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ASSESSMENT OF THE STRUCTURAL DEVELOPMENT OF RESIN BONDED TAPHOLE CLAY

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ABSTRACT

Resin in taphole clay provides good extrudability and strength at low temperatures. However, it also contains volatile matter that is lost on heating. The blast furnace taphole is subject to a large thermal gradient, leading to variation in the bonding and structure of the clay along the taphole's length. This has a critical effect on properties. Effects of this variation in properties on furnace operations are not well understood.

A simple laboratory test was devised to simulate the thermal gradient, and assess its effects on taphole clays. Thermogravimetric tests were also conducted at different heating rates. Results of experiments are compared with the results of plant trials, and with a taphole structure removed from a blast furnace prior to demolition. The laboratory results correlate well with plant data and observations.

1. INTRODUCTION

Previous work on taphole clay (THC) has focused primarily on the composition), curing of the resin and standard property measurements, such as compressive strength, and crude measurements of curing temperature and required extrusion pressure.^{1,2)} This has led to the optimisation of the composition within the limits of current knowledge. Ikeda et al³⁾ also studied the cross section of a taphole taken out of a quenched blast furnace (BF). They observed that there was a complex structure incorporating layers of metal and slag, as well as agglomerates of the tar bonded taphole clay. They suggested that as the clay was injected its behaviour may have changed such that instead of forming an adherent layer, large agglomerates formed which could be easily dislodged. Andou et al⁴⁾ reported further results from analysis of the same taphole, and suggested that a clay that expanded slightly on heating would be beneficial. Some work on simulation of taphole clay injection was carried out by Uenaka et al⁵⁾, focusing on the effects of changes in taphole clay composition on adhesion.

In light of this information, it was decided to attempt to develop a simple laboratory test that would simulate the thermal gradient in the crucial first 2 metres of the taphole where volatiles are generated, and properties and texture vary widely. The test

would be validated by comparison to data from plant trials and analysis of a quenched taphole. If successful, this would provide a valuable tool for assessment and development of new taphole clays.

2. EXPERIMENTAL METHOD

2.1 Thermal gradient test

The method was designed specifically for the evaluation of taphole clay. It involves the use of a 1m long horizontal tube furnace with six independently controlled heating zones to simulate the thermal gradient in the furnace taphole.

For this project, the 6 furnace controllers were set to provide a linear thermal gradient from 100 to 1200°C over a distance of 800mm. This gradient was based on measurements of the temperature along the taphole length of Port Kembla No. 6 blast furnace (PK6). The calibration curve is shown in Fig. 1.

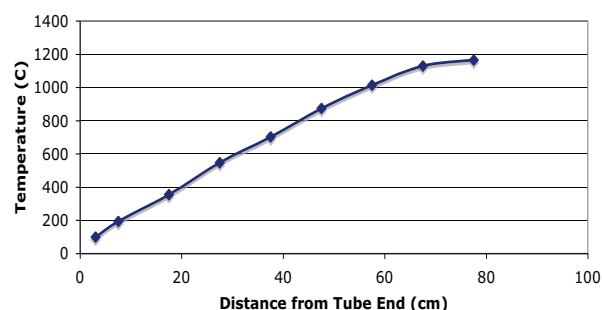


Fig. 1 Thermal profile used in tube furnace

The six controllers were set at the desired temperatures and the furnace allowed to heat overnight before calibration to ensure that a steady state had been reached.

The taphole clay was warmed to the manufacturer's recommended extrusion temperature, and then extruded into a 25mm internal diameter mullite tube. The tube was used to constrain the taphole clay in a manner similar to the way in which freshly gunned clay in the BF is constrained by the older material surrounding it. The filled tube was then weighed and inserted into the preheated furnace, which is enclosed in a fume cabinet. The tube's position and orientation were marked so that sample position could be correlated to temperature. Pyrex beakers were placed under the ends of the tube to catch any material that came out of the ends of the tube during the test. Observations of the smoke generation, liquids and solids lost and flame generation were all recorded. The tube was left in the gradient furnace for 1hr, and was then removed and allowed to cool to ambient temperature. The weights of the tube and any materials in the beakers were then measured. Fig. 2 shows the test arrangement.

The cooled tube was then cut into segments 100mm long. A 25mm slice from the end of each segment was cut and photographed. Image analysis was used to determine the voidage, which includes shrinkage that has occurred around the periphery of

each slice and large voids present in the sectioned surface as a percentage of the original area (% voidage). This value does not include normal porosity.

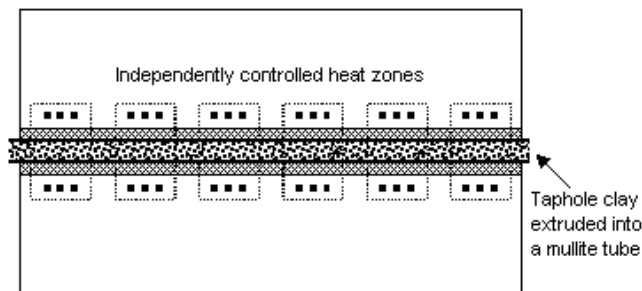


Fig. 2 Experimental set-up for thermal gradient tests

Hardness of the material in each section was measured at five different locations, using a Rockwell hardness tester with a load of 15N. Note that due to the nature of the material being tested, this is not a true hardness test, but rather an indicator of sample strength. Voidage and hardness were then plotted as a function of temperature.

2.2 Thermogravimetric Analysis (TGA)

For TGA tests, a ~3g sample of the test material was pressed into a 10mm dia pellet, and heated in a TGA apparatus with an infrared furnace. Test samples were heated in a nitrogen atmosphere at a rate of 10°C/min to 900°C. The weight of the sample was recorded to ±0.000001g every second by a data logging system. The use of nitrogen ensured that there was no significant loss of carbon from the samples during heating.

In addition, samples of one material were heated at 10, 50, 100 and 400°C/min to study the effects of accelerated heating rates on volatile generation.

2.3 Plant trials

Seven different commercial taphole clays were assessed. One of these was a material normally used at BlueScope Steel (THC A). The other six all underwent plant trials, and data were gathered to allow some comparison of lab results with observations from actual blast furnace operations and assess validity of the test technique. Due to page restrictions, results from only two materials can be included in this paper.

Data collected during plant trials included taphole length and drilling speed, as well as observations of liquid leakage and flaring.

3. RESULTS AND DISCUSSION

3.1 Laboratory testing

Cross-sections and hardness results for THC A tested are shown in **Fig. 3** and **Fig. 4**. The measured shrinkage voidage as a function of temperature is shown in **Fig 5**. These figures demonstrate the type

of information that was obtained from these experiments.

Measurements of the shrinkage voidage around the perimeter of the samples did show striking differences between the various clays. Whilst four had low voidage at low temperatures, increasing into the 600-700 degree range, the THC A had a very high voidage (>20%) at lower temperatures, and had its lowest voidage at 1000°C. This corresponds to observations of liquid trickling out of the cold end of the tube during testing. This was not observed for any other clays. The shrinkage was concentrated around the top of the tube, forming a large channel between the THC and the tube.

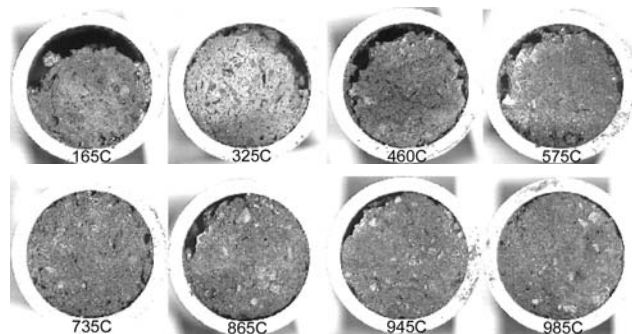


Fig. 3 Photos of cross sections of THC A after heating, temperature shown

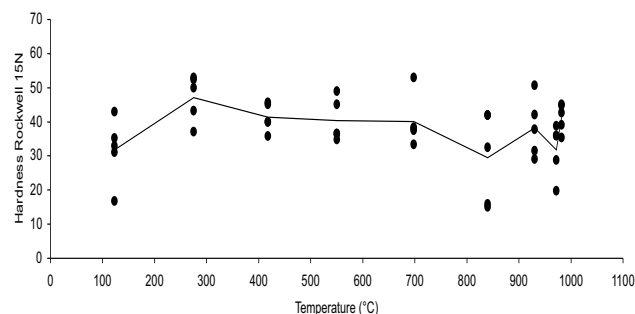


Fig. 4 Rockwell hardness as a function of temperature for THC A

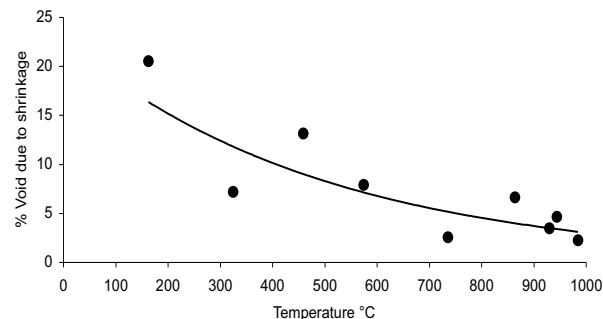


Fig. 5 Voidage due to shrinkage as a function of temperature for THC A

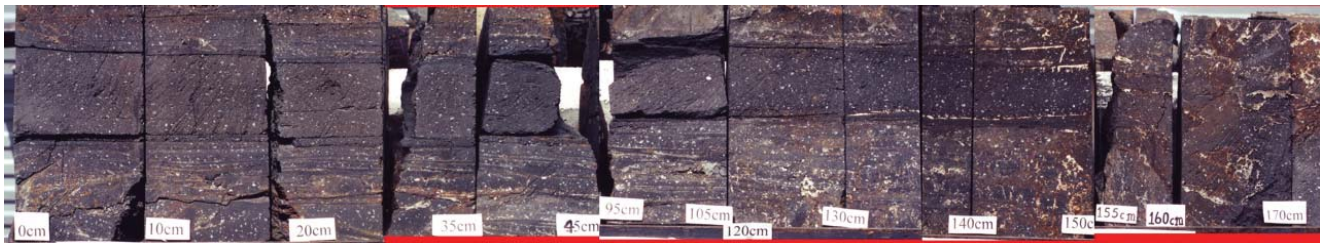


Fig. 6 Cross section of taphole taken from PK4. Note that the material from 45cm to 95cm is missing

This result may explain observations made during plant operations. Liquid iron tributaries have been observed during opening of tapholes filled with this clay that may correspond to void formation. Drill operators also noted pockets of friable material consistent with voids in the central region of this material during drilling of the taphole. Experience with this clay suggests that batches that are softer (higher resin content) are more prone to the formation of these tributaries. This may be associated with escape of volatiles and non-uniform shrinkage.

Hardness results did not show major variation as a function of temperature, nor did they vary greatly between materials. Therefore, it is difficult to use these measurements to discriminate between taphole clays. This is despite care being taken to avoid indenting in large grains during testing. During plant trials, however, there were major differences in the drilling behaviour of the clays. This implies that hardness measurements do not provide an adequate indication of drilling behaviour. There did appear to be a correspondence between in-plant uniformity of drilling, and voidage measurements, with those clays that displayed less shrinkage and more uniform structures in lab tests drilling more evenly and providing smoother liquid flow during casting.

Comparison of the lab samples with a cross-section of a taphole taken from PK4 blast furnace shows good correlation, although the taphole clay used in PK4 was slightly different in composition. It was made by the same manufacturer as THC A. The sectioned taphole is shown in **Fig. 6**, and shows a similar overall structure to that reported for the Kimitsu No. 3 BF taphole.^{4,5)} At the colder end of the taphole, there is a distinct separation of the newly installed clay from the older material around it, and annular layers of clay and slag. The shrinkage of the clay accompanying volatile lost would contribute to this separation. The gap observed in the actual taphole is not as large as might be expected from the lab tests, since during gunning additional clay is pushed into the the taphole as a result of sustained gun ram pressure against furnace pressure.

Cross sections of thermal gradient test specimens from a second, different taphole clay THC B trialed on the BF are shown in **Fig. 7**. Note that this material does not display large shrinkage at low temperatures as did the previous clay.

The maximum voidage for this clay was 12.8%, as shown in **Fig. 8**, and shrinkage was uniform around the circumference. There was no evidence of channeling, and no liquids dripped from the tube

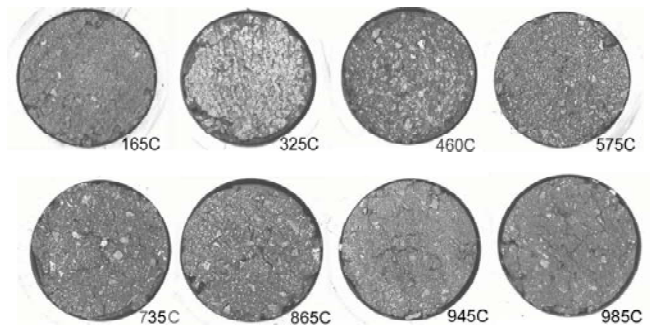


Fig. 7 Photos of cross sections of trial THC B after heating, temperature shown

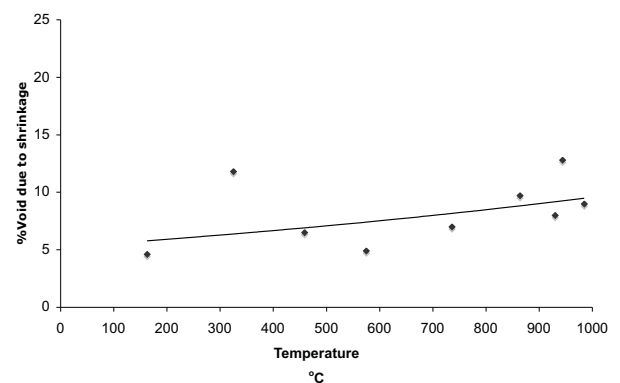


Fig. 8 Voidage due to shrinkage as a function of temperature for THC B

during testing. In plant trials, this material did not suffer from formation of liquid iron tributaries. Drilling was very uniform, with no evidence of internal void formation. This suggests that assessment of shrinkage during thermal gradient tests may be useful in predicting some aspects of taphole clay performance.

Results of TGA support the observations made from the thermal gradient tests. Weight loss as a function of temperature for THC A at three heating rates is shown in **Fig. 9**.

The resin system used in THC A shows weight loss principally between approximately 180 to 600°C. All of the tested taphole clays are bonded with a Novolak resin dissolved in a solvent, such as propylene glycol or furfural alcohol, which have boiling points of 187.3°C and 170°C respectively. Most of the early weight loss would be due to boiling of the solvent. At higher temperatures, a series of chemical reactions occur that generate gases (H₂O, CO₂, methane, etc) leading to additional weight loss. At about 600°C

the polymeric structure breaks down, and any remaining gases are liberated. Total weight loss for THC A was 10.2%, which was found to be fairly typical for most of the materials tested.

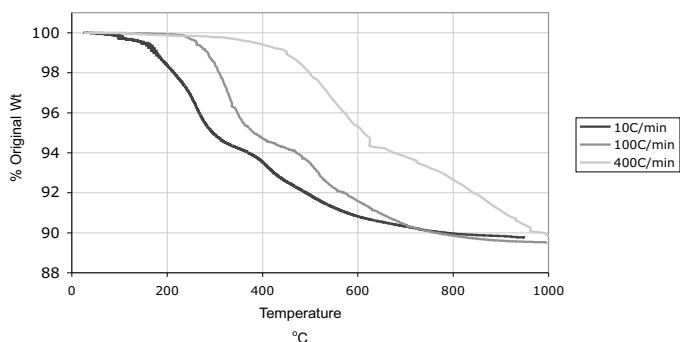


Fig. 9 Weight loss as a function of temperature during TGA tests at three heating rates for THC A

Increasing the heating rate pushed the weight losses up to higher temperatures, as would be expected. This highlights the potential for volatile entrapment in the taphole.

The TGA trace for THC A was similar to that of several other THC materials that were tested, but these materials did not suffer from channel formation and non-uniform shrinkage. It is thought that the particle size distribution of THC A, which was significantly different to that of THC B, may be such that it reduces permeability, making it more difficult for the volatile material to escape through the bulk of the material.

3.2 Plant Trials

Assessment of drill carriage forward speed from three separate casts using the same clay was undertaken to determine if this could provide insights into the taphole clay structure. Constant drill rotation speed and hammer action were assumed. Some variation in operator practice made detailed comparisons unreliable, but similarities in general results allowed identification of five distinct regions, as **Fig. 10** shows.

These regions are 1) cool face, resin bonded material, 2) reducing speed region, material changes from weak unbonded material to sintered material, 3) constant speed, uniformly sintered material, 4) hot face, may have mixture of clay and iron and slag, and 5) the end of the tap hole. If significant differences in operator practice were eliminated through greater standardization of procedures, or automation, the carriage speed could provide routine insights into taphole structure as a function of distance and temperature, without the need to extract whole tapholes for analysis.

4. CONCLUSIONS

A simple test that involves heating of an extruded column of taphole clay in a thermal gradient similar to that found in a BF taphole can provide useful information about volatile evolution and structural changes that occur in the clay when gunned into the taphole. The observations from the lab tests compare well with information gained from in-plant drilling speed data, and observations made during trials. The structures formed in the test also seem to be similar to those observed in a taphole structure removed from a BF prior to demolition.

Although several materials assessed in the thermal gradient test had similar weight loss due to volatile generation, THC A suffered from channel formation and non-uniform shrinkage. This may be related to the particle size distribution.

Monitoring of drill carriage speed when opening tapholes also has potential to provide valuable information about the structure of the taphole clay. However, drilling procedures need to be standardized before detailed comparisons analyses can be made from this data.

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Fig. 10 Gun carriage forward speed as a function of drill distance from the taphole face for three casts