fig. 10. Test casting - pattern mixture 3

The occurrence of this defect participates in defective production in foundries and is the cause of casting scrapping.

4. Conclusion

Appropriate physical and chemical characteristics of clay materials are a prerequisite for the usage of raw materials in the foundry industry and affect almost all technological characteristics of bentonite mixtures and hence the quality, especially the surface of castings, cast into these forms. These properties cannot be affected, are the genesis and the deposit place of material. Measured results, mainly almost double content of montmorillonite in bentonite, indicates a better binding ability of bentonite B and the associated greater strength properties of the bentonite mixture, which is reflected mainly in the economic field.

By evaluation of the tests the following were mainly identified:

- High decrease of severity of mixtures - more for bentonite A (by 72%) compared with a mixture with bentonite B (by 52%) and conversely, the strength of the graft decreased significantly in the mixture with bentonite B (by 56%), also decrease of breathability with bentonite B (by 56%), compared with A (by 34%).
- The decrease of strength in the condensation zone of water was more pronounced in mixture with bentonite A (by 46%) than with bentonite B (by 18%), at the whole temperature range.
- The resulting severity at the temperature 550°C is even in a mixture of bentonite A lower than with bentonite B, namely A = 36 kPa and B = 45 kPa (by 25%).
- Based on the results, the effect of thermal exposure on the properties of moulding mixtures stronger in bentonite A, and this means that bentonite B is thermally stable[5].

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