

STUDY OF ASTM C1567 EXPERIMENT OF ASR MORTAR BAR CONSIDERING ALKALI CONTENT

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ABSTRACT

The ASTM C1260 and C1567 are important standards to evaluate the reaction caused by silica and alkalis using mortar bars. They also give fast answer related to alkali-silica reaction for the application of the aggregate materials in constructions. The ASTM C1567 is particularly related to combinations of cementitious materials and aggregates. The methodology for preparation of the tests specifies that the amount of cement and cementitious material have to be together equal to 440g, with water-binder ratio of 0.47. It implies that, with the use of a different material, the amount of cement in the mix decrease. This procedure can affect the amount of alkalis content inside the mix and also its reaction with the active silica in the mortar. Even with the external availability of alkalis in the solution (NaOH), the internal amount of alkalis from the cement vary and the result reflect in the real intensity of the reaction. So, this study investigated the variation of the alkali amount in the mix due to the decrease of cement and its influence in the final result of the experiment. The results showed that the amount of alkali has influence in the speed of the alkali silica reaction to happen, however low or high use of SCM does not have influence over the expansion results.

Keywords: mortar bar test, alkali-silica reaction, alkali content, ASTM C1567.

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1. INTRODUCTION

An important topic related to sustainability in construction industry is the use of alternative material in substitution of clinker. The production of clinker for fabrication of ordinary Portland cement (OPC) emits huge amount of CO₂ due to the process of calcination. The average amount of carbon dioxide generated by cement production process is for 1 ton of cement, 0.50 ton of CO₂ is produced [1]. So, in order to decrease the greenhouse effects caused by the cement manufacture process, the use of alternative binder is important. In this matter, recycled glass has been studied. Soda lime glass has amorphous silica and, when finely pulverized, it can present some pozzolanic activity. The pozzolanic activity is a characteristic of some material that when finely divided, in a moisture condition, at ambient temperatures, it can react with the calcium hydroxide from cement hydration and form cementitious products. This reaction results in a stronger and more durable concrete.

Glass has dual behavior when used in cement structures. The glass' silica can react strongly with the cement paste and result in Alkali Silica Reaction (ASR). However, when pulverized, it can react in the same environment and result in pozzolanic activity, increasing concrete durability. When the particle is small (around 150µm), the reaction of dissolved silica components and portlandite create cementitious products, but if the particle is too big (around 2.36mm), the reaction occurs slowly and instead, the silicate gel expands by absorbing water. From a Chemistry perspective, Taylor [2] describes that ASR and pozzolanic reaction are the same but the main difference is the particle size of the siliceous material.

Three factors are important for ASR to occur: availability of moisture, reactive silica and alkalis. From these, in order to protect the structure from ASR, the source of moisture can be controlled from the external sources in concrete, however active silica and alkalis are sometimes unavoidable. Depending on the region and convenience of resources, the necessity of use of reactive aggregates or high alkali cement can result in ASR. The solution would be to study ways to decrease the effects of ASR for high alkali cements (>0.60% alkalis) or reactive aggregates. Studies show that ASR expansion, when considering reactive aggregates, can be controlled or decreased using supplementary cementitious materials in the mix design. Blast furnace slag and fly ash, for example, can be used together with OPC and archive results of less expansion when compared with only OPC mixes. The glass powder also has been showing good results for decreasing the deleterious effects of ASR.

The tests using supplementary cementitious materials (SCM) to measure the ASR expansion consist to mix OPC, SCM and reactive graded aggregate. If the aggregate is reactive, the SCM can show its competency in decrease the reaction. In order to do that, tests from standards such as ASTM C1567 are often used. These tests are parameters to consider the potential of expansion for a reactive aggregate when SCM is used. The experiments consist of casting mortar bars and submit it to high temperature (80°C) and alkaline condition in order to accelerate the reaction and obtain parameters to compare between the indexes of expansion from the standard. The ASTM C1567, specifically, is a test to combine OPC and SMC to evaluate the efficiency of the SCM in decrease the ASR from a reactive aggregate. This experiment, called standard test for determining the potential alkali-silica reactivity of combinations of cementitious material and aggregate (accelerated mortar bar method), specify that the mix design uses OPC and SCM however the total amount of binder in mass and water cement ratio are fixed. This situation results in a decrease of the amount of cement when the SCM is used and, consequently, it leads to a decrease of alkalis from cement in the mix design. In these conditions, it is logically assumed that the alkali-silica reaction will also decrease in the same proportion of the decrease in OPC because of the smaller availability of alkalis. The investigation that isolate the factors that have influence on ASR, is important when combining specific aggregates and SCM. Individually, any parameter can have influence and keeping the amount of alkalis equal to the reference samples (usually OPC) reduce one of the variants to consider in the results because all mixes have same availability to react with.

This standard also includes that the specimens have to be kept inside sodium solution to prevent alkalis leaching, that maximize aggregate dissolution and contributes for ASR gel formation [3]. In this situation, even with the external source of alkali (sodium solution), the internal amount of alkali stills

different due to the less OPC in the mix. So, in order to keep the same amount of alkali inside the mix design, this study included extra alkali in the mix proportion and evaluated the expansion for the samples using soda-lime glass as pozzolanic material and fine aggregate performing ASTM C1567 test. The test standard ASTM for concrete number C1293 (standard method for determination of length change of concrete due to alkali-silica reaction), includes the extra alkali content in the concrete mix design, concerning that the decrease in cement has influence in the final result of the experiment. However, for mortar bars, the experiment does not mention the adjustment. Some standards such as Japanese Industrial Standards (JIS) A 1146 (method of test for alkali-silica reactivity of aggregates by mortar-bar method), require that the alkalis have to be adjusted for all mixes (including OPC alone), keeping it at 1.2% (high alkali content) as reference.

Among the researches about the ASR test methods, comparative study between mortar-bar methods can be found. Saha [3] compared the efficacy of the ASTM C1567 and C227 to identify ASR of ferronickel slag aggregates. However, he did not consider the internal amount of alkalis from the decrease of cement due to the SCM addition. Yazici et al. [4] compared ASTM C1260, C1567 and RILEM AAR-4 for the results of mitigation properties of SCM and lithium salts. For this experiments, the RILEM standard also requires to achieve the 1.2% of alkali in mix the concrete prisms, yet nothing was mentioned about the alkalis in mortar for the other tests. Shon [5] also compared the effectiveness of ASTM C1567 and C1260 for SCM applications considering the pore solution alkalinity. For his research, the amount of alkalis in the soaking solution concentration varied from 0N, 0.25N, 0.50N and 1N. The study concluded that the increase in NaOH concentration in the solution can exacerbates the ASR and from 0N to 0.5N the samples showed no deleterious expansion for all mix designs. He also did not consider the internal difference in the amount of alkalis coming from OPC. So, regarding the amount of alkalis inside the mix design from cement, there is not much data available.

In this present study, some samples were cast following the ordinary procedure of ASTM C1567 and another set of specimens were cast using the same standard however, the amount of alkalis was adjusted proportionally to the decrease of OPC in mass. This environment was used to compare the readings between the samples without extra alkali and with extra alkali reaching the same amount as if 100% OPC was used. Following the standard procedure, the alkali quantity varies from the control mix (100% OPC) the aggregate had a specific availability of alkalis to react with, but it decreases for the other batches using SCM. If the OPC decreases, the alkalis also vary so the aggregate will react with different intensity and it will interfere in the evaluation of the effectiveness of the SCM alone in decrease the reaction. So the results related to SCM would be questionable if it is considered that the decrease in OPC itself already affects the ASR intensity directly. So, the objective of this study is to observe the changes in expansion due to the variation of alkali content inside the samples for OPC substitution using glass powder while we keep the same soaking solution concentration for all samples.

2. EXPERIMENTAL OUTLINES

2.1. Materials

The materials used were glass aggregate and Powder from Fujino Kogyo Ltd. and Ordinary Portland cement from Taiheiyo Cement Corporation (NaOeq = 0.62%). The glass powder average particle size was 75 μ m and the glass sand was used as specified at ASTM C1567. The alkali used for the mix design and soaking solution was Na produced by Kanto Chemical Co. as extra pure (95.0%) solid NaOH. The Chemical composition of glass is presented in the Table 1.

Table 1. Glass chemical composition

Content wt%	SiO ₂	CaO	Na ₂ O	K ₂ O	Al ₂ O ₃	Fe ₂ O ₃	MgO	Na ₂ Oeq
Glass (Powder/ Aggregate)	69.2740	20.9849	04.6117	01.8740	01.8376	00.4682	00.2504	05.8448

2.2. Testing methods and mix designs

The source of material mix proportions was the ASTM C1567 that established one part of binder for 2.25 parts of graded aggregate (Table 2) and water-binder ratio of 0.47 (mass). Therefore, 440 g of cementitious material was used with 990 g of graded aggregate and 207 g of water. In order to study the ASR response for alkali content variation, eight mix designs were prepared with different amounts of SCM. Glass powder was used as pozzolanic material substituting ordinary Portland cement in a proportion of 5%, 10%, 25% and 50% in mass.

Table 2. ASTM C 1567 - Aggregate Grading Requirements

Sieve Size		Mass, %
Passing	Retained on	
4.75 mm (No. 4)	2.36 mm No. 8	10
2.36 mm No. 8	1.18 mm No. 16	25
1.18 mm No. 16	600 μ m (No 30)	25
600 μ m (No 30)	300 μ m (No 50)	25
300 μ m (No 50)	150 μ m (No 100)	15

The application of pozzolanic material in the mix design resulted in a decrease of alkali content from cement. This situation was balanced using additional alkali dissolved in the mix water. All the mixes were designed in order to keep the same amount of alkali as the OPC (0.62%) and the alkalis from the glass powder were not considered because it was evaluated as the SCM material characteristic that has to be observed as well. They were named according to percentage of substitution and extra alkali presence (For example: GP50A = Glass Powder, 50%, extra Alkali). Table 3 shows the mixes proportions and nomenclature.

Table 3. Mix designs

Mix Design	Cement (g)	% of Pozzolan	Glass Powder (g)	Alkali needed (g) for 0.62%	Calculated NaOH (g)	
Alkali	GP5A	418	5	22	0.1364	0.176
	GP10A	396	10	44	0.2728	0.352
	GP25A	330	25	110	0.682	0.880
	GP50A	220	50	220	1.364	1.760
No extra Alkali	GP5	418	5	22	No extra alkali	
	GP10	396	10	44		
	GP25	330	25	110		
	GP50	220	50	220		

The samples were mixed following the ASTM C305 procedure for mixing mortar. First, the water was placed in the bowl and the cement added and then started the mix. After that, the aggregate is slowly included. The total process of mixing one set of samples take 4 minutes. For the proportions with extra alkali content, the NaOH was included in the mix water and the following procedures were also in accordance with the standard.

The molding and storage method followed the ASTM C1567. After casting process, the samples were submitted to a sequence of 3 specific situations to stimulate the reaction process. First, the samples were

placed in a moist room for 24 hours (20°C and RH60%). Thereafter, they are demolded and the initial reading was recorded. Following, the samples were submerged in a container with tap water and placed inside a chamber at 80°C. The subsequent reading was recorded after 24 hours. After reading, the tap water was substituted by NaOH solution (40g of NaOH/L) at 80°C. The next readings were taken at 5, 7, 10, 16, 21 and 28 days from casting.

3. RESULTS AND DISCUSSION

The results for ASR expansion of the mix design can be seen at Figure 1, 2, 3 and 4. The difference in expansion by percentage between the samples with and without extra alkali can be seen at Table 3. The results for 5% of substitution of OPC by glass powder showed small difference between of results with and without alkali during the 28 days of curing period. It can be observed that GP5A expansion is 5.66% bigger than GP5 at 28 days of experiment. The use of glass powder as 10% substitution also had small difference in results between the mix without alkali and with extra alkali at 28 days (6.79%), however the difference was higher at 16 days (30.23%), decreasing within the curing time.

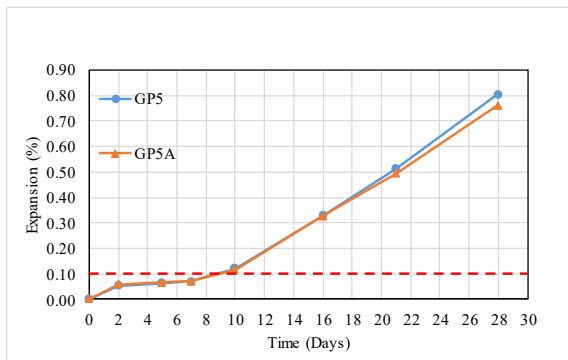


Figure 1. ASR expansion GP 5%

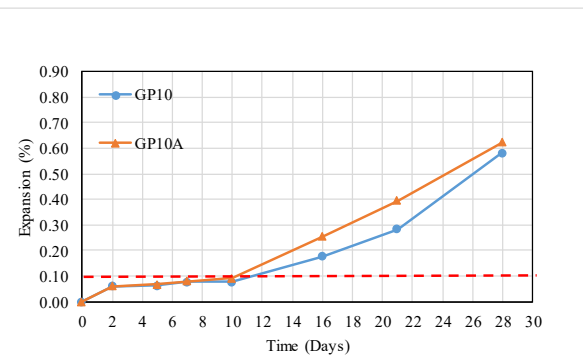


Figure 2. ASR expansion GP 10%

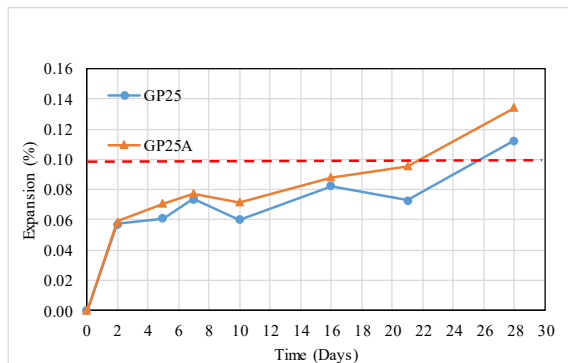


Figure 3 ASR expansion GP 25%

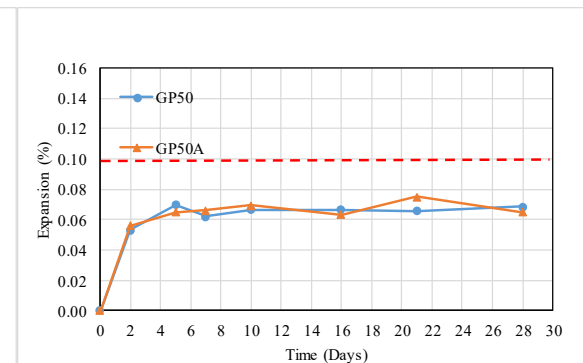


Figure 4. ASR expansion GP 50%

Table 3. Difference in percentage of expansion

Mix Design	Difference in Expansion in 16 days (%)	Difference in Expansion in 28 days (%)
GP5A GP5	-0.47	-5.66
GP10A GP10	30.23	6.79
GP25A GP25	6.67	16.18
GP50A GP50	-5.15	-5.42

The expansion rate for the GP10 and GP10A overcame the standard index so both mixes design showed deleterious behavior for ASR. The reaction for the samples with 25% and 50% of glass powder showed no deleterious behavior for ASR in all mixes (GP25, GP25A, GP50 and GP50A) at 16 days. However, at 28 days the glass powder mix of 25% showed expansions above of specified in the standard for deleterious behavior. GP25 and GP25A samples had similar expansion values at 16 days and different at 28 days of experiment.

The result for OPC substitution of 5% gave a variation of -5.66 percent comparing the mixes with and without extra alkali. This small difference is related to the amount of alkali added in the samples. For GP5A, only 0.136 g of alkali was added, and it did not have huge impact in the final answer, so the results are almost the same. The GP10 mix design showed a huge difference in results at 16 days when comparing with GP10A (30.23% bigger), decreasing during the curing period of 28 days (6.79%). This result shows that the high alkali content in the GP10A helped to develop the ASR gel but at 28 days, the samples without extra alkali also reached a higher value showing almost same potential expansion results.

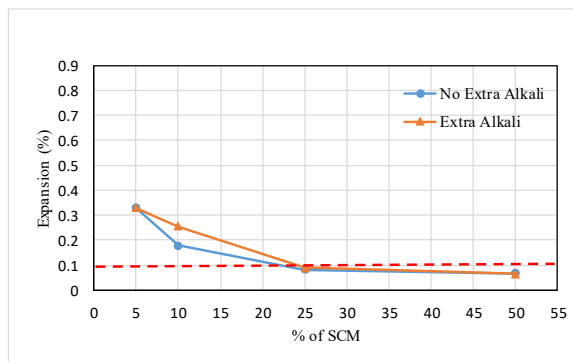


Figure 6. Expansion vs amount of SCM at 16 days

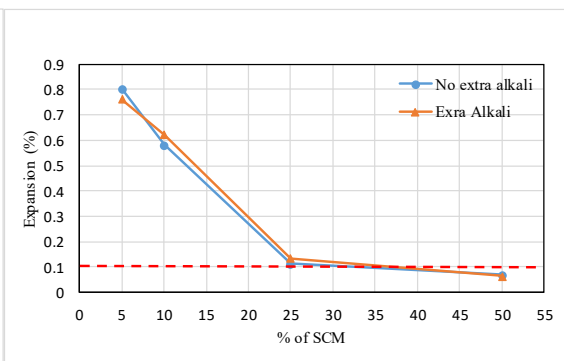


Figure 7. Expansion vs amount of SCM at 28 days

Both of the samples with 10% of SCM showed deleterious behavior for ASR, overcoming 0.10% of expansion after 28 days of experiment. However, the samples with extra alkali still showed higher expansion.

The mixes GP25 and GP25A had similar results at 16 days of experiment, showing 6.67% of difference in expansion. However, at 28 days, the expansion of GP25A was 16.18% higher than GP25. For this mix, the increase in alkali affected the result considerably. The results for 5% and 10% of substitution had similar and closer results with and without alkali at 28 days, the only difference was in the process, where the mix without alkali took more time to reach the same expansion because the extra amount of alkalis accelerated the reaction. However, as the amount of SCM increase at GP25, the expansion showed different results at 28 days because of the influence of the high amount of alkali. As the reaction proceeds, the dissolution of the silica at the aggregate is influenced by the amount of alkali in the samples with extra alkali and the expansion shows to be higher for GP25A. The difference in expansion is explained by the increase in concentration of Na^+ and OH^- inside the samples. The negative ions accelerate the dissolution process of siloxane bridges in the aggregate structure. So, the alkalis attach to the oxygen terminals and then, it forms a weak structure for the reaction, changing the speed of the reaction and accelerating the gel formation. The increase in alkalis can make the reaction happen faster, with the similar final potential of expansion.

Shon [5] tested the variation in pore solution alkalinity changing the soaking solution concentration of NaOH to observe the variation of expansion. His experiments concluded that the samples were sensitive to the external source of alkali and it can alter the expansion results. As can be seen from this present study that the samples can also be sensitive to the internal amount of alkalis as well.

The results also show at figure 4 that the mix designs 50% of glass powder did not present deleterious behavior for ASR according to the standard indexes. This can be explained by the pozzolanic behavior of the SCM. The glass powder can decrease the ASR when used finely divided in small particle size. In

order to occur, the alkali-silica reaction needs a source of alkalis, reactive silica and moisture. The increase in pozzolanic material in the mix, decreases the availability of alkalis to form expansive gel because pozzolanic reaction takes place instead. So, for GP50 and GP50A mix designs, the expansion was not deleterious according to the standard index. At 16 and 28 days, GP50 showed similar results when compared with GP50A, 5.15% and 5.42% respectively. This result is similar to the behavior of GP5 and GP5A and can indicate the existence of a pessimum amount of alkalis to develop significant difference in expansion when SCM is used between 0 and 50%.

Figures 1, 2, 3 and 4 show the ASR expansion of all mix designs. As can be seen, the only mix that succeeded in controlling ASR was GP50 with and without alkali. The other mixes showed expansion higher than 0.10% at 28 days and consequently, they can be evaluated as possibly reactive even when pozzolanic material is used. However, when comparing the substitution rate, the ASR decreases as the amount of pozzolanic material increases in the mix design.

Figures 6 and 7 show the expansion and amount of SCM at 16 and 28 days respectively. At 16 days, the expansion of GP10 and GP10A showed the higher difference in expansion between the results, however these mixes reached almost the same expansion value at 28 days. This can indicate that, even when more alkali is used, it did not affect the final potential expansion. All the results followed the same trend and similar results can be observed at 28 days, regardless of the previous difference in expansion.

4. CONCLUSIONS

From the results of this present study, it can be concluded that the amount of alkali inside the samples tested using ASTM C1567 method can change the expansion results around 30.23% at 16 days and 16.18% at 28 days depending on the substitution of OPC by SCM. However, the results trend to reach the same potential expansion over the time of curing.

For ASTM C1567, when analyzing the SCM capacity to decrease ASR using a reactive aggregate, the reference mix for comparison is the 100% OPC. This mix has a specific amount of alkalis available to react with the aggregate and produce ASR gel. However, when changing the binder content, the alkalis in the mix also change. So, for comparison reasons, the standard situation changed and the aggregate will not be inserted in the same cement alkali content environment to show the real effectiveness of the SCM to decrease the expansion. Submitting the aggregate to, as close as possible, the same condition of the reference mix is important to understand if its reactivity has been controlled or not by the SCM and its intensity. So, for comparison parameters in the ASTM C1567, the reactivity of the aggregate with SCM and OPC could be better evaluated if the mix design contains the same amount of alkali content as the reference situation using 100% of OPC, in this study 0.62%.

As specific conclusion:

- (1) The extra alkali amount changed the expansion rate for all mix designs;
- (2) The highest variation in expansion at 16 days was for GP10/GP10A and presented 30.23% of difference between the mixes;
- (3) For 28 days, the highest difference in expansion was for 25% of SCM and presented 16.18% between the mixes with and without extra alkalis;
- (4) The amount of alkali did not show relevance for mix design with high substitution rate (GP50/GP50A) because the pozzolanic reaction took place over ASR;
- (5) The mixes with low use of SCM over cement did not show higher difference in expansion because the ASR was strong and provided high deleterious behavior;
- (6) The increase in alkali content showed a small difference in the overall results between the samples with same SCM substitution, changing the speed of expansion values over time and consequently the reaction speed.

Future investigations to clarify the behavior of the results tendency to produce a pessimum amount of SCM usage that will be influenced by the quantity of alkali in the mix (Table 3) are necessary. So, it is suggested as a next step of the work.

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