The high temperature deformation behaviour of bentonite bonded sands

The methods for testing of moulding materials are working mostly at room temperature. Examples for these testing procedures are the different green strengths or the wet tensile strength. The results of these tests we are able to use for the controlling of the behaviour of the green sand moulds in the steps mouldmaking, transport and partly also pouring. For testing of properties at higher temperature (hot compression strength, residual strength ...) we often don't have suitable testing equipment or procedures. We also got no information to specific sand related casting defects from the steps pouring, cooling, solidification and shake out.
The paper shows results of investigations in the field of high temperature deformation behaviour of bentonite bonded sand systems. We analyze the strength and the deformation of different sand mixtures in the temperature range between room temperature and 1000 °C. After the investigation of different heating procedures of the used samples the following points were observed: type of bentonite, amount of bentonite, type of additives and amount of additives. With the used testing equipment it is possible to show force-way-curves at different testing temperatures. The investigation shows, that the hot temperature deformation behaviour and also the hot and the residual strength depend from the used sand mix. With that knowledge we can affect or prevent some of the casting defects occurring in our foundries.

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1 Theoretical background

1.1 Requests on moulding materials and mould parts

The shape of modern castings is more and more difficult and complex. Therefore also the requests on the moulding materials for the mold and core production are higher and higher. There are a lot of important properties for bentonite bonded sands. The most important group are the working properties: compactibility, flowability, storage behaviour and sticking tendency. More complex geometries need also a better reproduction accuracy of the moulding material and the mould. In the bentonite bonded sand system the strength increases with the compaction of the sand, one of the most important points is therefore a higher density. With a higher density we can avoid casting defects such as roughness and penetration. High strength at room temperature can be realized through high green strength. Very important for the stripping behaviour is the green tensile strength. The strength at higher temperatures also has a special importance, for example the wet tensile strength, the hot shear strength, the hot bending and the hot compression strength.

The next interesting point is the deformation behaviour of moulding materials. At room temperature, it is important with a view at the request in stripping of the pattern or the transport of the moulds. A typical test for this is the shatter index (plasticity of the sand) or the deformability. The deformation behaviour at higher temperatures is important for the avoidance of specific defects such as scabs or finning and a high dimension accuracy of the castings. Tests in this field are the hot distortion test, deformability or the measurement of the E modulus. Other requests on (all) moulding materials are high thermal stability of the used sand (refractoriness, sintering behaviour), a high gas permeability, a low gas evolution and low environmental impacts (emissions, reclaimability, use of old sand in other areas, dumping behavior).

1.2 The deformation behaviour of moulding materials

Knowledge in the area of the deformation behaviour of moulding materials is important not only from the point of view at avoidance of specific casting defects. It also is important for calculation of stress and strength of moulds and cores for the use in casting simulations. Besides the knowledge about the thermophysical properties of the different sands and binders as heat conductivity, coefficient of thermal expansion and heat capacity is it necessary to know the correlation of strength and deformation of the bentonite bonded sand. This is possible through the measurement of strength and deformation in a range between room temperature and 1000 °C. With that information, statements with the view on dimensional stability of the mould, compression and shrinkage behaviour, shake out, residual strengths and defect tendency (scabbing, finning) are possible (Figures 1 and 2).

For investigations of the deformation behaviour in former times we had only the shatter test, the impact deformation test, the deformability (GF – Georg Fischer) at room temperature and the test equipment for hot compression strength and hot deformation (Figure 3) for investigations at higher temperatures. Figure 4 shows two graphs for different bentonites with statements for their behaviour at pouring (test temperature 900 °C). This was the reason for the development of a new test procedure for bentonite and chemical bonded sand systems with the following targets:

1. Determination of material data for expansion and deformation processes through
   - mechanical claims (stripping, pattern drawing, manipulation etc.) at room temperature;
   - thermo-mechanical claims (pouring, solidification) at higher temperatures.
2. The use of the data for calculation of expansion and deformation processes (simulation)

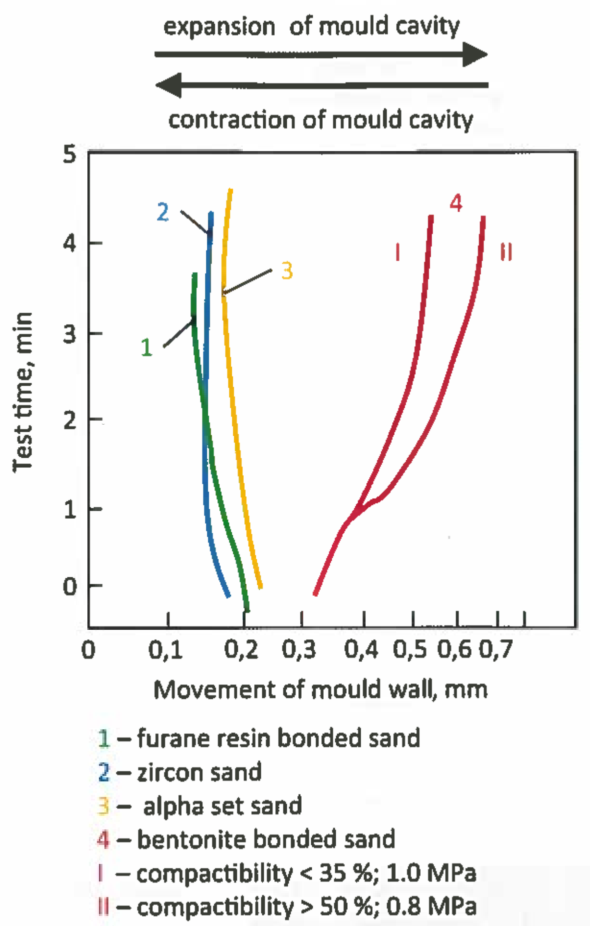

Figure 2: Movements of mould walls with different moulding materials [2, 3]

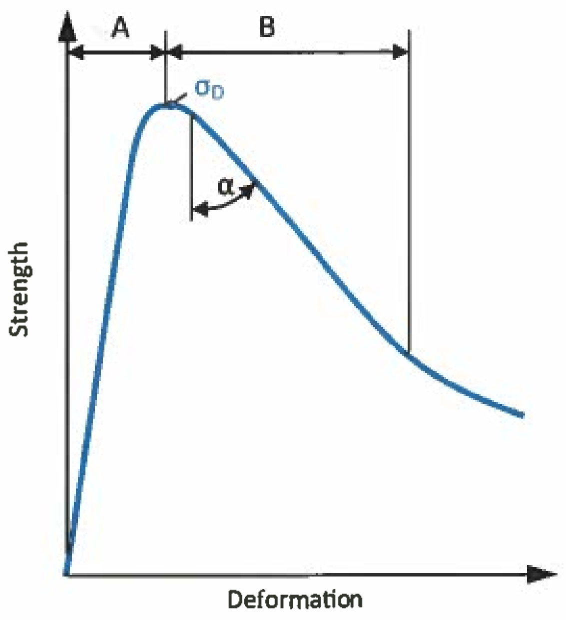

Figure 1: Deformation diagram of moulding materials [1]; σ_D – maximum strength; A – deformation of the sample with increased deformation resistance; B – Deformation area behind the maximum strength with linear decrease of deformation resistance (deformability)

Figure 3: Testing equipment for measurement of hot compression strength and hot deformation

- calculation of the stress strength behaviour of moulding materials (moulds and cores) at room temperature;
- calculation of the stress strength behaviour of moulding materials (moulds and cores) at pouring and solidification (stresses, casting defects, finning etc., broken cores, hot deformations, geometry allowances).

The paper describes the new testing equipment and shows first results for bentonite bonded sand systems.

2 The used universal strength tester

Figure 5 shows the used universal strength tester. The machine has a larger frame than a normal machine. In this frame is enough space for a high temperature furnace with a maximum temperature of 1000 °C. For determination of sand properties the machine uses water cooled pistils for compression, tensile or bending strength. With the connected laptop the machine can create force way diagrams at different temperatures. The test procedure is us-

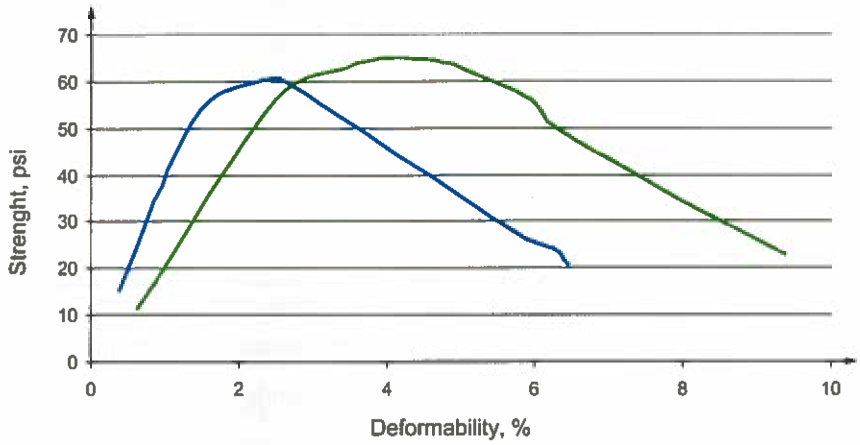

Figure 4: Strength deformation diagram of two different bentonites (test equipment Simpson-Gerosa, temperature 900 °C) [4]; green graph: deformability 5 %, bentonite typ II, bad shake out properties, low defect tendency; blue graph: deformability 2.5 %, bentonite typ I, good shake out properties, high defect tendency

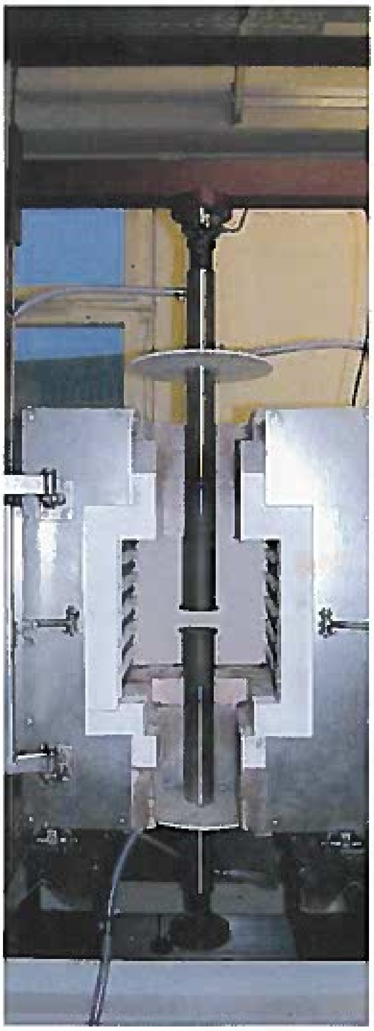

Figure 5: The used universal strength tester

Table 1: Recorded heating times for different sand mixtures

Temperature furnace, °C	Temperature sample, °C	Time, s	Time, min
Heating times mixture A			
200	180	3282.33	54 min 42 s
600	580	2173.66	36 min 17 s
800	780	1540.33	25 min 40 s
1000	980	1318	21 min 58 s
Heating times mixture B			
200	180	2553.5	42 min 34 s
600	-	-	-
800	580	1873	31 min 13 s
1000	980	1211	20 min 11 s
Heating times mixture C			
200	180	2671.66	44 min 32 s
600	600	1158.66	19 min 19 s
800	800	1040	17 min 33 s
1000	1000	934.5	15 min 35 s
Heating times mixture D			
200	180	2549	42 min 29 s
600	600	1178.33	19 min 38 s
800	800	1123	18 min 43 s
1000	1000	1026.53	17 min 6 s

able for chemical bonded and for bentonite bonded sand systems.

3 Experimental work

For investigation of the deformation behaviour of bentonite bonded sands we use cylindrical samples with a diameter of 50 mm and a height of 50 mm. In first experiments it was to find out, which heating technology gives the best and uniformly heating of the samples [4]. This first step includes three different ways to heat the samples.

1. Heating up of the sample with the furnace from room temperature to the test temperature and test at this temperature. In this case we have got the test temperature at the surface of the sample but not inside.
2. Put in of the sample in the preheated (1000 °C) furnace for a calculated time. In this case we often have lower test temperatures (e. g. 200 °C) and higher temperatures at the sample surface.
3. Heating of the sample with the cold furnace, determination of the properties after a measured time (thermocouple inside of the sample). In this case we have the same (test) temperature inside and outside of the sample.

In the following we are going to discuss only results from the testing procedure 3 with a uniform temperature distribution in the sample.

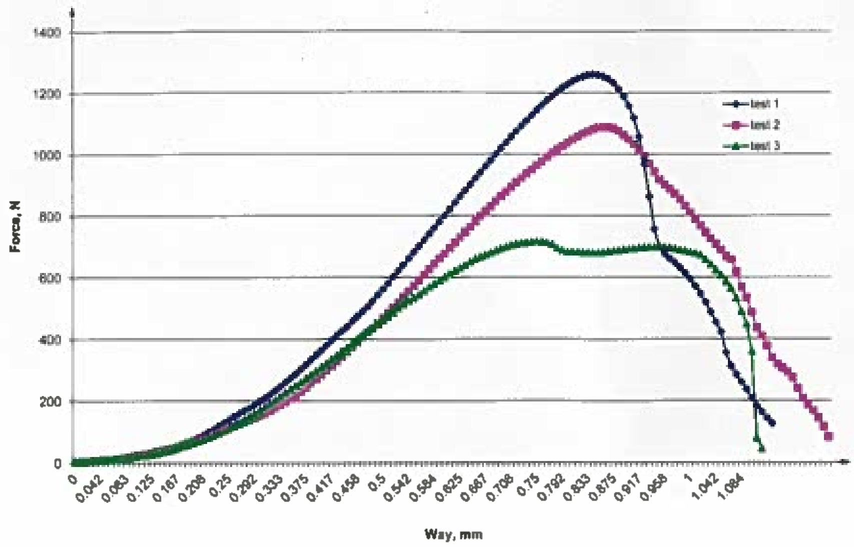

Figure 6: Force way diagram mixture E at 600 °C

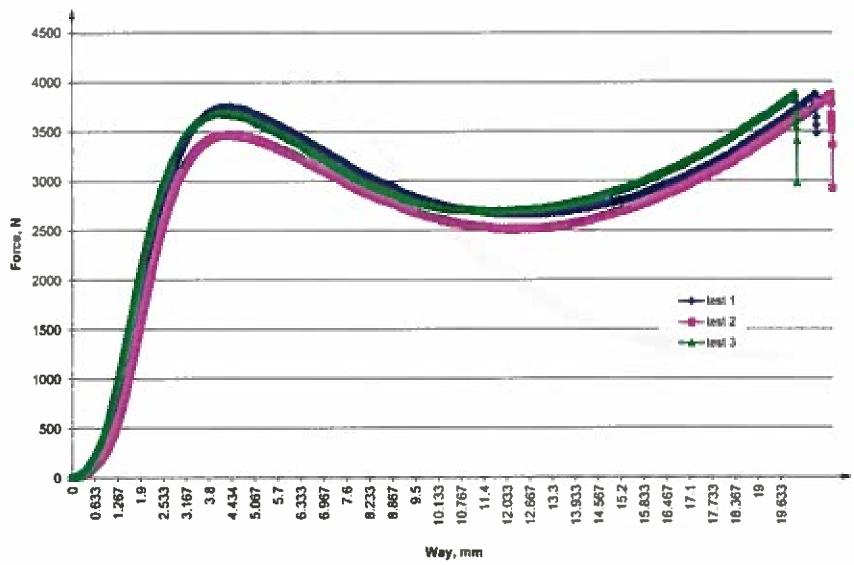

Figure 7: Force way diagram mixture E at 1000 °C

3.1 Investigations of the heating conditions

In the first step heating curves were recorded for sand systems with different compositions. The compactibility of all mixtures in this article was ΔH = 40 % ± 2 %. The used sand has an average grain size of 0.28 mm. The following sand mixtures have been investigated.

- 7 % calcium bentonite, not activated – mixture A;
- 7 % calcium bentonite, activated – mixture B;
- 7 % real green sand mix (iron foundry) – mixture C;
- 7 % calcium bentonite, activated, 4 % lustrous carbon former – mixture D.

Figure 8: The samples mixture E after 600 and 1000 °C

The heating curves were recorded for the temperatures 200, 600, 800 and 1000 °C, Table 1 shows the results of this measurements.

The data in Table 1 show us, that the heating to higher temperatures is faster than to lower temperatures. In the case

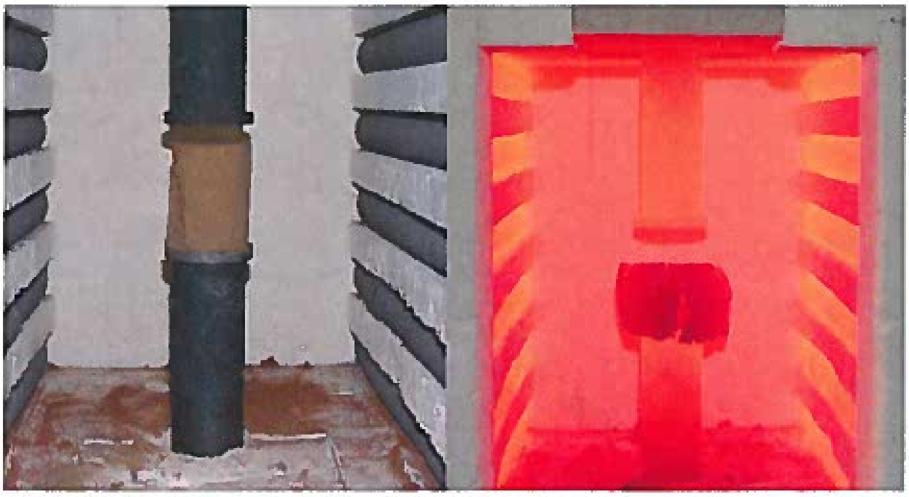

Figure 9: The samples mixture F after 600 and 1000 °C

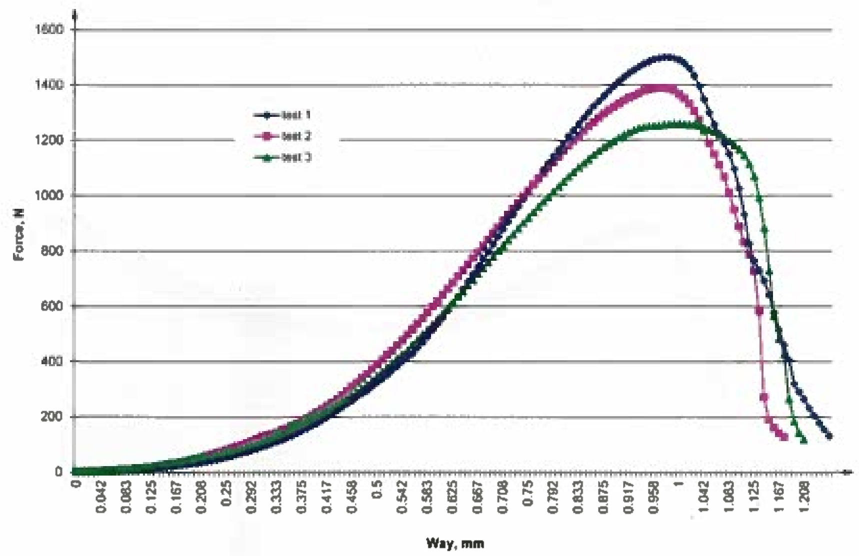

Figure 10: Force way diagram mixture G at 600 °C

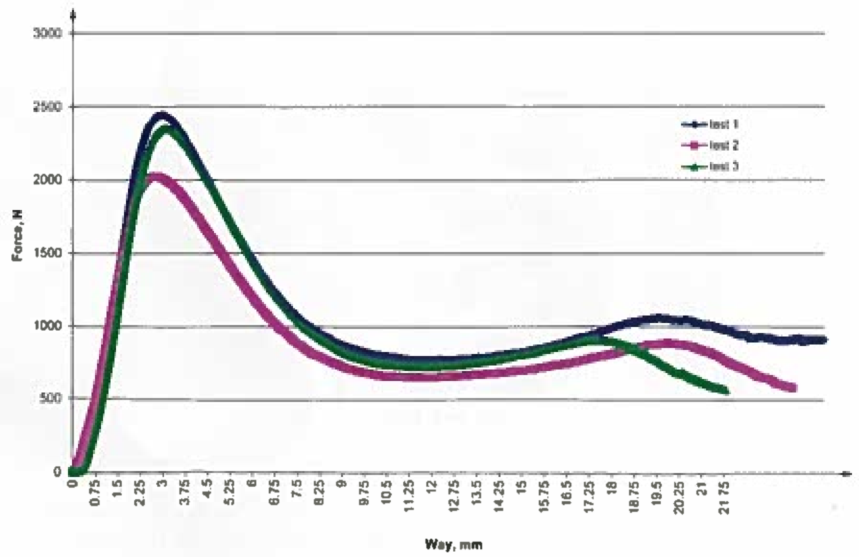

Figure 11: Force way diagram mixture G at 1000 °C

of mixtures A and B the heating had been stopped at lower temperatures than planed, because the further heating was very slow. A significant difference in heating time was found between the mixtures A and B and the mixtures C and D at temperatures of 600 °C and more. The explanation for this behaviour is the carbon in the mixtures C and D, it makes the heating faster and also the theoretical temperatures are possible. The received results we can use for all other investigations.

3.2 Recording of force way diagrams

In the next step it was the target, to create force way diagrams for different bentonite bonded sand mixes. The maximum force of the samples gives an information about the strength of this mixture. The course of the graph gives information about the behaviour of the sample under a thermo mechanical load. The sand can have a more brittle or a more plastic behaviour. This is depending from the temperature and from the composition of the moulding material. Further, the pictures of the deformed sample were supposed to deliver explanations for the thermo mechanical behaviour of the sand mix. The following sections present the results of this investigations for the five different sand mixtures:

- 7 % activated calcium bentonite – mixture E;
- 7 % activated calcium bentonite + 0.5 % additiv A (cellulose) – mixture F;
- 7 % activated calcium bentonite + 2 % additiv B (coal) – mixture G;
- 7 % activated calcium bentonite (mixture from two different bentonites) – mixture H;
- 7 % mixture H + 2 % additiv Z (zeolite) – mixture I.

The measurement is very time consuming. The Figures 6 and 7 contains every graphs from three samples.

Mixture E contains 7 % of an activated calcium bentonite without additives. At the temperature of 1000 °C it has a very long plastic zone. The breakage is brittle (Figure 7).

Mixture F contains 0.5 % of an additive and shows very similar graphs for the force than the mixture E. In this picture we can also see a similar deformation behaviour of this mixture. The additive is not usable for improvements (Figure 9).

Figure 10 and 11 shows the graphs for mixture G, it contains coal. The strength at lower temperatures is higher than for the mixtures without coal E and F. At 1000 °C the maximum force is lower and Figure 12 shows a very brittle breakage.

The sand mixes H and I are mixtures from two different bentonites, mixture I contains also an additive. Both mixtures have higher strength at 1000 °C (Figures 13 and 14). The Figure 15 shows the very plastic behaviour of these mixtures especially the mixture I with the additive.

4 Conclusions

The "classic" properties of bentonite bonded sands (different strength) deliver only limited information about the behaviour of produced moulds. The information from these tests are only valid for room temperature conditions. For the properties under conditions of higher temperature we need new test procedures and test equipment. These new test technologies can deliver us information for a guaranteed high casting quality and the avoidance of casting defects.

With the presented new test equipment it is possible to record the strength deformation behaviour of sand mixtures in the temperature range between room temperature and 1000 °C. In a first step we have investigated the heating technology for the used samples. This is necessary for guarantee a uniform temperature distribution in the sample. The research shows, that the heating time is depending from the composition of sand. Mixtures with coal do not need such a long time for heating as mixtures without coal.

The next step of the investigations include the test of five different sand mixtures with different bentonites (bentonite content was uniformly 7 %) and with different additives at temperatures 600 and 1000 °C. The following results come from these investigations.

Figure 12: The samples mixture G after 600 and 1000 °C

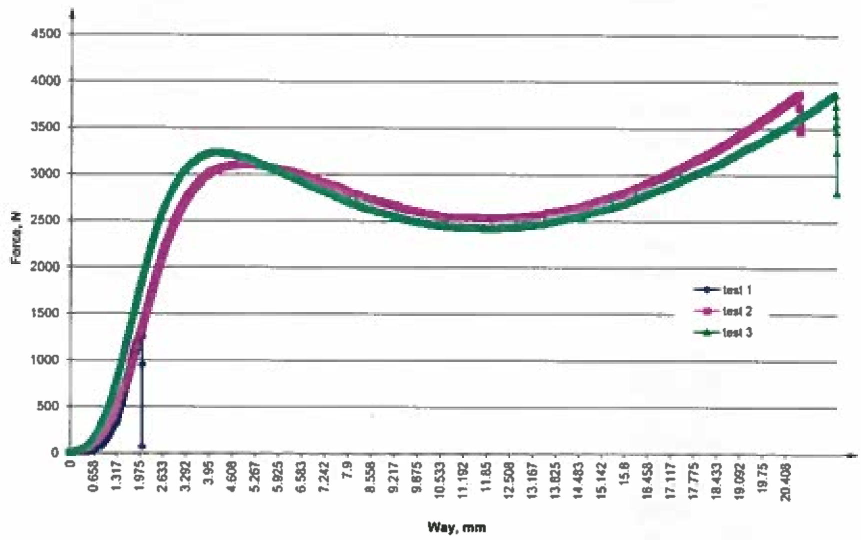

Figure 13: Force way diagram mixture H at 1000 °C

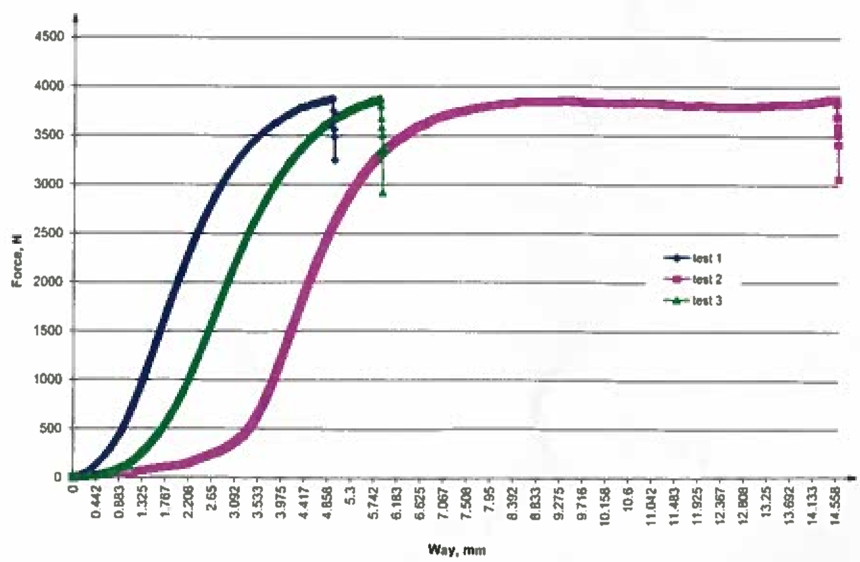

Figure 14: Force way diagram mixture I at 1000 °C

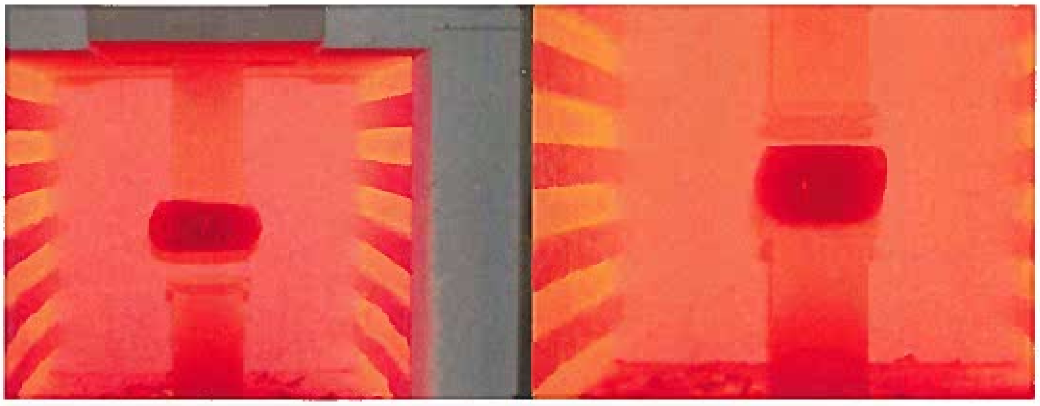

Figure 15:
The samples mixture E (left) and I (right) at 1000 °C

1. Mixtures only with one bentonite have a plastic phase behind the maximum force at 1000 °C, but the breakage is relatively brittle (E).
2. On examinated additive brings no improvement of this behaviour (F). It is possible, that the mixtures E and F have a bad shake out but a low defect tendency.
3. The mixture with coal (G) has a higher strength at 600 °C, but a lower at 1000 °C and a very brittle breakage. The shake out of this sand will be better, but the defect tendency is higher.
4. Mixtures from different bentonites (H and I) have a better deformation behaviour and also higher strengths, especially when they use suitable additives.
5. This mixture has also a more plastic behaviour under conditions of higher temperatures. Probably the mixtures H and I have good shake out and a low defect tendency.

The results of the presented investigations are suitable for a better understanding of the high temperature deformation behaviour of bentonite bonded sands and the avoidance of casting defects. Further investigations are necessary.

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