EFFECT OF AGGREGATE GRADING ON CONCRETE MICROBAR EXPANSIONS

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Abstract

This study is a part of an extensive study conducted in order to evaluate and modify concrete microbar test which was first proposed by Grattan-Bellew et. al [1] in 2003. This test is suitable for determination of both alkali silica reaction and alkali carbonate reaction. Proposed method evaluates ASR expansions by using aggregate having particles between 4.75-12.5 mm, w/c ratio of 0.33 and aggregate/cement ratio of 1:1.

In this study, different aggregate gradings were placed in the concrete microbar mixtures which were cured in 1M NaOH solution at 80°C. Some of the mixtures had aggregate sizes between 4.75-12.5 mm, while for some other mixtures fine aggregate was also added. It was found that the microbars having aggregate between 4.75-12.5 mm expressed a linear expansion trend while fine aggregate-bearing mixtures showed an expansion trend similar to accelerated mortar bar specimens. Mixtures having fine aggregate expressed higher expansions than no-fine mixtures.

Keywords: alkali-silica reaction, concrete microbar test, aggregate size, aggregate grading

1 INTRODUCTION

Concrete prism test (CPT) and the accelerated mortar bar test (AMBT) are widely used ASR research tools. CPT was standardized by many agencies, ASTM C1293 [2], CSA A23.2 -14A [3] and RILEM AAR-3 [4]. This method indicates the most realistic results to identify the reactivity of the aggregates; however, 1 year curing period is its major disadvantage. This test is generally considered as a reference method to determine the reliability of other alkali reactivity test methods. AMBT was standardized by many agencies, ASTM C1260 [5], CSA A23.2-25A [3] and RILEM AAR-2 [4]. This method determines the potential reactivity of aggregates in 16 days; however, it should not be used to reject aggregates due to the severe curing conditions. Grosbois and Fontaine [6] state that AMBT is not suitable for carbonate aggregates and higher expansion limits may be proposed for granites and other metamorphic rocks. The results of CPT and AMBT are not well correlated for sandstones and other sedimentary rocks.

Grattan-Bellew et al. [1] proposed a universal accelerated test method, the concrete microbar test (CMT), by adopting the test method for alkali carbonate reactive rocks proposed by Xu et al. [7]. CMT is suitable for both alkali carbonate and alkali silica reactive rocks. Concrete microbars are prepared with aggregates in the size range of 4.75 mm to 12.5 mm, dry aggregate/cement ratio of 1 by weight and water/cement ratio of 0.33. Prismatic specimens of 40x40x160 mm are cured at 80°C in 1 N NaOH solution similar to that applied in AMBT. The researchers studied the reactivity of carbonate reactive limestone, silica reactive limestone, greywacke and a non-reactive limestone and established a linear expansion-time relationship. One year CPT and 30-days CMT expansions were also compared; siliceous limestone aggregates generated a different correlation line among the other aggregates. The proposed expansion limit at 30 days was 0.14% for siliceous limestone aggregates and 0.04% for other aggregates. Grattan-Bellew et. al. also conclude that the mortar bars made with reactive siliceous limestone (Spratt) expands more significantly than concrete microbars which indicates that the ASR expansions increase by decreasing particle size [1].

RILEM TC 191-ARP [8] proposed CMT in order to evaluate the alkali carbonate reactivity of dolomitic limestones as AAR-5 by using aggregate having size range of 4 to 8 mm. According to the committee, the suspicious aggregate should be tested both by AAR-2 and AAR-5, using the same

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cement and bars with same dimensions (40x40x160 mm). If AAR-5 expansions are smaller than AAR-2 expansions the possible reaction is a typical ASR.

With contrast to the behavior of carbonate aggregates, in ASR, reducing the particle size accelerates the rate of reaction by increasing the specific surface area of siliceous aggregates. The alkali silica reaction is a more complex phenomenon, microstructural and textural parameters of aggregate as well as crack distribution of the aggregate-cementitious material system are of importance. Reducing the aggregate size below a specific limit consumes the available alkali in the system before hardening, thus, reducing the expansions [9].

Generally accelerated tests for diagnosing reactivity of siliceous aggregates are conducted on specimens cast by using graded fine aggregates or aggregates of single size fraction. CMT seems to be a useful tool in order to investigate the effect of middle-sized aggregates and the effect of gradation on accelerated ASR expansion. This study investigates the effect of size and gradation of aggregate on ASR expansions tested by CMT. One type of siliceous reactive aggregate was used for this purpose. Aggregate/cement ratio of all CMT mixtures were kept constant as 1:1. Fine aggregate was used in some of the CMT series. The specimens were cured in 1M NaOH solution at 80^{o}C and the expansions of the mixtures were recorded up to 40 days. Residual compressive strength values of CMT samples were determined after 40 days curing.

2 MATERIALS AND METHODS

2.1 Materials

The aggregate used in this study is a clinopyroxene-olivine basalt type [10] with 0.833% AMBT expansion at 14 days (cf. ASTM C1260 [5]). Cement is CEM I 42.5 type in accordance with TS EN 197-1 [11]. Na_2O and K_2O content of the cement is provided by the producer as 0.30% and 0.85%, respectively.

2.2 Test methods and mix proportions

Proposed CMT method was modified by using different aggregate sizes and gradations. Aggregate/cement ratio of all of the mixtures was kept constant as 1:1. A series of mixtures were prepared at constant w/c ratio of 0.33 (by weight) and using different aggregate gradations. Some of these mixtures were prepared with aggregate in the size range of 4.75 mm to 12.5 mm as stated in the study of Grattan-Bellew et al [1]. However, fine aggregate was also added to some of these mixtures in order to evaluate the effect of aggregate size on ASR expansions. Flow values of the mixtures were determined in accordance with ASTM C1437 [12]. The specimens were cured in 1M NaOH solution at 80^{o}C and the expansions of the mixtures were recorded up to 40 days. Aggregate proportions of the mixtures are given in Table 1 and fine aggregate grading is given in Table 2.

The residual compressive strength values of CMT samples were determined in accordance with TS EN 196-1 [13] except that the specimens were cast in accordance with the method described above and cured in CMT conditions for 40 days before loading. The specimens were broken by mid-point loading and broken pieces were loaded in compression as 40x40 mm modified cubes. Compressive strength results given in this study are the average of 4-6 modified cubes. After visual examination of broken pieces, segregation was observed in M5 sample containing 75% aggregate having particles between 9.5 and 12.5 mm.

3 RESULTS

Flow values of the mixtures are given in Table 2. It is important to note that the flow value of the mixture containing 60% fine aggregate (M13) is considerably lower than flow of other mixtures.

Expansion-test period graphs of no-fine CMT samples (M2, M3, M4, M5) are given in Figure 2. The expansions of these mixtures are linear with correlation coefficients (R) higher than 0.98. Since at the beginning of the test period (x=0), no expansion is observed (y=0), the regression lines start from x, y = 0.

The expansion-test period graphs of the mixtures containing fine aggregate as well as coarse aggregate (M6, M7, M10, M13) are given in Figure 3. The 30 day expansions of all of the mixtures prepared in this study is given in Table 3 which evidently shows the effect of different aggregate gradings on CMT expansions.

Residual compressive strength values of CMT samples having w/c ratio of 0.33 are given in Figure 4. This test was conducted in order to see if there is a discrete CMT sample among the different mixtures prepared. Residual strength results of all of the mixtures ranges between ~35 to ~45 MPa.

Visual examination of the broken samples revealed that M5 mixture showed evidence of segregation. Map-cracking and pop-outs were observed on the surface of CMT samples and on their broken sections. It was also observed that, the cracks were wider and less when the sample consisted of only coarse aggregate, while cracks were narrower and widespread when fine aggregate was added to the mixtures.

4 DISCUSSION

Table 2 revealed that addition of 60% sand had a considerable reduction (approximately 14% when compared to no-fine mixtures) in flow values of the CMT mixtures. Addition of 50% sand also decreased the flow values when compared to no-fine mixtures. Replacement of sand instead of coarse aggregate particles decrease the placeability of the mixtures, thus it is important to obtain proper mix design for CMT mixtures having different aggregate gradations.

Considering the no fine mixtures (Figure 2), generally, by increasing coarsest aggregate size fraction in coarse aggregate (9.5-12.5 mm) the expansions decrease. Thus, an increase in the surface area of the coarse aggregates used in no-fine mixtures leads to an increase ASR expansions. The mixture containing 25% fine aggregate (M6) shows lower expansion values than other mixtures containing fine and coarse aggregate which is markedly seen in Figure 3. Besides, the expansion-time relationships of the fine aggregate containing mixtures (except for M6) show distinct deviation from linearity. The deviation may be attributed to the difference in the expansion rates of the particles having different particle sizes. The expansion-test period graph of the mixtures containing fine and coarse aggregate resembles the curve of AMBT mixtures rather than a straight line. Considering the expansion values of all of the mixtures used in this study, the samples containing fine aggregate show higher expansion values than no fine mixtures. Fine aggregate addition increased the expansion at early ages.

Up to a certain extent, decreasing the reactive aggregate size is a method to accelerate the reaction in testing siliceous aggregates. However, any processing performed on the aggregates such as crushing, grading etc. should change their textural characteristics; thus, alter their expansions [9, 14]. It is clear that, even other parameters are constant; the size gradation is an important parameter in accelerated testing of siliceous aggregates.

The residual compressive strength values of the mixtures vary between ~35 to 45 MPa and are not related to the grading of the aggregate. It is important to note that, strength results do not solely represent the effect of different aggregate gradings or the effect of ASR expansions, actually, represents the cumulative of two actions.

The broken specimens were visually examined after strength test. It was found that, M5 sample having the highest percent of coarsest aggregate fraction (75% aggregate of 9.5-12.5 mm) exhibited considerable segregation. Grattan-Bellew [1], cast CMT mixtures by using the aggregate between 4.75-12.5 mm. The authors proposed that grading of coarse aggregate might differ from one another depending on the type of the crusher and a middle-size sieve is necessary to limit the gradation of the aggregate. The results of this study reveal that limiting the coarsest fraction of coarse aggregate to 60% may be proper if 9.5 mm is chosen as the middle-size sieve. Map-cracking and pop-outs were observed on the surface of CMT samples and on their broken sections as evidence of ASR.

This study is a part of an extensive study in order to modify the CMT method. The effect of w/c on different CMT mixtures, the evaluation of supplementary cementing materials by CMT and the comparison of other ASR test methods (AMBT and CPT) with CMT are other parts of this experimental study.

5 CONCLUSIONS

Following conclusions were drawn from this experimental study:

- More than 50% sand replacement instead of coarse aggregate particles decrease the placeability of the mixtures, thus it is important to obtain proper mix design for CMT mixtures having different aggregate gradations.
- Considering the no fine mixtures, increasing coarsest aggregate size fraction in coarse aggregate decrease the expansions.
- The expansion-time relationships of the fine aggregate containing mixtures show distinct deviation from linearity. The deviation may be attributed to the difference in the expansion rates of the particles having different particle sizes.
- The samples containing fine aggregate show higher expansion values than no fine mixtures. Fine aggregate addition increased the expansion especially at early ages.

- The broken specimens were visually examined after strength test. It was found that, M5 sample having the highest percent of coarsest aggregate fraction (75% aggregate of 9.5-12.5 mm) exhibited considerable segregation. It may be proper to limit the coarsest fraction (the fraction above 9.5 mm sieve) of coarse aggregate to 60%.

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TABLE 1: Aggregate proportion of the CMT mixtures.

Sieve Size	Aggregate by weight (%)							
mm	M2	M3	M4	M5	M6	M7	M10	M13
< 4.75	-	-	-	-	25	40	50	60
4.75 - 9.50	60	50	40	25	25	30	25	20
9.50 - 12.50	40	50	60	75	50	30	25	20

TABLE 2: Flow values of the CMT mixtures (w/c = 0.33).

CMT mixture	M2	M3	M4	M5	M6	M7	M10	M13
Flow values (mm)	189	189	183	188	189	187	182	162

TABLE 3: Expansions of CMT mixtures at 30 days.

CMT mixture	M2	M3	M4	M5	M6	M7	M10	M13
Expansion@30days(%)	0.604	0.424	0.436	0.390	0.436	0.854	0.794	0.850

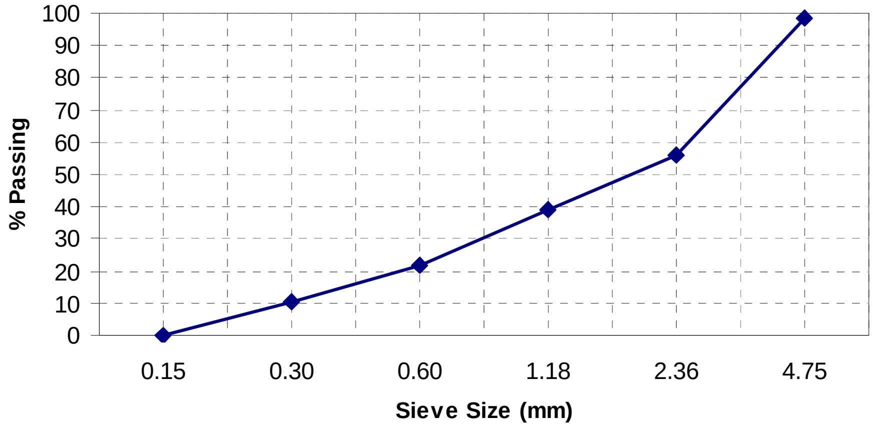

Figure 1: Grading of fines.

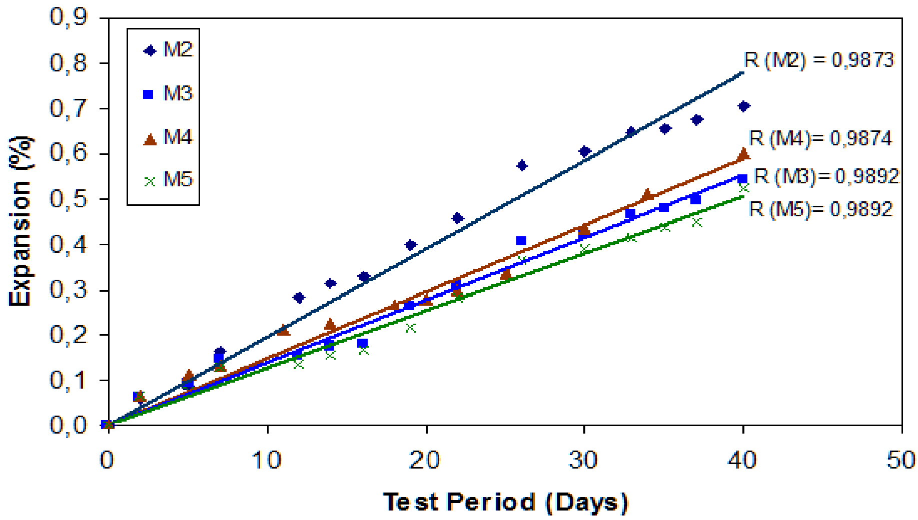

Figure 2: Expansion-time graph of no-fine samples.

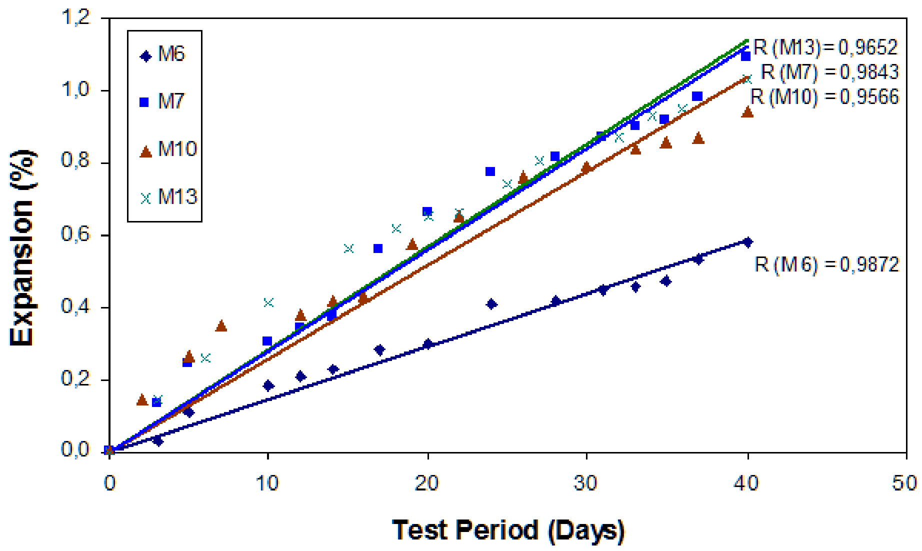

Figure 3: Expansion-time graph of samples containing fine and coarse aggregate.

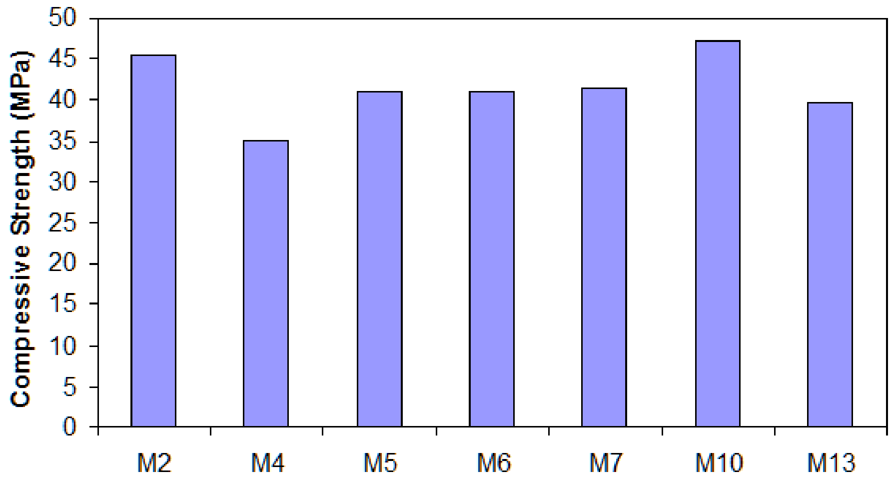

Figure 4: Residual compressive strength of mixtures (w/c = 0.33).