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H04/6

INFLUENCES OF CONCRETE COMPOSITION ON STENGTH AND DEFORMATION UNDER UNIAXIAL AND BIAXIAL LOADING AT ELEVATED TEMPERATURES

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ABSTRACT

The strength and deformational behaviour of uniaxially and biaxially loaded concrete at high temperature both depend on the composition of the concrete. The maximum aggregate size plays a dominant role for the strength-temperature relation up to 600 °C. The aggregate/cement- and water/cement-ratio are factors of the same magnitude, but their influence is less pronounced. The influence of different concrete compositon is the same for concrete loaded with a different stress ratio κ, however the strength reduction due to increasing temperature is generally smaller in biaxial compression.

1 INTRODUCTION

The influence of composition of the concrete was the subject of previous investigations concerning the concrete behaviour at high temperature e.g. /1-3/. In most cases the changes in composition were realized by simultaneous alterations of the aggregate/cement- and water/cement-ratio. This procedure implies that variations in water/cement-ratio within the practical range do not influence the high temperature characteristics of concrete.

Another important influence is the type of loading. The mechanical behaviour of concrete at high temperature was primarily studied with uniaxially loaded specimens. Only a few tests were performed under biaxial loading conditions. These tests exhibit a strong influence of biaxial stress state on strength and deformation.

2 EXPERIMENTAL WORK

Uni- and biaxial tests with a deformation-controlled loading were performed with plate-shaped specimens (200 · 200 · 50 mm^3). These disks were saw-cut from cubes after at least 90 d. The standard curing regime was: demoulding after 1 d with a subsequent curing under water for 7 d, followed by storage at 20 °C/65 % r.h. until testing. The specimens were heated unsealed with a constant rate of 2 K/min and tested after a hold-time period of 2 hours at the test temperature (150 °C, 300 °C, 450 °C and 600 °C). Additional tests were performed at ambient temperature. The load was applied by brushes to provide a homogeneous stress state /4/. The deformations were measured longitudinally as well as lateraly. The tests described in this paper were performed with two stress ratios (κ = 0.0 and 0.7).

Three concretes and one mortar with the same type of quarzitic aggregates were used. The three concretes differ with respect to the aggregate/cement - and the water/cement-ratio. The mortar differs in the maximum aggregate size and also in the aggregate/cement-ratio. The cement used in this investigation was German Portland cement PZ 35F. The detailed compositions are given in Table 1.

Table 1. Concrete composition

Type of concrete	$f_{1,20}$ [N/mm^2]	Cement content [kg/m^3]	Mix proportions by weight [C:A:W]*	d_{max} [mm]	Plasticizer [% of cement content]	Air [%]
QB1	35.6	292	1:6.84:0.45	16	3	1.9
QB2	45.0	346	1:5.45:0.45	16	-	2.1
QB3	35.5	328	1:5.47:0.61	16	-	1.8
M	35.0	562	1:3.00:0.48	2	-	5.9

* C = cement, A = aggregate, W = water

3 RESULTS AND DISCUSSION

3.1 Compressive strength

Fig. 1 shows the results of the strength tests for the concretes QB1 and QB2 at different temperatures under uniaxial and biaxial loading. The high-temperature strength values for both stress ratios κ were normalized with respect to the corresponding strength at ambient temperature and the same stress ratio. The tests exhibit a smaller decrease in compressive strength for concrete with a higher aggregate content at both temperatures. Under biaxial loading an increase in strength even appears at 300 °C for the leaner mix. In this case it was stated /5/ that for leaner mixes there were probably lower internal stresses caused by the different thermal expansion of the concrete constituents and consequently a smaller reduction in strength. Nevertheless, the observed differences in strength are small with respect to the variation in aggregate/cement-ratio of A = 5.45 ÷ 6.84.

The temperature-strength relationship of the concretes QB1 and QB2 under uniaxial loading is shown in Fig. 2 together with the same relationship of mortar M. A more or less pronounced temporary decrease in strength is obvious at 150 °C. This reduction can be attributed to the initial moisture content of the specimens and correlates well with results obtained by a differential thermal analysis /6/. However, no correlation exists between these strength losses and the concrete compositions.

The strength is not only influenced the moisture, but also by physical and chemical reactions in the cement paste e.g.
- an increasing total porosity due to dehydration and
- a decreasing total porosity due to shrinkage.

These reactions are the main cause of the observed slight decrease in strength up to 300 °C.

Along with the formation and growth of microcracks due to increasing thermal incompatibility between aggregates and cement stone a more pronounced decrease in strength occurs above 300 °C. This strength loss is additionally supported by the decomposition of portlandite between 450 °C and 550 °C. The desintegration of portlandite corresponds with a further increase in porosity, which in consequence leads to pronounced structural alterations in the cement stone.

As indicated in Fig. 2 a comparativly smaller reduction in strength is exhibited by the mortar than both concretes at temperatures above 300 °C. If only the aggregate/cement-ratio is taken into account this observation would be in contradiction with the observations in Fig. 1. With regard to the aggregate/cement-ratio, the mortar should exhibit the strongest decrease in strength. The higher thermal stability of mortar must therefore be attributed to the different maximum aggregate size. A smaller aggregate size leads to smaller thermally induced crack widths and to better temperature resistance /7/. This influence is more pronounced at higher temperature and dominates over the differences induced by the aggregate/cement-ratio. The same observations hold for biaxially loaded specimens.

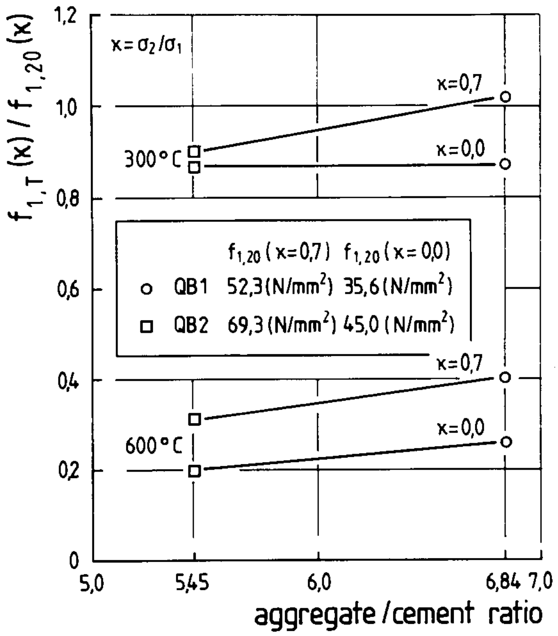


Fig. 1: Influence of the aggregate content on the high temperature compressive strength

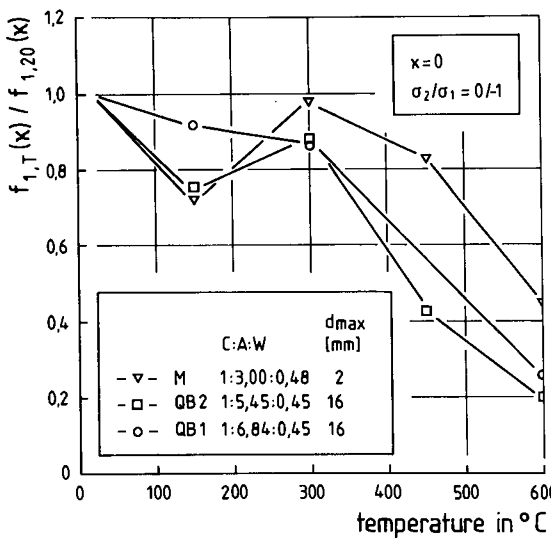


Fig. 2: Influence of the maximum aggregate size on the strength loss

Test results for the concretes QB2 and QB3 for uni- and biaxally loaded specimens are shown in Fig. 3. They are normalized in the same way as indicated above. The different water/cement-ratios cover the practical area of reinforced concrete. At first the water/cement-ratio did not affect the temperature dependent strength losses at 300 °C. After the decomposition of portlandite in the temperature range from 450 °C to 550 °C the decrease in strength is at a lower rate for concrete QB3 which was made with a higher water/cement-ratio than for QB2. The influence is of the same magnitude as the one induced by the differences in aggregate content (Fig. 1). The effects are equal for both stress ratios κ, although the reduction in compressive strength is more pronounced under uniaxial load.

The water/cement-ratio directly affects the porosity. It was shown earlier that strength is a function of porosity even after thermal treatment at high temperature /8/. At first the total pore volume of the cement stone increases slowly with the increase in temperature, but this will be significantly enlarged during the decomposition of portlandite. In course of this change the initial influence of the water/cement-ratio vanishes, so that the strength values of both concretes are very similar at 600 °C. This leads to a smaller decrease of the normalized strength for concrete with a higher water/cement-ratio.

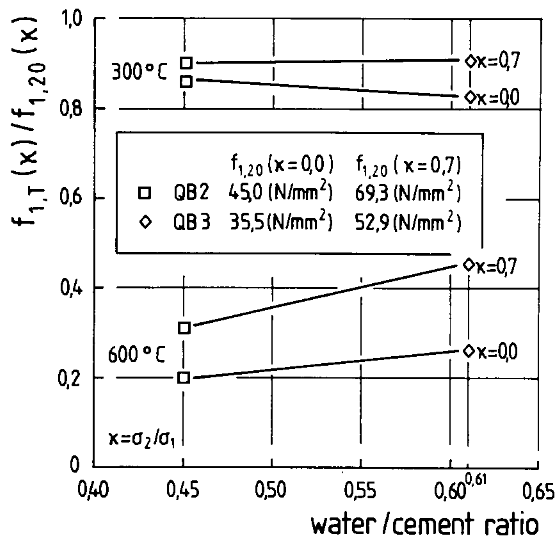


Fig. 3: Influence of the water/cement-ratio on the strength at high temperature

3.2 Modulus of elasticity

The modulus of elasticity was determined as a secant value at 0.3 $f_{1,T}$. The tests show a stronger decrease of the Young's modulus than of the strength. This is due to its higher sensitivity to thermally induced cracks. Fig. 4 shows the influence of different aggregate content on the residual values at 300 °C and 600 °C, respectively. While at 300 °C the modulus of elasticity is less reduced for the leaner mix, at 600 °C the opposite is the case. The differences are of the same order. The behaviour observed at 300 °C results from the smaller amount of crack growth due to the differing thermal expansion of aggregate and cement stone in leaner mixes. No explanation is yet available regarding the behaviour at 600 °C.

The effects are the same if a higher water/cement-ratio is used, but in this case the difference is more pronounced at 300 °C. The modulus of elasticity and the strength both depend on the water/cement-ratio in a similar way.

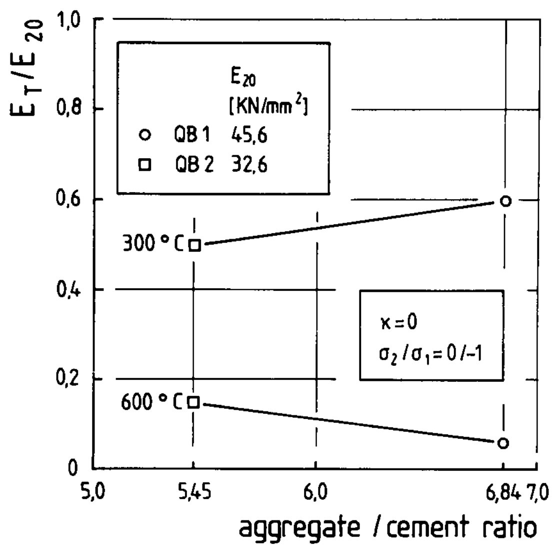


Fig. 4: Influence of the aggregate content on the modulus of elasticity

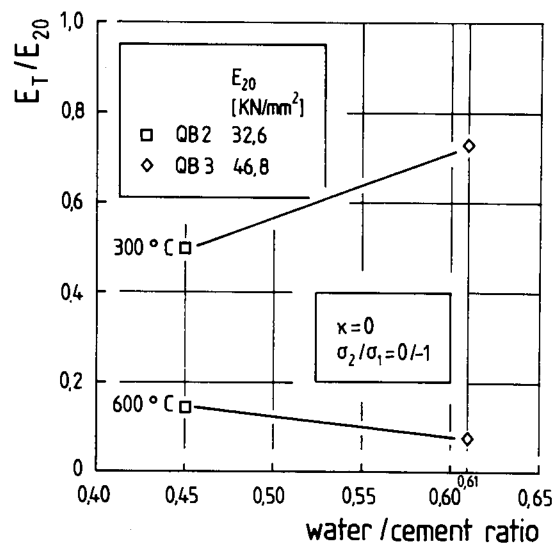


Fig. 5: Influence of the water/cement-ratio on the modulus of elasticity

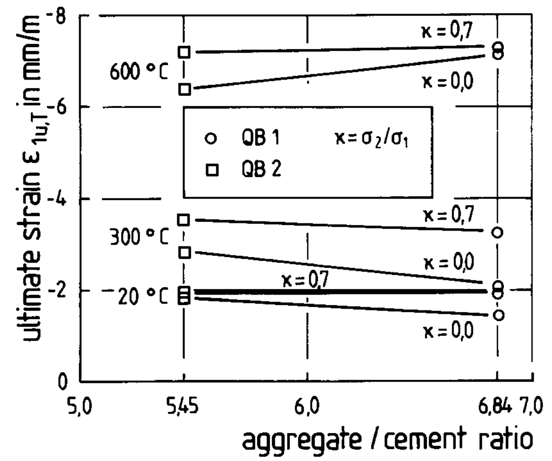
3.3 Ultimate strain

The dependence of the ultimate strain $\varepsilon_{1u,T}$ in the main loading axis on the aggregate/cement-ratio is shown in Fig. 6. The results were obtained for different stress ratios and for varying temperature levels. The ultimate strain increases with temperature. Up to 300 °C a slight tendency towards lower strain values for concrete with a higher aggregate/cement-ratio is apparent. The same tendency can be experienced with uniaxial tests at ambient temperature /9/. At 600 °C the ultimate strains were significantly increased, but the influence of the aggregate content appeared to be slightly reversed. Biaxial compression results in higher strain values throughout the temperature range. The influence of the aggregate content nearly has vanished almost completely.

No clear dependence of the ultimate strain $\varepsilon_{1u,T}$ on the different water/cement-ratios was indicated when the temperature was raised from 20 °C to 300 °C (Fig. 7). At 600 °C a higher water/cement-ratio resulted in higher ultimate strain values for both uniaxial and biaxial loading.

4 CONCLUSIONS

The strength and deformation characteristics of uniaxially and biaxially loaded specimens both depend on the composition of the concrete. The maximum aggregate size has a significant influence, while aggregate content and water/cement-ratio generally are second order effects. A difference was stated regarding the magnitude of these influences. As is known from tests at ambient temperature, strength and deformation are affected by the concrete composition before the desintegration of portlandite between 450 °C and 550 °C. Above this temperature range the before mentioned tendencies were changed or become more pronounced.



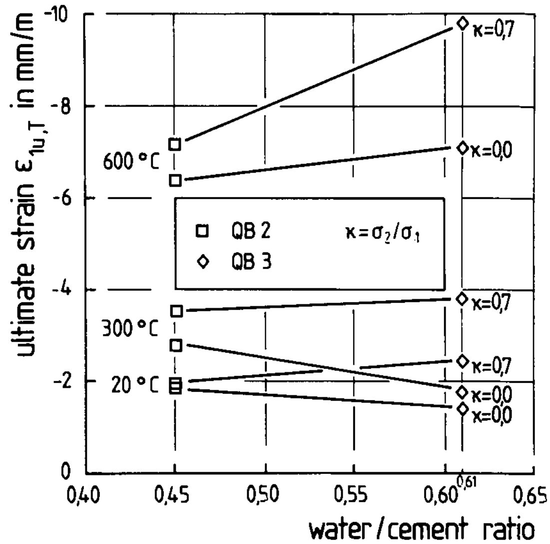


Fig. 6: Influence of the aggregate content on the ultimate strain $\varepsilon_{1u,T}$ at high temperature

Fig. 7: Influence of the water/cement-ratio on the ultimate strain $\varepsilon_{1u,T}$ at high temperature

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