Shrinkage and Swelling of Rocks due to Moisture Movements

by

P. NEPPER-CHRISTENSEN

Concrete Research Laboratory Karlstrup

Abstract

It has proven that many rock types are sensitive to variations in the relative humidity of the surrounding atmosphere since they shrink or swell as they give off or absorb moisture. In the present article measurements of the shrinkage of a type of basalt and a Danish, dense flint are described.

Introduction

Concrete can be described as an artificial conglomerate, in which the binder, known technologically as cement paste, is a porous, permeable system, the solid components of which consist principally of hydrated calcium silicates, i.e. tobermorite-like products. These products, which are produced by reactions between cement and water, are formed in the course of a relatively short period. Thus, depending on the characteristics of the cement, about one month is sufficient for most of the cement to have hydrated and for the concrete to have attained most of its strength.

The aggregates (a mixture of fine and coarse aggregates) used for the concrete are both crushed rocks, e. g. crushed granite, basalt and limestone, and alluvium, either from rivers or the sea. The aggregates constitute an average of approx. 75 per cent of the total volume of the concrete. It is therefore clear that the physical and chemical characteristics of the aggregates have a considerable effect on the characteristics of the concrete (strength, elasticity, permeability, durability, etc.). The mineral composition, internal structure and surface texture of the individual aggregate particles, on which depend the porosity, permeability, absorption capacity, volume constancy, strength, elasticity, etc., of an aggregate, thus influence considerably the characteristics of the concrete.

Cement paste, the binder in concrete, has one very unfortunate characteristic as far as the practical use of concrete is concerned, and that is that it shrinks when giving off moisture and expands during absorption of water. The process is largely reversible. During drying from saturated condition to equilibrium with a relative humidity of the surrounding air of, say, 50 per cent, the shrinkage of the cement paste may amount to about 1 volume per cent, depending on the water/cement-ratio. However, the shrinkage of the concrete is considerably lower. Under the conditions mentioned above, the drying shrinkage of the concrete will normally be of the order of magnitude of 0.1 vol. per cent. Shrinkage of this magnitude will not normally prohibit the use of concrete as a building material. The reason why the shrinkage of the concrete is so much lower than that of the cement paste is that the aggregates, which, as mentioned above, constitute the greater part of the volume of the concrete, prevent free deformation of the cement paste. The degree to which the agregates reduce the shrinkage is conditional upon the elasticity of the aggregates, and upon their volume constancy when subjected to wetting and drying.

Experience has shown that certain rock types are subject to considerable variations in volume—in a few cases, of the same order of magnitude as the cement paste—during wetting and drying. If such a rock is used as concrete aggregate, the concrete will not only be subject to abnormally high shrinkage, but will also, under unfavourable conditions, disintegrate completely because of widespread cracking. For instance, the case may be imagined in which a dry aggregate absorbs water from the cement paste, thereby expanding, while the cement paste shrinks. This could lead to such great internal stresses that the strength of the concrete would be exceeded.

Literature on the subject contains several reports on concrete that has deteriorated badly because of the use of aggregates with high shrinkage. SNOWDON and EDWARDS (1962) have described cases of deterioration of prefabricated concrete products in which certain Scottish crushed dolerite materials had been used as aggregate, and have reported investigations on the shrinkage and swelling characteristics of dolerites and other rock types. STUTTERHEIM (1960) has described cases of deterioration and marked deformation of concrete works in South Africa, where the cause could be proved to be the use of an aggregate with high shrinkage, namely, fine-grained sandstone and shale, with a binder that was mainly sericitic and contained some kaolin and montmorillonite.

It will be understood from the above that the phenomenon that many rocks—and possibly all—undergo some degree of change in volume during wetting and drying is known within concrete technology. From a geological point of view too, the phenomenon is presumably of some interest since it is possibly an important factor in the processes of rock weathering.

In the following an investigation on the shrinkage and swelling characteristics of basalt and flint is described. The tests were carried out at the Concrete Research Laboratory Karlstrup in the summer of 1963.

Investigations

The investigation covered two types of rock, namely, 1) a dense, Permian basalt of Scandinavian origin, and 2) a dense, grey flint.

The measurements were made on sawn-out prisms measuring $2.5 \times 2.5 \times 11.5$ cm (Fig. 1), by means of a mechanical gauge (graduation 10^{-3} mm) with a gauge length of 100 mm. The measuring points were marked by

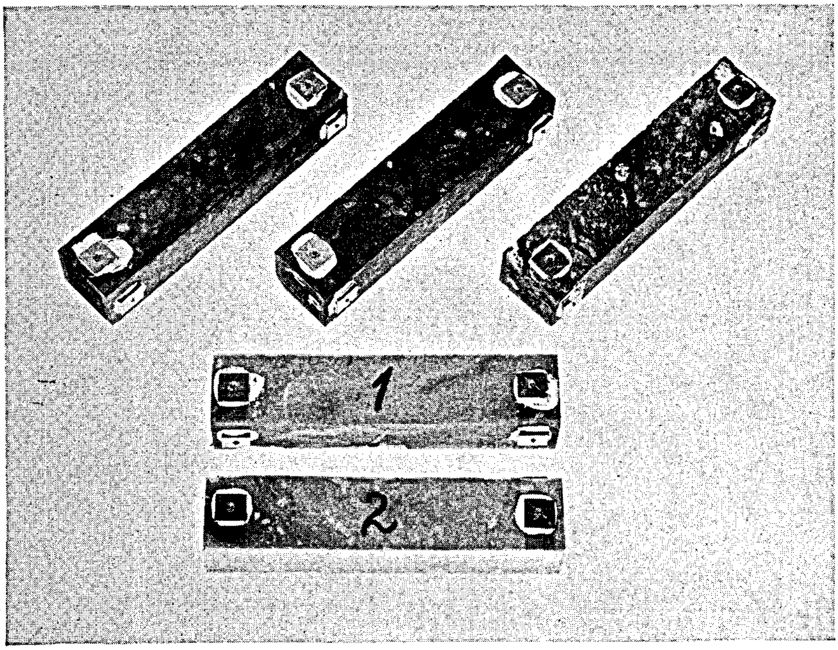

Fig. 1. Test specimens of basalt (above) and flint (below) measuring $2.5 \times 2.5 \times 11.5$ cm.

small steel balls knocked into rectangular copper discs, which were glued to the prisms by means of araldite (Fig. 2). Each prism was provided with four measuring points aranged in such a way that the deformations could be measured on two adjacent prism surfaces.

Measurements were made on a total of 3 basalt prisms and 2 flint prisms. Basalt prism No. 3 (see Fig. 1) differed from the other two basalt prisms in that it contained a large number of big, more or less altered phenocrysts.

The prisms were first dried in an oven for 72 hours at 105 °C. After weighing and measuring, they were placed horizontally on one prism surface at 100 per cent relative humidity (RH) and 20 °C. They were then weighed and measured again. For the next six days the storage conditions were alternated between 24 hours at 65 per cent RH and 20 °C and 24 hours at 100 per cent RH and 20 °C; finally, the prisms were kept constantly in 65 per cent humidity and 20 °C, until there was no longer any appreciable change in their length.

Fig. 3 shows the variations in length in per cent, registered in the above programme for the three basalt prisms and flint prism No. 1, measured on the upturned horizontal prism surface. The length of the prisms after oven-drying was used as the zero-measurement.

It will be seen that the comparatively short variations in climate at the beginning of the programme are clearly reflected in corresponding

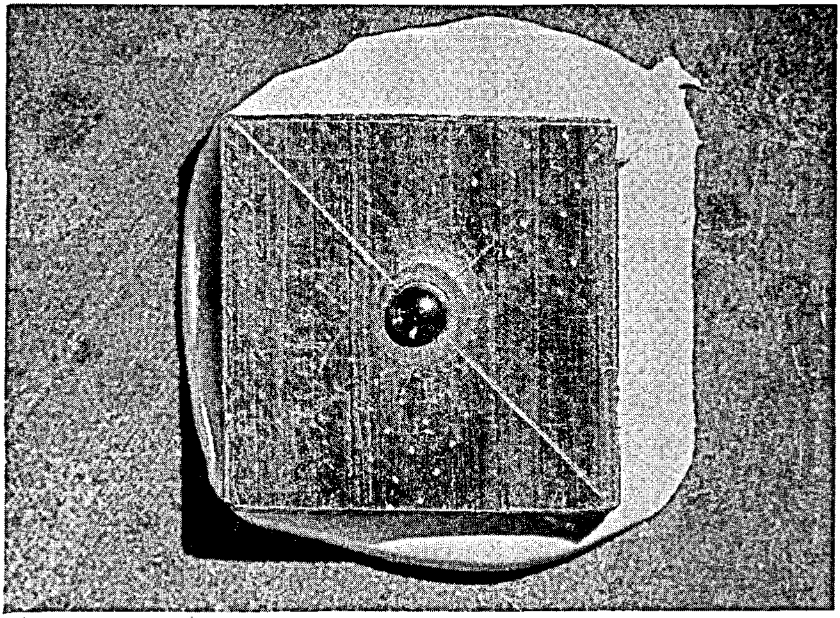

Fig. 2: Measuring point on test specimen. Cf. Fig. 1.

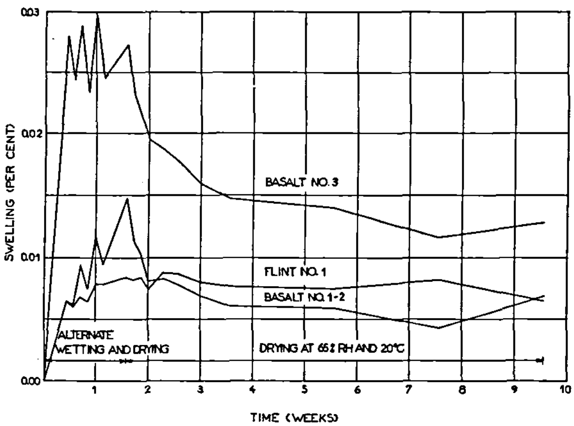

Fig. 3: Swelling vs. time of flint and basalt due to alternate wetting and drying, succeded by constant drying.

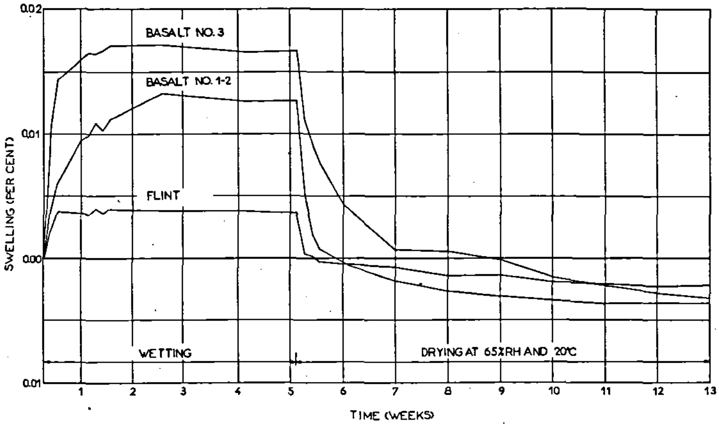

Fig. 4: Swelling vs. time due to wetting and drying.

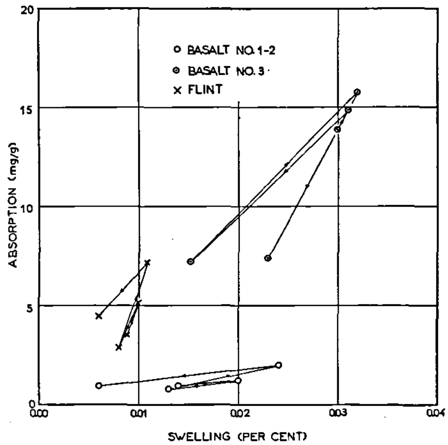

Fig. 5: Water absorption vs. swelling of flint and two types of basalt.

variations in length. Both the basalt prisms and the flint prisms shrink and expand in step with variations in the humidity. Basalt prism No. 3 shows the highest expansion—about 0.03 per cent, while the maximum expansion of the other two basalt prisms is about half this magnitude, and that of the flint prism about 0.01 per cent.

Moreover, it was seen that the horizontal top surfaces of the prisms expanded much less than the vertical prism surfaces during wetting in 100 per cent RH. This phenomenon is thought to be related to the fact that a film of water condensed on the horizontal top surfaces, while the vertical sides looked drier. It was later proved that when the prisms were stood on end so that no water could condense on any of the sides of the prism, both surfaces showed roughly the same shrinkage and expansion. This observation indicates that a film of water on a surface reduces the rate of water-absorption of a material when placed in an atmosphere with 100 per cent RH.

In the second part of the investigation the prisms were kept in a vertical position. After reaching equilibrium at 65 per cent RH and 20 °C, they were stored in 100 per cent RH and 20 °C. It took about one month for the prisms to reach equilibrium with this climate, i. e. for expansion to cease, and they were then moved back to 65 per cent RH and 20 °C. Measurements were stopped when the prisms had once more reached equilibrium with this climate. The expansion/shrinkage curves for this programme are given in Fig. 4.

Basalt prisms Nos. 1 and 2 proved to be subject to much the same shrinkage and expansion, for which reason the average curve for these two specimens is given in Fig. 4. The same applies to the two flint prisms. Basalt prism No. 3 deviated somewhat from Nos. 1 and 2, expanding faster but shrinking more slowly than these. It will be seen that the total shrinkage from saturation at 100 per cent RH to equilibrium at 65 per cent RH and 20 °C is of the order of magnitude of 0.02 per cent for basalt prism No. 3, slightly lower for prisms No. 1 and 2, and about 0.006 per cent for the flint.

The water absorption in relation to oven-dry condition was measured by weighing at various intervals. Fig. 5 shows the water absorption (expressed in mg per g aggregate) plotted against the expansion, similarly calculated in relation to the oven-dry condition. There appears to be some relationship between the absorption and the expansion for one and the same material, whereas the absorption for a given expansion may vary considerably for different materials.

Discussion

In the tests described above it was found that during drying from saturated condition to equilibrium at 65 per cent RH and 20 °C, the type of basalt investigated shrank 0.015 to 0.020 per cent, while the dense grey flint shrank 0.006 per cent, measured linearly.

Nishioka and Harada (1958) measured the linear expansion as a result of water absorption on a total of 22 different rocks (sandstone, shale, limestone, pumice, granite, et alia). They took measurements of the expansion and absorption at relative humidities varying between 0 per cent and 100 per cent. It was seen that in the zone from 0 per cent to 90 per cent, both expansion and absorption were practically proportional to the humidity while in the zone from 90 per cent to 100 per cent RH, both increased considerably. The processes were reversible during drying to 0 per cent RH, but with a small hysteresis. Expansion of a type of basalt was found to be approx. 0.020 per cent, and of a chert, approx. 0.005 per cent. As mentioned, a considerable part of the expansion took place in the zone from 90 per cent to 100 per cent RH, so these values can be roughly compared with those obtained in the above tests. It will be seen that the results agree well.

Snowdon and Edwards (1962) measured the shrinkage of various types of dolerite, sandstone, limestone, felsite, et alia. As test specimens they used 9×3×3 in. prisms, which, after wetting for 4 days, were dried at 17 per cent RH and 50 °C until equilibrium. The shrinkage of the dolerites varied between 0.0 per cent and 0.065 per cent, with an average value of 0.027 per cent.

Rhoades and Mielenz (1948) give a value of 0.06 per cent for the linear expansion and contraction resulting from wetting and drying for an altered dolerite containing approx. 30 per cent of the clay mineral, nontronite.

Opinions vary as to why many rocks undergo changes in volume when subjected to wetting and drying. Rhoades and Mielenz (1948) relate the phenomenon to a content of clay minerals, namely of the type belonging to the montmorillonite or hydromica group, whereas Snowdon and Edwards (1962) are of the opinion that the changes in volume of dolerit as a result of variations in moisture are related to its absorption, "but not to its mineralogical type or content of layer-type silicate minerals". Stutterheim (1960) has proved that clay minerals such as montmorillonite may contribute to the shrinkage and swelling of a rock, but that they do not constitute the only or the most important cause. He has further found that there is a certain correlation between the internal specific surface of a mineral and its shrinkage/expansion characteristics, although this correlation by no means explains everything. The above investigation also shows that the presence of clay minerals is not necessarily a condition for the shrinkage and expansion of a rock, cf. the shrinkage of flint.

It must thus be admitted that no clear reasons have yet been found for the shrinkage and expansion of rocks in step with variations in the relative humidity of the surrounding atmosphere. The mineral composition and the pore structure are presumably both important factors, and a content of clay minerals may also have a certain effect.

It is interesting to compare the shrinkage and swelling of a rock with its thermal changes in volume. For instance, the total shrinkage of a certain type of granite is of the order of magnitude of 0.04 % (cf. Nishioka and Harada (1958)). If its coefficient of expansion is assumed to be about 2×10^{-6} per °C, at a temperature variation of, say, 50 °C, it will expand or contract 0.01 per cent, i. e. a smaller movement than the shrinkage but still of the same order of magnitude. It is therefore possible that shrinkage and swelling are important elements in the weathering of rocks in nature.

Conclusions

Many, if not all, rocks are sensitive to variations in the relative humidity of the surrounding atmosphere since they shrink or swell as they give off or absorb moisture. The total shrinkage, i. e. the shrinkage that accompanies complete drying from a saturated condition, may, in extreme cases, be of the order of magnitude of 0.1 per cent, measured linearly, but generally varies considerably for the different types of rocks and also for various samples of any particular rock.

The reasons for this phenomenon have not yet been elucidated and should be made the subject of a more detailed study. Both the mineral composition and the pore structure are probably important factors, and a content of clay minerals may also have a certain effect. There is a relationship between the water absorption of a particular rock sample and its expansion, but the same water absorption does not necessarily result in the same expansion for different samples.

The total shrinkage or swelling of rocks is frequently of the same order of magnitude as the thermal changes in volume that accompany the heating and cooling of rocks at the earth's surface.

DANSK RESUMÉ

Beton er et kunstigt konglomerat, hvori grusmaterialet, sand og sten, er kittet sammen af cementpasta. Cementpastaen, der dannes ved reaktioner mellem cement og vand, er et porøst og permeabelt system, hvis faste bestanddele hovedsagelig udgøres af hydratiserede calciumsilikater. Cementpastaen, og derved betonen, svinder og sveller ved udtørring og vædning. Grusmaterialet virker ved sin stivhed reducerende på svindets og svelningens størrelse. Mange bjergarter, selv forholdsvis upermeable, undergår volumenændringer på tilsvarende måde ved vædning og udtørring, og i enkelte tilfælde har svind-svelningen vist sig at være så stor (f. eks. visse skotske doleriter), at de pågældende bjergarter har været uanvendelige som grusmateriale til beton. Ved undersøgelser på Betonforskningslaboratoriet Karlstrup er der på en norsk basalt og en dansk, tæt grå flint målt et lineært svind (ved tørring fra 100 % RH til 65 % RH) på henholdsvis ca. 0,2 ‰ og 0,06 ‰. Disse undersøgelser er nærmere beskrevet i den foreliggende artikel. I litteraturen er der eksempler på bjergarter med betydeligt større svind, f. eks. doleriter (op til 0,6 ‰), en japansk granit (0,4 ‰) og en japansk liparit (1,4 ‰).

REFERENCES

SNOWDON, L. C. and EDWARDS, A. G., 1962: The Moisture Movement of Natural Aggregate and Its Effect on Concrete. Magazine of Concrete Research. Vol. 14, No. 41. July 1962.

STUTTERHEIM, N., 1960: Deterioration of Concrete in Hot Dry Regions Due to Excessive Shrinkage of Aggregates. RILEM Symposium on Concrete and Reinforced Concrete in Hot Countries. Haifa, July 1960. Vol. 1.

NISHIOKA, SHIGEKA and TAMOTSU, HARADA, 1958: Elongation of Stones Due to Absorption of Water. Japan Cement Engineering Association. Review of the Twelfth General Meeting Held in Tokyo. May 1958.

RHOADES, R. and MIELENZ, R. C., 1948: Petrographic and Mineralogic Characteristics of Aggregates. Symposium on Mineral Aggregates. American Society for Testing Materials, Special Technical Publication No. 83.