Transport processes in thick concrete structures at high temperatures

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ABSTRACT

A change of the thermal equilibrium in thick concrete structures leads to transport processes which may result in a loss of moisture near the surfaces or across the whole cross section. The transport of moisture depends on the type of thermal state the water attains. If T ≧ 100°C vaporization starts. Plain and prestressed concrete members using different types of aggregaates have been tested up to 600 °C as to study the influence of different permeabilities and states of stresses on the water deliberation and transfer. Two different heat procedures were applied: a continuous and a step by step temperature increase from one side. During the tests measurements were made from temperatures, moisture distributions, and the pore pressure increase in the concrete members.

1. INTRODUCTION

Pressure vessels of prestressed concrete for high temperatur reactors are subjected to high mechanical and thermal stresses during the reactor's working and accidental conditions. In consequence the concrete structure is considerably altered due to strength and moisture changes during its life time. Concrete contains a fine porous system filled with adsorbed and evaporable water. Therefore certain types of stresses as heating or cooling are connected with transport processes concerning the liquid and gaseous phases in the concrete. During the heating process the temperature increase produces a pore pressure potential, which causes migration of moisture through the concrete. On the other hand the movement of moisture resp. the evaporation of pore water and the recondensation of steam in the porous system may influence the original temperature distribution.

The transport ability of a porous system can be described by the terms of porosity or permeability which are determined and characterized by the porous structure. Other important terms are the vaporization ability of the porous system as well as the crack system which may develope during transient temperature changes.

2. DESCRIPTION OF THE EXPERIMENTS

For studying transport processes thick concrete samples are necessary for practical reasons. Therefore seven concrete samples each of it weighting more than 800 kg with different aggregates and a constant water-cement-ratio of 0.5 were tested. As aggregates gravel, basalt or limestone were used. As to investigate the influence of prestress forces on the transport processes plain and also prestressed concrete samples have been made from the same mixes (comp. table 1).

The plain samples were plates with a cross section of 1 m x 1 m and a thickness of 0.5 m. The four lateral surfaces were sealed by a steel liner and isolated by mineral wool, so that nearly an uniaxial transport was achieved during the tests. The thickness of the prestressed samples was reduced to 0.35 m due to the limited capacity of the prestressing device. For getting the prestress force of 3000 kN 32 prestressing steel elements with a diameter of 1.2 cm were installed in one direction of the concrete. During the tests the steel stresses were measured by a couple of strain gages.

Table 1: Survey of the tested concrete samples

type of aggregate	water/cement-ratio	28 d-strength [N/mm²]	concrete density [kg/m³]
plain samples			
gravel 0/16	0.5	45.0	2330
gravel 0/16	0.7	31.3	2270
basalt 0/16	0.5	56.6	2520
limestone 0/8	0.5	43.3	2350
prestressed samples			
gravel 0/16	0.5	46.2	2310
basalt 0/16	0.5	57.7	2530
limestone 0/8	0.5	46.0	2340

During the tests the samples were hung horizontally in a steel frame with its lower surfaces directly above the opening of an electric furnace. In this position the concrete samples were heated to a temperature of 600 °C. During the tests the temperature data, the pressure inside the concrete, the moisture distribution as well as the weight loss of the samples were recorded.

3. PRESENTATION OF TEST RESULTS

In the following figures the measured weight loss rate, the moisture distribution and the pressure distribution in different basalt concrete samples under heating of one surface are shown. For all the figures the represented test duration is the same, i.e. the heating duration is 100 h. The achieved temperatures range from 400 °C or

500 °C in dependence of the applied temperature-time-program. The first three figures contain the behaviour of a 50 cm thick plain basalt concrete sample during a step by step elevation of temperatures up to 500 °C. The first of these diagrams shows the weight loss rate in comparison with the increase of the temperature of the heated surface and the average temperature of the sample. The weight loss rate is defined as % weight loss per hour whereby the weight loss refers to the weight at the beginning of the test, i.e. 1.0 %/h = 12 kg/m²h. The characteristic phenomena is the simultaneous in- and decrease of the weight loss rate with the stepwise temperature increase. This is caused on the one hand by the respective change of the temperature gradients in the concrete sample, on the other hand by the transport and evaporation conditions in the porous system of the concrete. Due to the vaporization of the water near the heated surface area the difference between the surface temperatures and the oven temperatures is comparatively large during the beginning of the heating process compared to the situation at a later time i.e. at high temperatures. While the first maximum describes the evaporation of the surface areas, the following maxima describes the evaporation and dehydration of internal zones of the sample. This can be seen in the second diagram, which shows the moisture distribution at different heating durations. In addition it can be seen that besides the vapour transport to the heated surface moisture is transported to the colder zones of the sample. The third diagram demonstrates the vapour pressure development in the porous system. The pressure was measured 10 cm apart from the heated surface. The pressure maximum achieved is about 2 bar and is caused by the low transport capacity of the heated concrete in this sample zone. After the vaporization and dehydration in this zone have completed the pressure decreases, i.e. the dry concrete zone is comparatively permeable.

A continuous increse of the furnace temperature with a rate of 5°C/h leads to a different behaviour of the same basalt concrete. In the fourth diagram the respective weight loss rate is presented. Due to the slow temperature increase the loss of weight starts comparatively late. Thereafter several maxima and minima in the weight loss rate occur . One explanation of this behaviour is the fact, that the transport processes need some time as to transport the vapour from the internal concrete zones to the heated surface and that these processes are being hindered by the vapour pressure in the zones between the vaporization zone and the heated surface. Further the moisture distribution curves indicate, that a strong moisture transport to the colder zones occurs which is also due to the vapour pressure in the vaporization zone (fig. 5).

The observes pressures in the porous system are distinctly higher than by the step by step temperature increase (fig. 6). Due to the continuous temperature increase there is no relaxation time for the compensation of transport processes which will reduce the vapour pressure. In this way the type of temperature exposure can strongly influence the evaporation behaviour of the concrete.

During the tests different pore pressures were recorded by the installed membran manometers. This was due to the effect that each manometer (which had a distance of 10 cm from the heated surface) had a different location with respect to the center of the specimen. The distance from the isolated sides were 40 cm, 20 cm and 10 cm. Fig. 6 indicates that near the sample border (distance 10 cm) the measured pressure differences were comparatively small. This effect may be explained by a pressure relieve near the isolated surfaces with a steel liner. It should be noted that the liner was not connected to the concrete by using anchors but two collar sheets were welded to the liner and stick into the concrete as to interrupt the moisture transport along the sample border.

Fig. 7 and 8 show the weight loss rates of two prestressed basalt concrete samples. A direct comparison with the results of fig. 1 and 4 is not possible as the prestressed samples were only 0.35 m thick. The expectations that the prestress forces lead to an increase of pore pressures and a shifting of the evaporation to a little higher temperatures are approximately be confirmed by the two test results shown on fig. 7 and 8. A tendency that the maximum evaporation rates of plain concrete increase by about 20 % due to 5 N/mm^2 prestress is recognizable too. At the time being it is not possible to make final statements about the effect of prestress on the transport processes. But the effect of prestress will be investigated shortly by theoretical evaluations of further test data which have been obtained during the experimental program.

4. CONCLUSIONS

Up to now the results achieved by testing different concrete samples have had to the following conclusions:

- Heating of a porous system like concrete leads to mass transfer processes, which are determined by the permeable properties and the pore structure of the concrete, the rheologic and thermodynamic properties of water and vapour as the transported quantities and the thermal behaviour and dimensions of the porous material.

- The development of a pressure in the porous system is determined by the permeability of the concrete, the temperature-time-program of the heating, the thermodynamical behaviour of the water as well as the thickness of the concrete sample.

- The concrete mix determines the permeability of the porous system and is one of the decicive factors when moisture transport and vaporisation have to be considered.

- The state of prestress of the porous system influences the evaporation behaviour and the transport processes in the porous sample.

5. REFERENCES

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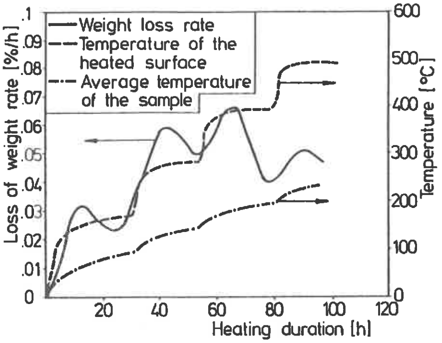

Fig. 1:

Loss of weight rate of a basalt concrete sample (W/C: 0.5, thickness: 0.5 m) during the heating of one surface (stepwise elevation of temperature)

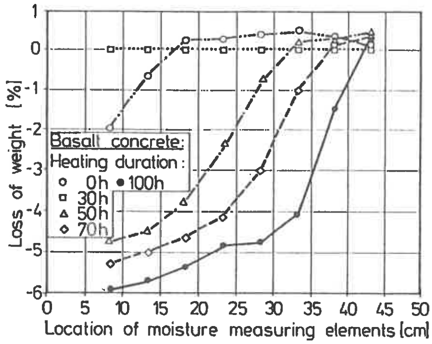

Fig. 2:

Moisture distribution curves of a basalt concrete sample heated at one surface (x = 0 cm) at different heating durations (stepwise elevation of temperature)

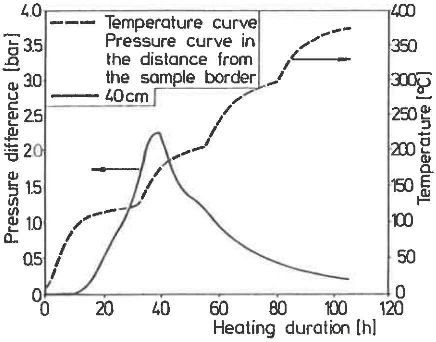

Fig. 3:

Pressure development curve of a basalt concrete sample in a distance of 10 cm from the heated surface (stepwise elevation of temperature)

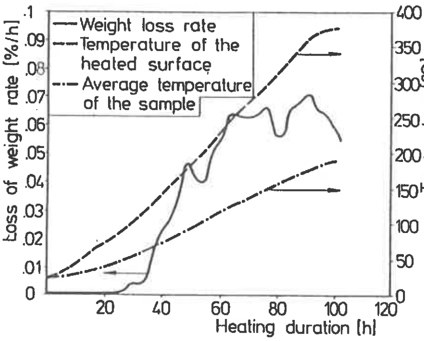

Fig. 4:

Loss of weight rate of a basalt concrete sample (W/C: 0.5, thickness: 0.5 m) during the heating of one surface (continuous elevation of temperature)

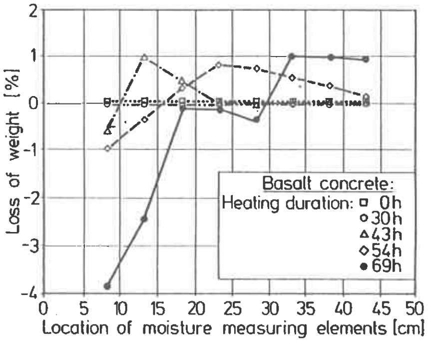

Fig. 5:

Moisture distribution curves of a basalt concrete sample heated at one surface (x = 0 cm) at different heating durations (continuous elevation of temperature)

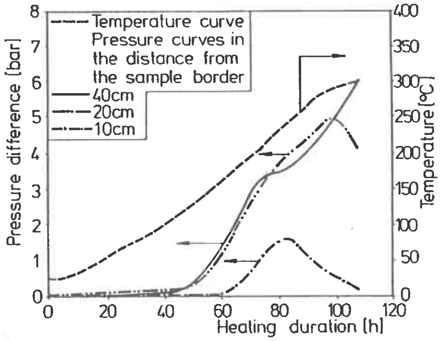

Fig. 6:

Pressure development curves of a basalt concrete sample in a distance of 10 cm from the heated surface (continuous elevation of temperature)

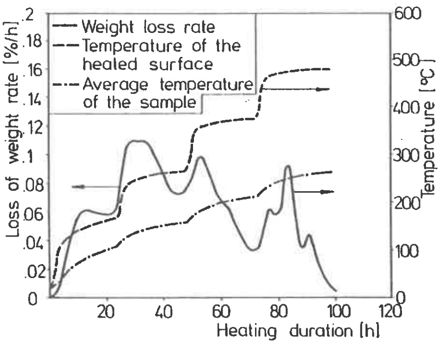

Fig. 7:

Loss of weight rate of a prestressed basalt concrete sample (W/C: 0.5, thickness: 0.35 m) during the heating of one surface (stepwise elevation of temperature)

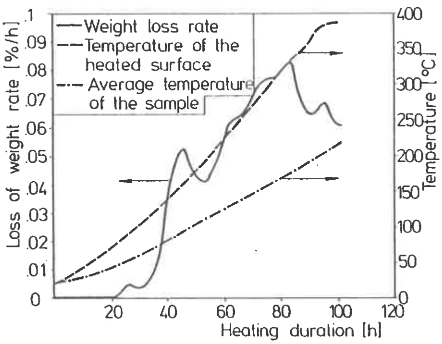

Fig. 8:

Loss of weight rate of a prestressed basalt concrete sample (W/C: 0.5, thickness: 0.35 m) during the heating of one surface (continuous elevation of temperature)