VIII International Conference on Fracture Mechanics of Concrete and Concrete Structures
FraMCoS-8
J.G.M. Van Mier, G. Ruiz, C. Andrade, R.C. Yu and X.X. Zhang (Eds)

EVALUATION OF ALKALI SILICA REACTION EFFECTS ON MECHANICAL BEHAVIOUR OF MORTAR

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Key words: Alkali silica reaction, Mortar, Mechanical properties, Microstructure, Microcracking

Abstract: This study aims to evaluate the effects of alkali silica reaction (ASR) on mechanical behaviour of cement based materials. Two mortars are fabricated respectively with reactive and non-reactive aggregates. After a maturation period of 28 days, triaxial compression tests with confining pressures of 0, 5 and 15MPa and bending tests are performed on a part of the samples in order to obtain a reference state as the sound material. The other part of samples is subjected to a controlled environment with temperature of 60°C and relative humidity of 95% for ASR development, and the axial expansion of the two mortars is monitored. It is observed that after storage period of samples in controlled environment, the triaxial compressive strength increase of the reactive mortar is more significant than that of the non-reactive one. According to the results of microstructural analyses, this can be attributed to the more compact microstructure of the reactive mortar compared with the non-reactive one. However, the ASR process leads to the deterioration of the Young's modulus and bending strength of the reactive mortar. Therefore, the tensile strength and Young's modulus are more significantly affected by the ASR induced damage than the compressive strength.

1 INTRODUCTION

The alkali silica reaction (ASR) is the most widespread type of alkali-aggregate reaction and leads to the formation of alkali-silica gels and/or alkali-calcium-silica gels which absorb water, swell and can provoke microcracks. The gels fill the microcracks in the aggregates and paste as well as the voids. The formation of ASR requires the simultaneous presence of three conditions at ambient temperature: sufficient quantity of alkalis in the pore solution, reactive aggregates and relative humidity higher than 80-85%. The extent of the ASR induced deterioration is influenced in particular by the reactivity, quantity, size and particle size distribution of the reactive aggregates, the amount of the alkalis available, porosity of material and pre-existence of microcracks [1-3]. Several types of disorders such as expansion, differential movements, gel exudations, decrease in mechanical properties etc. can be observed in the ASR affected structures [1,2].

Many studies have been carried out in order to evaluate the mechanical performances of ASR affected concrete. For this purpose, uniaxial compression and tension tests are generally performed. Some authors reported a decrease in the compressive strength [4,5] whereas others did not observe such a diminution due to the ASR related expansion [6,7]. The compressive strength decreases in particular when the aggregates are highly reactive [8,9]. However, whether the compressive strength increases or not during the development of the alkali silica reaction, a clear degradation of elastic modulus is observed [2-4,6-9] and the material becomes more deformable [4,6,7]. The elastic modulus is thus very sensitive to the ASR induced damage, and decreases even if the aggregates are slowly or moderately reactive. This sensitivity is also reported for the direct tensile strength which decreases drastically with the ASR expansion [5]. The evolution of the flexural strength also seems to be affected by the ASR [7-9].

However, as concrete structures can also be subjected to multi-axial mechanical loading during their service life, it is necessary to understand the influences of ASR on the mechanical properties of materials under such complex loading conditions. The results obtained will contribute to the improvement of constitutive models for ASR affected materials as well as design tools for the ASR affected structures. Therefore, two selected mortars, one with reactive aggregates and the other with non-reactive aggregates are investigated. In the following, the experimental program is first presented. Then the results obtained are detailed and analysed by comparing the behaviours of the two groups of mortar.

2 EXPERIMENTAL PROGRAM

2.1 Materials, samples preparation and conditioning

Two mortars whose composition is inspired by Poyet [10] are fabricated to conduct the study. The mortar samples have a water to cement ratio of 0.5 and sand (1613.4 kg/m^3) to cement (537.8 kg/m^3) ratio of 3. The non-reactive mortar (designated as NR mortar) is fabricated with an inert crushed limestone sand while the reactive mortar (designated as R mortar) with a reactive siliceous limestone crushed sand [10]. The mortars are fabricated with specific sand grains composed of only three different grain-size fractions: fine aggregates with an equivalent diameter between 0.08-0.16mm; medium aggregates with an equivalent diameter between 0.63-1.25 mm and coarse aggregates with an equivalent diameter between 2.5-4 mm. For each mortar, the sand grains are composed of 25% of fine aggregates, 50% of medium aggregates and 25% of coarse aggregates. These fractions are obtained by sieving; the sands are then washed to be disposed of very fine particles and dried before use. CEM I 52.5 R with a high alkali content of 1.11% Na_2O_{eq} and demineralised water are used to cast the mortars. The alkali content is increased to 15 kg/m^3 by adding NaOH to the mixed water.

Prismatic (40x40x160 mm^3) and cylindrical (ϕ36x100 mm^3) samples are cast for this study. The first are used for the monitoring of length variation in order to determine the expansion of material and also for the bending strength measurements. The second are used to carry out uniaxial and triaxial compression tests.

Three days after the casting, the samples are un-moulded and kept in sealed bags for 28 days at ambient temperature. During this period, the cylindrical samples are sliced to obtain smaller samples for tests. This operation is done under dry conditions in order to avoid any leaching of alkalis [10]. After 28 days of maturation, the samples are stored in a temperature and humidity controlled chamber with temperature of 60°C and relative humidity 95% for ASR development [10]. This intermediately high temperature can facilitate the beginning and increase the initial kinetics of the ASR process [2,6,10].

2.2 Tests and measurements performed

Three point bending tests on prismatic samples 40x40x160 mm^3 and uniaxial (P_c=0MPa) and triaxial compressive tests (P_c=5 and 15MPa) on cylindrical samples (ϕ36x72 mm^3) are carried out during experimental investigation. These tests are performed respectively after a period of 28 day maturation and after 100 days of conditioning of samples at 60°C and 95% HR. The results obtained at 28 day maturation are taken as the reference values. The change in length of samples is measured during the conditioning of samples. All tests are performed after a cooling period of samples for at least six hours at ambient temperature.

The length change of the prismatic samples (equipped with stainless steel studs at both end) during time is measured with a mechanical retractometer. Uniaxial and triaxial compression tests are carried out using a hydraulic press under displacement controlled condition. The axial displacement rate used is $2\mu m/s$. A triaxial cell is used in order to apply desired confining pressures by injection of oil into the cell. The axial strain is measured by LVDT. The triaxial compression tests are classically conducted: increase of hydrostatic pressure until the desired value (5 or 15MPa) and application of the deviatoric stress by keeping the radial stress constant. The deviatoric strength is identified as the maximum (peak) deviatoric stress reached during the test. Three-point bending tests are carried out on prismatic samples with a loading rate of $0.1\mu m/s$ using a specific bending system mounted on the hydraulic press.

3 RESULTS AND ANALYSIS

3.1 Expansion of mortars

Fig. 1 shows the evolution of the average expansion of NR mortar and R mortar. As expected, the expansion of the NR mortar is very weak, approximately 0.02%. However, the expansion of the R mortar is significant, about 0.40% indicating that the ASR induced expansion is 0.38%. The expansion of NR mortar is an intrinsic expansion mainly due to water absorption, and reaches a maximum value very quickly. The kinetics of the expansion of the R mortar is very high up to approximately 25 days and the expansion is stabilized after 50-60 days.

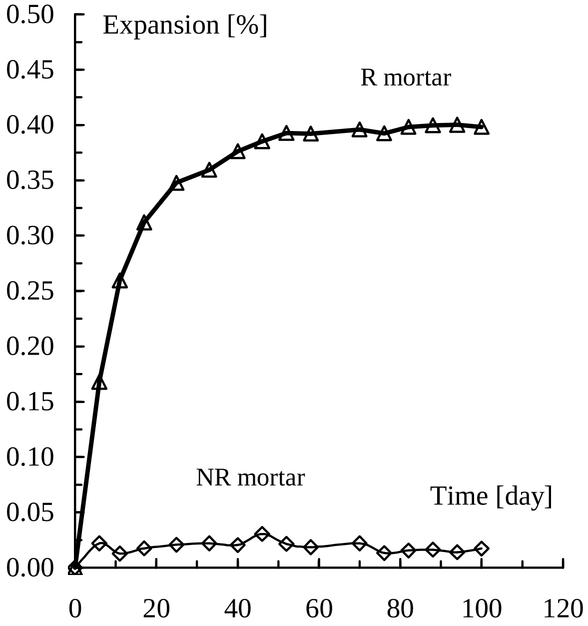

Figure 1: Axial expansion of the NR mortar and R mortar.

The higher the level of aggregates reactivity is the higher will be the weight gain [9]. Notice that this expansion is mainly due to the presence of the medium and coarse size aggregates. The presence of reactive fine aggregates leads to a reduction in expansion [10,12]. In addition, the expansion obtained by the mixture of the three fractions remains lower than the sum of the expansions obtained for each fraction of aggregates [10] (the expansion for a given reactive fraction is obtained by replacing the two other fractions by non-reactive ones). Even if the free expansion is only measured in the longitudinal direction in the present study, it is important to point out that this one is generally anisotropic in nature [6,9].

3.2 Effects of ASR on compressive strength evolution

Figure 2 shows the evolution of deviatoric strength versus confining pressure for the two mortars after maturation period and after conditioning period at 60°C and 95% RH for the development of the ASR expansion. Depending on confining pressure, the mechanical strength increases during the conditioning period of samples. The increase is in the range 6-14% for the NR mortar and 26-42% for the R mortar. On the other hand, the results obtained after the maturation period show that the multi-axial compressive strength of the R mortar is slightly higher than that of the NR mortar (3-9%). After the conditioning of samples at 60°C and 95% RH, the deviatoric strength of the R mortar becomes significantly higher than that of the NR mortar (23-34%). Thus, the relatively small difference of multi-axial strength between the two materials at the reference state becomes significant after the storage period for ASR process.

After the maturation period, the very slightly higher mechanical strength of the R mortar with respect to the NR mortar seem to be well correlated with the microstructural analysis [11] carried out by SEM (scanning electron microscopy) together with EDS (energy dispersive X-ray spectrometry). Indeed, this microscopic analysis indicates that the microstructure of the two mortars is overall rather similar and that their rate of hydration is close each other. On the other hand, the important increase of the multi-axial strength of the R mortar after the conditioning period for ASR comes from a more compact microstructure [11]. The compactness of the material is due to filling of voids by the alkali-calcium-silica gels and also probably to the reaction of some such gels with portlandite to form C-S-H. This compactness plays a dominant role with respect to the induced microcracking, which leads to the increase of the deviatoric strength.

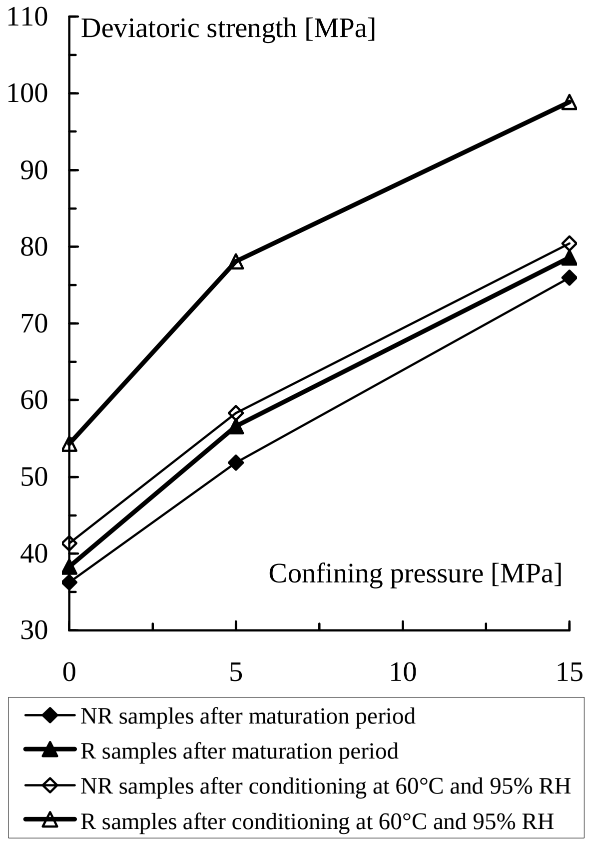

Figure 2: Deviatoric strength versus confining pressure for NR mortar and R mortar after maturation period and after conditioning at 60°C and 95% RH.

The results obtained in this study on the evolution of uniaxial compressive strength with ASR process are different from those reported by other authors who observed a decrease in the strength of cement-based materials with reactive aggregates [4,5]. However, the level of aggregate reactivity seems to play an essential role on the mechanical strength [2,8,9]. The higher the level of aggregate reactivity the more the strength will decrease. However, some authors observed an increase of compressive strength compared to that measured at 28 days for a concrete made with highly reactive aggregate [7]. Thus, the ASR does not necessarily prevent the increase in mechanical strength but this increase seems to remain weak compared to the concrete without reactive aggregates. On the other hand, a study on the mechanical behaviour of two concretes fabricated with the aggregates (sand and gravel) of the same origin than those used in the present study showed that the increase in compressive strength of a cement-based material with reactive aggregates can be as high as that of a material without reactive aggregates [6].

3.3 Effects of ASR on elastic modulus evolution

Figure 3 shows the evolution of elastic modulus with confining pressure for the two mortars. The initial value of elastic modulus is determined on the third cycle of loading-unloading of each test.

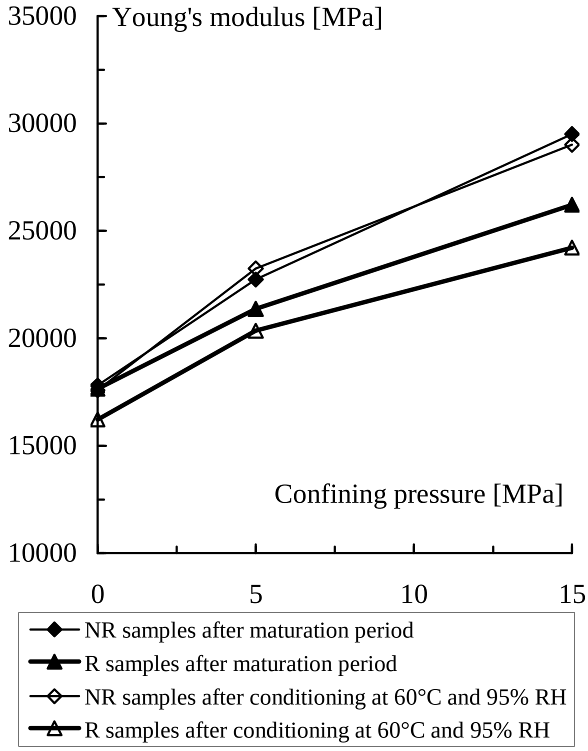

Figure 3: Initial Young's modulus versus confining pressure for NR mortar and R mortar after maturation period and after conditioning at 60°C and 95% RH.

As for the deviatoric strength, the Young's modulus depends on confining pressure and increases with this one. Regarding the conditioning effects, the initial Young's modulus of NR mortar nearly does not change while that of the R mortar decreases by 8% after the conditioning of the samples at 60°C and 95% RH. On the other hand, the tests after the maturation period show that the Young's modulus of the R mortar is lower than that of the NR mortar by 0-11%. After the conditioning of samples at 60°C and 95% HR, the Young's modulus of the R mortar becomes much lower than that of the NR mortar by 8-17%. Thus, the difference between the Young's modulus of the two materials is accentuated after the conditioning of samples.

The Young's modulus of the R mortar decreases slightly during ASR process in spite of an important increase in multi-axial compressive strength. As underlined already by several authors, this shows a more important sensitivity of the Young's modulus to the development of ASR which induces microcracks.

3.4 Influence of ASR on bending strength

Table 1 gives the values of average bending strength of two mortars after maturation period and after conditioning period at 60°C and 95% RH. The bending strength increases by 45% for the NR mortar and by 6% for the R mortar.

Table 1: Average bending strength of NR mortar and R mortar after 28 day maturation and after conditioning at 60°C and 95% RH for ASR development.

Material	Bending strength after maturation [kN]	Bending strength after conditioning [kN]
NR mortar	2.2	3.2
R mortar	3.2	3.4

Contrary to the multi-axial compressive strength, the increase in the bending strength of R mortar remains marginal compared to that of NR mortar. This shows again a higher sensitivity of the flexural strength to the ASR induced microcracking compared to the compressive strength [2,3,5,7-9]. This could be explained by the closing of the ASR induced microcracks under compressive stress whereas the tensile stress in flexion tests quickly leads to the propagation of the microcracks [2,5].

5 CONCLUSIONS

Two mortars, one with reactive aggregates

(R mortar) and the other with non-reactive aggregates (NR mortar) are investigated in order to study the influence of ASR on mechanical behaviour evolution.

After a maturation period of 28 days, the difference between the multi-axial strength of the two mortars is relatively small even if the compressive strength of the R mortar is slightly higher (3-9%) than the NR mortar. This result is in good accordance with the microscopic analysis which indicates that the microstructures of the mortars are overall similar and that their rate of hydration is close. After the storage of samples at 60°C and 95% RH during 100 days for ASR development, the compressive strength of the R mortar becomes higher than that of the NR mortar by 23-34%. The compacted microstructure of R mortar, generated by the activity of alkali-calcium-silica gels, could explain this significant increase.

The tests also show that after ASR process, the elastic modulus of the R mortar slightly decreases while that of the NR mortar remains unchanged. Consequently, the ASR expansion leads to a decrease of the elastic modulus by inducing microcracks. The ASR expansion-related microcracking also leads to a decrease of bending strength in the R mortar compared with the bending strength in the NR mortar. Therefore, the results of the present study illustrate that, as indicated by other authors, the tensile strength and elastic modulus are more significantly affected by the ASR induced microcracking than the compressive strength.

Acknowledgements:

The present work is supported by the Chinese Ministry of Water Resources' special Funds for Scientific Research on Public Causes (Grant No.200801057) and the National Natural Science Foundation of China (Grant No.51009061). The microstructural analysis was conducted by LERM. The authors are very grateful to Dr. N. Rafai for his valuable comments and discussions.

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