SUITABILITY OF TEST METHODS FOR ALKALI-SILICA REACTIVITY OF AGGREGATES TO CHINESE AGGREGATES

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Abstract

Petrographic examination, micro-mortar bar, mortar bar, accelerated mortar bar and concrete prism tests were used to evaluate the alkali-silica reactivity of some aggregates in China. Expansion due to alkali-silica reaction is dependent upon microstructures of aggregates. Test results from different test methods are not always consistent. It seems that test methods which use a smaller aggregate such as NF P18-588 are more sensitive to denser aggregates such as tuffs and gneisses. The reactivity of porous aggregates such as sandstones may be evaluated by test methods such as ASTM C1293 and ASTM C1260 in which a coarser aggregate is used. ASTM C227 mortar bar test method is not suitable to test for reactivity of aggregates contained micro- to crypto-crystalline quartz. ASTM C1260 accelerated mortar bar test method seems to be not suitable for river sand with a large amount of single quartz crystals.

KEYWORDS: Alkali-silica reactivity, aggregate, test method, suitability

1 INTRODUCTION

Many infrastructures are being constructed all over China. Main aggregates used for concrete are granites, basalts, tuffs, sandstones, limestones, dolostones, gneisses and schists etc. The alkali-reactive component in aggregates is mainly micro- to crypto-crystalline quartz [1], which may causes aggregates to be alkali-silica reactive [2].

Petrographic examination, mortar test, accelerated mortar bar test, micro mortar bar test and concrete prism test have been widely used to evaluate alkali-silica reactivity of aggregates in China [3-7]. The micro mortar bar test designated as CECS 48-1993 is similar with NF P18-588-1991[8]. Other test methods used are based on ASTM C295 [8], ASTM C227 [9], ASTM C1260 [10] or ASTM C1293 [11]. Aggregates used for buildings, pavements, bridges, tunnels or quay are generally tested by a rapid test method such as accelerated mortar bar test method, micro mortar bar test method or petrographic examination. Aggregates used for long-term projects such as dams and nuclear power stations may be tested by combinations of petrographic examination, accelerated mortar bar test method and concrete prism test method. Petrographic examination is often used to evaluate sort and amount of alkali-reactive components in aggregates and may not be used to determine whether aggregates are reactive or not. Classification of alkali-silica reactivity of aggregates is usually made according to expansion of mortar bars or concrete prisms. This paper tries to reveal the suitability of test methods by comparing the test results of alkali-silica reactivity of aggregates.

2 MATERIALS AND METHODS

2.1 Materials

Cement

A Portland cement with 5wt% limestone was used. Its alkali content was 0.50wt%.

Sandstones and slates

Sandstones were collected from Sichuan, Yunnan and Jiangxi provinces. Petrographic examinations demonstrated that twelve sandstones from Muli, Sichuan province contained 44vol%-66vol% quartz, 12vol%-35vol% calcite, 8vol%-10vol% feldspar, 3vol%-6vol% chlorite, 3vol%-7vol% mica and 5vol%-12vol% micro- to crypto-crystalline quartz. Sixteen sandstones from

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Yunlong, Yunnan province contained 50vol%-78vol% quartz, 2vol%-20vol% dolomite, 2vol%-30vol% feldspar, 5vol%-15vol% mica and 6vol%-30vol% micro- to crypto-crystalline quartz. Six sandstones from Mojiang, Yunnan province contained 45vol%-70vol% quartz, 12vol%-20vol% calcite, 0vol%-5vol% feldspar, 1vol%-5vol% mica and 20vol%-28vol% micro- to crypto-crystalline quartz. Two sandstones from Deqing, Yunnan province contained 50vol%-55vol% quartz, 18vol%-25vol% calcite, 5vol%-10vol% feldspar, 4vol%-9vol% mica and 5vol%-8vol% micro- to crypto-crystalline quartz. Three sandstones from Yifeng, Jiangxi province contained 60vol%-70vol% quartz, 2vol%-8vol% feldspar, 12vol%-15vol% mica and 12vol%-20vol% micro- to crypto-crystalline quartz. Figure 1 shows the typical microstructures of sandstones.

Tuffs

Tuffs were collected from Chongqing city and Zhejiang province. Three tuffs derived from Bashan, Chongqing city were in porphyrotopic textures. Phenocrysts were consisted of 2vol%-10vol% quartz and 3vol%-8vol% feldspar. Matrixes were composed of 55vol%-60vol% micro-crystalline feldspar, 10vol%-15vol% micro- to crypto-crystalline quartz, 2vol%-6vol% mica, 2vol%-6vol% chlorite and 3vol%-8vol% calcite. Eleven of thirteen tuffs derived from Sanmen, Zhejiang province contained with 4vol%-10vol% feldspar phenocryst, 0vol%-8vol% quartz phenocryst, 5vol%-15vol% small quartz crystals, 30vol%-50vol% micro-crystalline feldspar, 25vol%-35vol% micro- to crypto-crystalline quartz, up to 4vol% chalcedony and up to 5vol% chlorite, and 1vol%-6vol% calcite. Two of the thirteen tuffs were consisted of 15vol%-17vol% quartz, 18vol%-20vol% feldspar, 30vol% micro-crystalline feldspar, 28vol%-30vol% micro- to crypto-crystalline quartz and 4vol%-6vol%. Two tuffs from Linan, Zhejiang province were consisted of 45vol%-50vol% feldspar, 35vol% quartz, 13vol%-17vol% micro- to crypto-crystalline quartz, 1vol% mica and 1vol%-2vol% calcite. Two tuffs from Linan, Zhejiang province were in porphyrotopic textures. Phenocrysts were consisted of 10vol%-12vol% feldspar. Matrixes were composed of 81vol%-83vol% micro-crystalline feldspar, 3vol%-5vol% micro- to crypto-crystalline quartz, 1vol% mica and 2vol% calcite. Figure 2 demonstrates microstructures of tuffs.

Gneisses

Gneisses from Lanping, Yunnan province were composed of 35vol%-75vol% quartz, 8vol%-40vol% feldspar, 4vol%-20vol% mica, up to 10vol% calcite and 3vol%-20vol% micro- to crypto-crystalline quartz. Their microstructures are shown in Figure 3.

River sands

Sands from Baoshan, Yunnan were consisted of 10vol%-35vol% quartz, 12vol%-22vol% feldspar, 1vol%-2vol% mica, 1vol%-6vol% chert, 15vol%-27vol% sandstone, 8vol%-18vol% limestone, 5vol%-14vol% basalt, 4vol%-8vol% quartzite, 3vol%-10vol%dolostone, up to 6vol% argillite, and up to 3vol% tuff. There were 4vol%-10vol% micro- to crypto-crystalline quartz in sands which existed in chert, sandstone, argillite and limestone. Four sands from Xiushui, Jiangxi province were mainly composed of quartz and sandstone lithoclast. There were a few of mica, feldspar, chert, quartzite and argillite. There were 4vol%-9vol% micro- to crypto-crystalline quartz in sands which existed in chert, sandstone and argillite. Six sands from Yangtse river, Gan river and Min river were composed of 50vol%-60vol% quartz, 38vol%-42vol% feldspar, less than 1vol% mica, 1vol%-2vol% chert and 3vol%-6vol% lithoclasts such as sandstone, quartzite and basalt. There were 1vol%-2vol% micro- to crypto-crystalline quartz in sands which existed in chert, and sandstone. Figure 4 illustrates alkali-silica reactive components in sands.

2.2 Test methods

The alkali-silica reactivity of aggregates was evaluated by micro mortar bar test, mortar bar test, accelerated mortar bar test, concrete prism test in accordance with CECS 48, GB/T 14685, JGJ 52, DL/T 5151 and JTG E42 [3-7], which were almost the same as NF P18-588 [8], ASTM C227 [9], ASTM C1260 [10] and ASTM C1293 [11], respectively.

Three group specimens in the ratio of cement to aggregate 10:1, 5:1 and 2:1 were prepared and tested when NF P18-588 micro mortar bar test was used. The size of aggregates used was in 0.16-0.63mm. If the maximum expansion of the three micro mortar bars is larger than 0.11%, the aggregate will be classified as alkali-silica reactive [8].

Aggregates used in mortar bars and accelerated mortar bars were combinations of 15% 0.15-0.300mm, 25% 0.300-0.600mm, 25% 0.600-1.18mm, 25% 1.18-2.36mm and 10% 2.36-4.75mm. If expansion of ASTM C227 mortar bars at 6 months is more than 0.10%, the tested aggregate will be accessed as alkali-silica reactive [9]. More than 0.20% expansion of ASTM C1260 mortar bars cured for 14 days is indicative of potentially deleterious expansion [10]. Expansion of less than 0.10% at 14 days after curing is indicative of innocuous behavior. Expansion between 0.10% and 0.20% at 14 days is indicative of possibly innocuous or deleterious. At this time, reactivity of aggregates may be determined according to test result of ASTM C1293 concrete prism, result of petrographic examination [11], or expansion of ASTM C1260 mortar bars cured for 28 days [10].

Coarse aggregates used in concrete prism were combinations of 33.3% 5-10mm, 33.3% 10-16mm and 33.3% 16-20mm. Fine aggregates were in the same grade as the aggregate in ASTM C227. The appendix to test method ASTM C1293 suggests that aggregates with expansions equal to or greater than 0.04% at one year are considered potentially deleteriously reactive [11].

3 ALKALI-SILICA REACTIVITY OF AGGREGATES

3.1 Sandstones

Figure 5 gives relationship between test results of sandstones according to NF P18-588 and ASTM C1260. Fifteen sandstones with expansion located in zone 1 and zone 3 were classified as non-reactive by NF P18-588. Twentyfour sandstones with expansion located in zone 2 and zone 4 were classified as reactive by NF P18-588. Expansion of ASTM C1260 mortar bars with all sandstones cured for 14 days are more than 0.10%. Except for two sandstones, expansion of ASTM C1260 mortar bars with other sandstones cured for 28 days are larger than 0.20%. Considering of expansion of more than 0.20% at 28 days and 5%-28% micro- to crypto-crystalline quartz in tested samples as described above, 37 of 39 sandstones may be classified as alkali-silica reactive. This implies that ASTM C1260 is more suitable to be used to evaluate alkali-silica reactivity of Chinese sandstones.

Figures 6-7 demonstrate the relationships between expansion of ASTM C1293 concrete prisms and maximum expansion of NF P18-588 micro-mortar bars or expansion of ASTM C1260 accelerated mortar bars for sandstones. The results in Figure 6 show that twenty-one out of twentyfour sandstones were accessed as alkali-silica reactive by ASTM C1293. However, only 52% of these reactive sandstones were classified as non-reactive by NF P18-588. Figure 7 reveals that expansions of accelerated mortar bars at 14d prepared with twenty one sandstones were more than 0.10%. Ten out of twenty one sandstones were simultaneously accessed as alkali-silica reactive by ASTM C1293 and ASTM C1260 when 0.20% expansion criterion for ASTM C1260 at 14d was used. If 0.20% expansion criterion for ASTM C1260 at 28d was set, both ASTM C1293 and ASTM C1260 accessed eighteen of twenty one sandstones as alkali-silica reactive. It seems that there is poor consistence in alkali-silica reactivity of sandstones determined by ASTM C1293 and NF P18-588. Better correlation exists between results of alkali-silica reactivity of sandstones determined by ASTM C1293 and ASTM C1260 if innocuous expansion of accelerated mortar bars was set as 0.10% at 14d or deleterious expansion 0.20% at 28d was used for ASTM C1260.

Figure 8 demonstrates the relationship between expansions of ASTM C227 mortar bars and ASTM C1293 concrete prisms made with sandstones. According to results of ASTM C227, 18 sandstones were all accessed as non-reactive. However, fifteen of eighteen sandstones were classified as alkali-silica reactive by ASTM C1293 concrete prism test. The results for sandstones are consistent with Bérubé's conclusion for quartz-bearing aggregates [12].

3.2 Tuffs

Figure 9 illustrates the relationship between the maximum expansion of NF P18-588 micro-mortar bars and expansion of ASTM C1260 mortar bars. All twenty tuffs were classified as alkali-silica reactive by NF P18-588. 7 of 20 tuffs with expansion located in zone 2 were classified as reactive by ASTM C1260 when 0.20% deleterious expansion criterion at 14d was used. If 0.20% deleterious expansion criterion at 28d was set, ten out of twenty tuffs were accessed as reactive by ASTM C1260. These results show that NF P18-588 may be more sensitive than ASTM C1260 in testing alkali-silica reactivity of Chinese tuffs.

The relationships between expansion of ASTM C1293 concrete prisms and maximum expansion of NF P18-588 micro-mortar bars or expansion of ASTM C1260 accelerated mortar bars for tuffs are illustrated in Figures 10-11. Eight of eleven in all tuffs classified as alkali-silica reactive by NF P18-588 were assessed as reactive by ASTM C1293. Six out of eleven tuffs were classify as alkali-silica reactive by ASTM C1293 and ASTM C1260 when 0.20% deleterious expansion criterion for ASTM C1260 at 14d was used. If 0.20% deleterious expansion for ASTM C1260 at 28d is taken as a criterion, then both ASTM C1293 and ASTM C1260 classify eight out of eleven tuffs as alkali-silica reactive. There is better relationship between results of alkali-silica reactivity of tuffs determined by ASTM C1293 and ASTM C1260 if deleterious expansion 0.20% at 28d was used for ASTM C1260.

3.3 Gneisses

The relationship between expansions of NF P18-588 and ASTM C1260 prepared with gneisses is demonstrated in Figure 12. Seven out of nine gneisses were accessed as alkali-silica reactive according to the test results of NF P18-588 micro-mortar bars. One gneis was classified as reactive by ASTM C1260 mortar bar test when 0.20% deleterious expansion criterion at 14d was used, and the other eight gneisses were reactive if 0.20% deleterious expansion criterion at 28d or 0.10% innocuous expansion criterion at 14d for ASTM C1260 was set. There is good correlation between results of alkali-silica reactivity of gneisses determined by NF P18-588 micro-mortar bars and ASTM C1260 when 0.20% deleterious expansion criterion at 28d was used.

Figure 13 gives the relationship between expansions of ASTM C227 mortar bars and ASTM C1260 accelerated mortar bars made with gneisses. Expansions of ASTM C227 mortar bars were far less than 0.10%. All gneisses were accessed as non-reactive by ASTM C227. Expansions of accelerated mortar bars made with eight of nine gneisses are more than 0.10% at 14d or 0.20% at 28d. As described above, the gneisses contained 3%-20% micro- to crypto-crystalline quartz. Thus, eight of them may be be regarded as potentially alkali-silica reactive. ASTM C227 may be not suitable to be used to evaluate alkali-silica reactivity of gneisses.

3.4 River sands

Figure 14 shows the expansions of NF P18-588 micro-mortar bars and ASTM C1260 accelerated mortar bars. Six of eighteen sands were accessed as alkali-silica reactive by NF P18-588. Ten of eighteen sands were reactive according test results of ASTM C1260 when 0.20% deleterious expansion criterion was used. Expansions of other eight sands classified as non-reactive by NF P18-588 were more than 0.10% at 14d or 0.20% at 28d. These eight sands contained more than 1wt% micro- to crypto-crystalline quartz. Therefore, all eighteen sands may be potentially alkali-silica reactive according to the results of ASTM C1260 and petrographic examination.

However, six sands from Yangtse river, Min river and Gan river show good field performances over the past 60 years and are widely used in bridges, nuclear power stations, tunnels and highways. They contained 1wt%-2wt% micro- to crypto-crystalline quartz and 50wt%-60wt% quartz crystals, and caused less than 0.060% expansion in NF P18-588 micro-mortar bar test. It seems that ASTM C1260 accelerated mortar bar test may overstate the expandability of these sands with large amount of quartz crystals due to alkali-silica reaction.

4 DISCUSSION

As demonstrated by petrographic examination, the alkali reactive component - micro- to crypto-crystalline quartz in sandstones, tuffs and gneisses were inhomogeneously distributed between quartz crystals, feldspar and mica etc. To react with micro- to crypto-crystalline quartz in the aggregates, alkali ions must access the aggregate particles through pores. The MIP porosities of sandstones, tuffs and gneisses tested ranged from 3.1vol%-7.2vol%, 1.8vol%-4.0vol% and 0.7vol%-2.1vol%, respectively. It is expected that the more porous the aggregates are, the more easily the alkali ions penetrate into aggregates. Therefore, porosity may enhance the reaction between micro- to crypto-crystalline quartz in aggregates and alkali solutions. And decreasing particle size of aggregates may also promote alkali-silica reaction. On the other hand, alkali-silica gel produced will be less restrained when aggregates are more porous or smaller. This may decrease expansion due to alkali-silica expansion. Larger particle of porous aggregates such as sandstones seems to cause a larger expansion than smaller porous aggregates during the test period.

For denser aggregates such as tuffs and gneisses tested, influence of particle size of aggregates on expansion due to alkali-silica reaction depends upon coordination of positive effects on promoting of the reaction and negative effect on weakening the restraint on alkali-silica gels. It seems that small particle tend to promote expansion of tuffs and gneisses due to alkali-silica reaction under the test conditions.

NF P18-588 micro-mortar bar test on 0.16-0.63mm aggregates seems to be sensitive to evaluation of alkali-silica reactivity of denser aggregates. ASTM C1260 accelerated mortar bar test on 0.15-4.75mm or 5-20mm aggregates seems to be sensitive to evaluation of alkali-silica reactivity of more porous aggregates. This difference may relate with many complex factors and the reason for it need to be studied further.

Individual quartz crystal in sands may be involved in alkali-silica reaction of ASTM C1260 accelerated mortar bars. 50wt%-60wt% of quartz crystals in 6 sands from Yangtse river, Min river and Gan river may to some extent contribute to the expansion due to alkali-silica reaction. The larger the amount of quartz crystals in sands, the more the contribution to expansion is. It seems that ASTM C1260 accelerated mortar bar test may not suitable to be used to evaluate alkali-silica reactivity of river sands with many quartz crystals.

5 CONCLUSIONS

- NF P18-588 micro-mortar bar test on 0.16-0.63mm aggregates seems to be sensitive to evaluation of alkali-silica reactivity of denser aggregates. ASTM C1260 accelerated mortar bar test on 0.15-4.75mm or 5-20mm aggregates seems to be sensitive to evaluation of alkali-silica reactivity of more porous aggregates.
- ASTM C1260 accelerated mortar bar test seems to be not suitable to evaluate alkali-silica reactivity of river sands with many quartz crystals.
- ASTM C227 may not be used to evaluate alkali-silica reactivity of some Chinese aggregates contained alkali-silica reactive component micro- to crypto-crystalline quartz.

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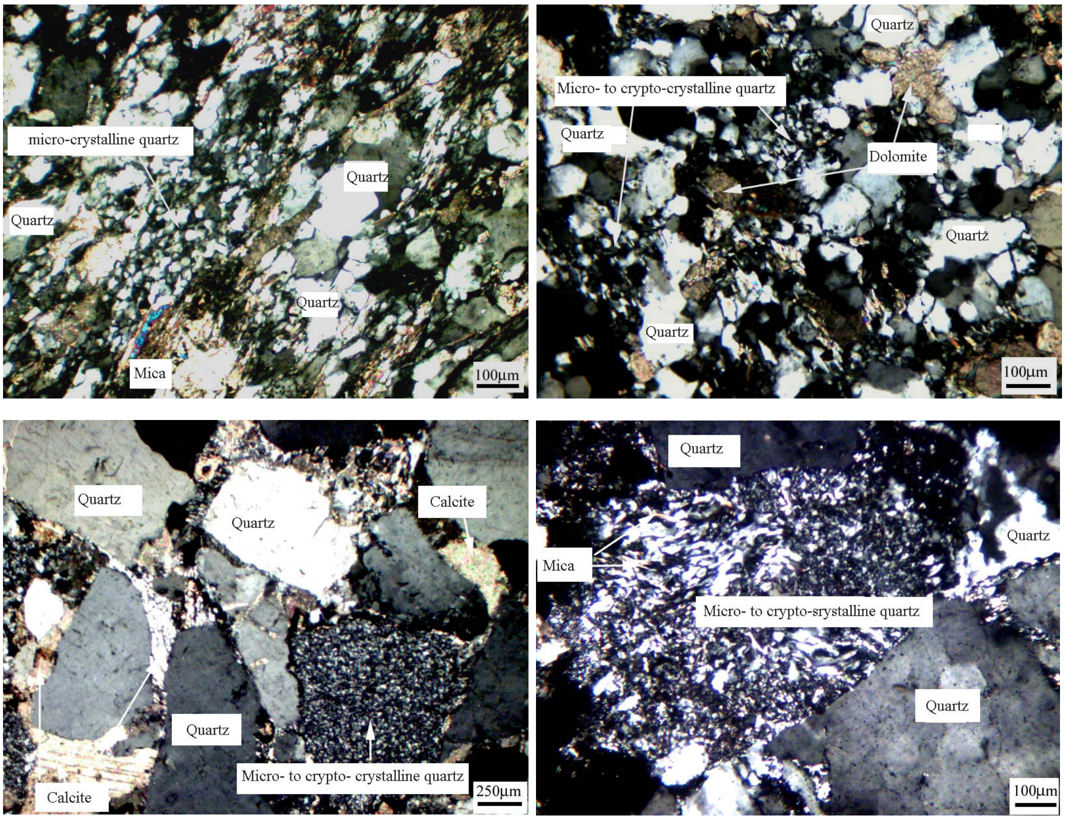

Figure 1: Typical micrructures of sandstones

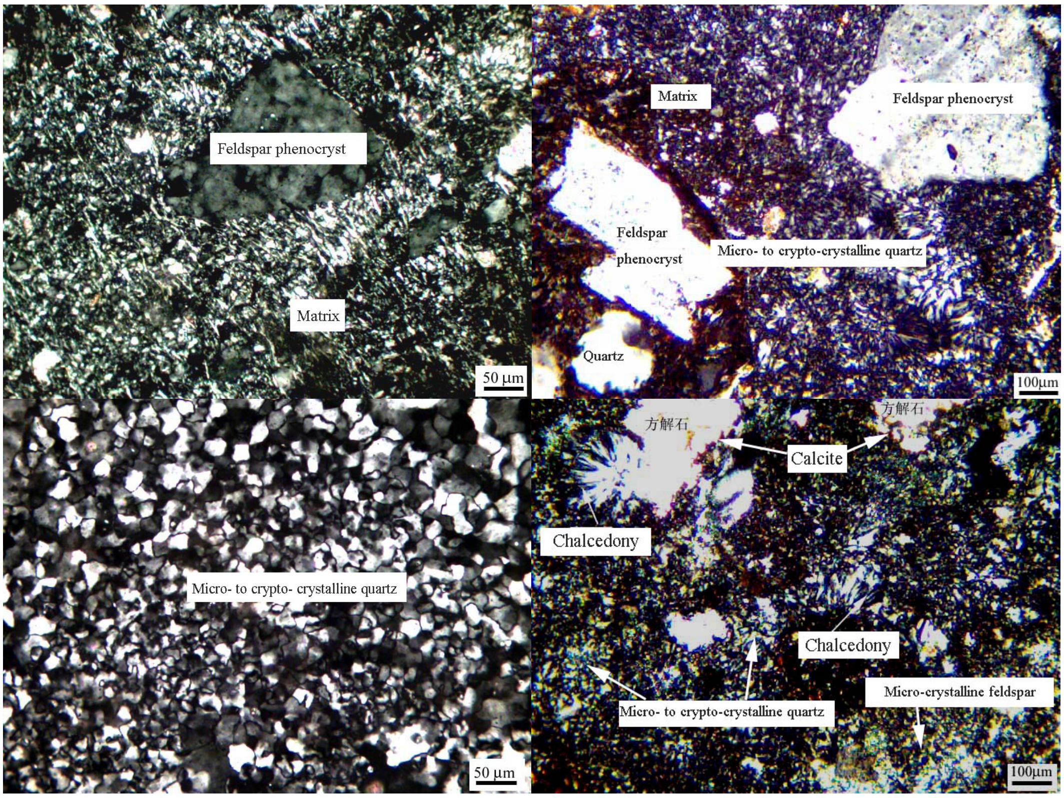

Figure 2: Typical microstructures of tuffs

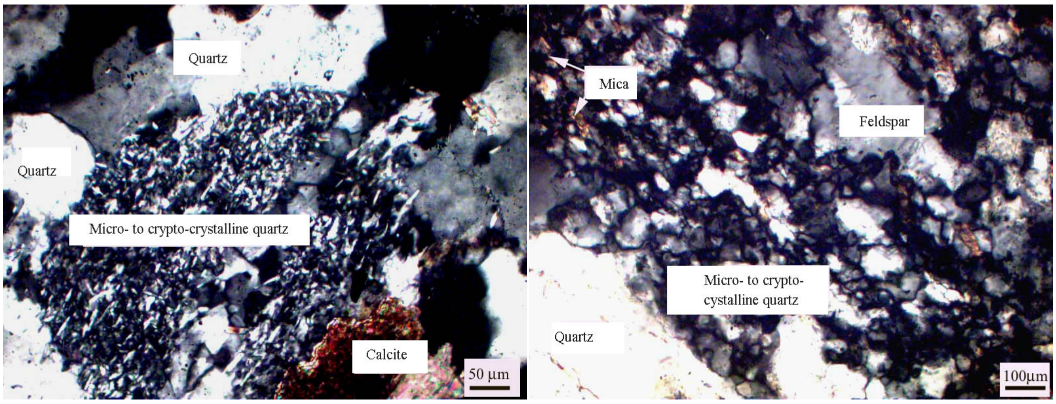

Figure 3: Typical microstructures of gneisses

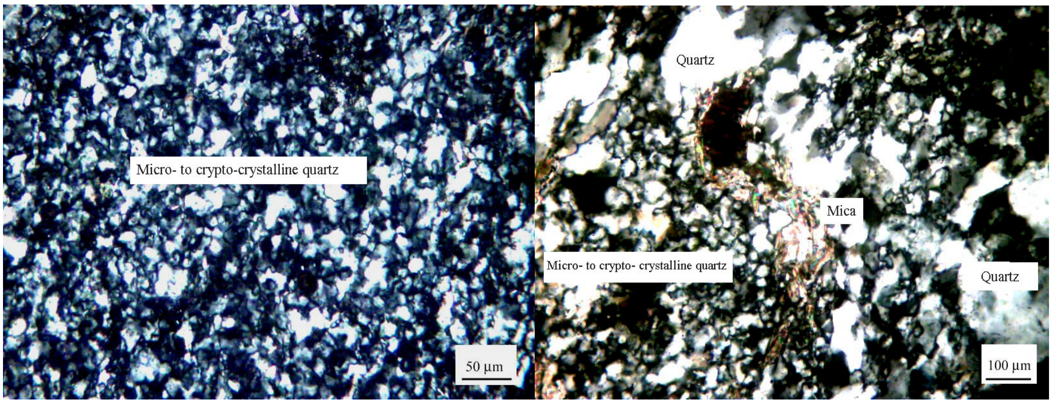

Figure 4: Micro- to crypto- crystalline quartz in chert (left) and lithoclast (right) in sands

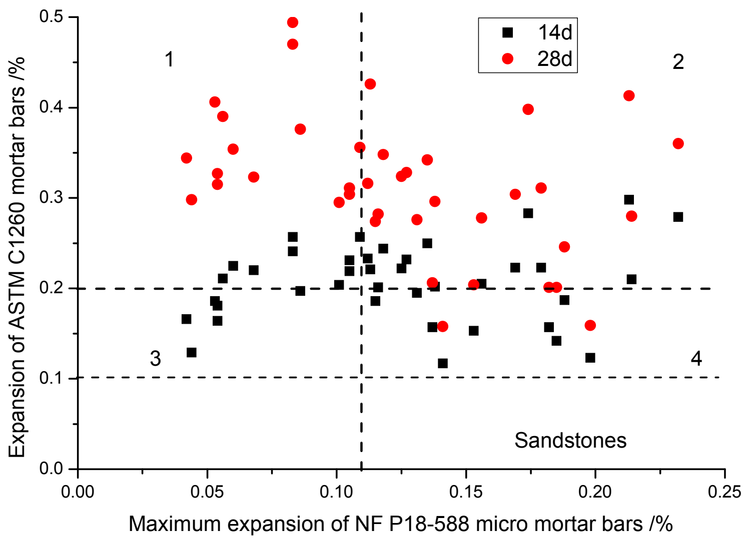

Figure 5: The maximum expansion of NF P18-588 micro-mortar bars vs expansion of ASTM C1260 mortar bars for sandstones

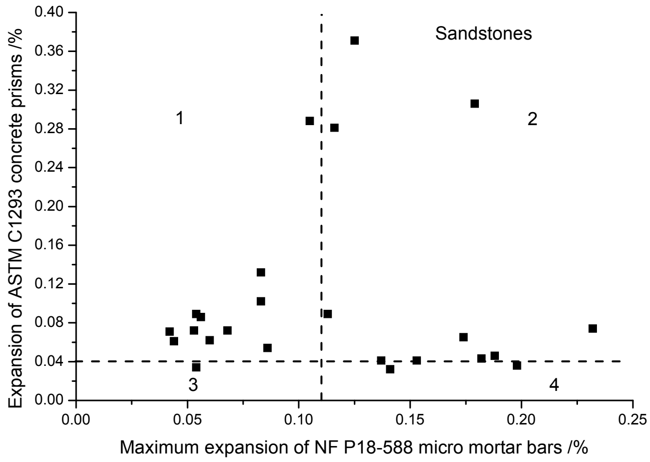

Figure 6: Relationship between the maximum expansion of NF P18-588 micro-mortar bars and expansion of ASTM C1293 concrete prisms for sandstones

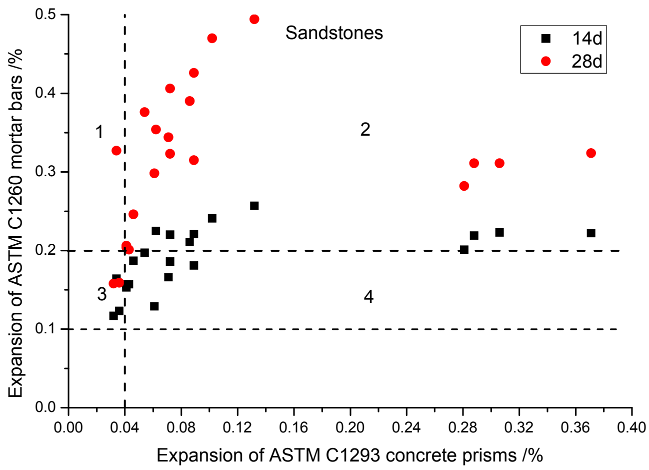

Figure 7: Correlation between expansions of ASTM C1260 accelerated mortar bars and ASTM C1293 concrete for sandstones

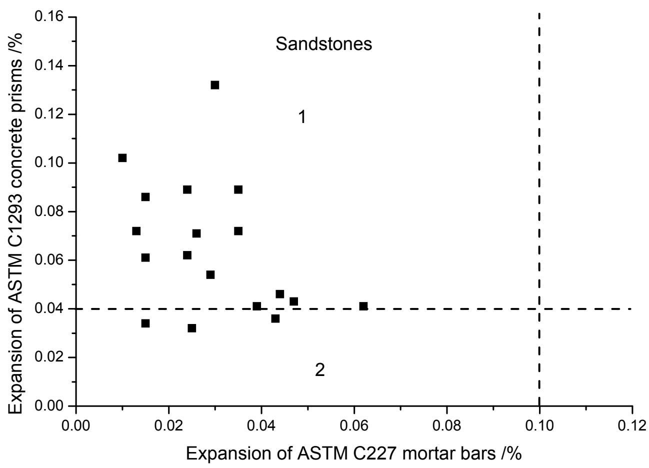

Figure 8: Correlation between expansions of ASTM C227 mortar bars and ASTM C1293 concrete prisms for sandstones

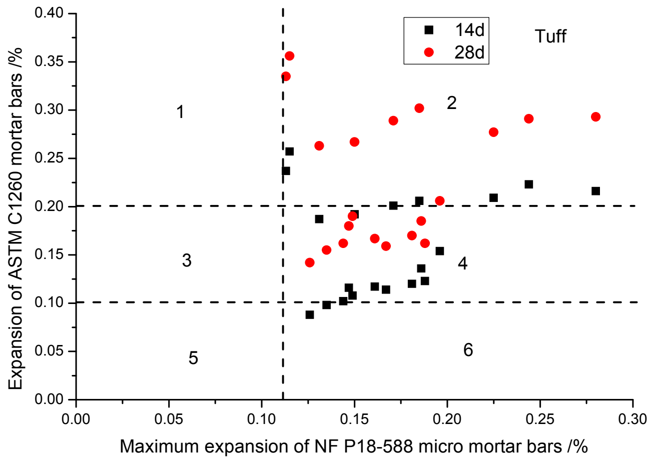

Figure 9: Relationship between the maximum expansion of NF P18-588 micro-mortar bars and expansion of ASTM C1260 accelerated mortar bars for tuffs

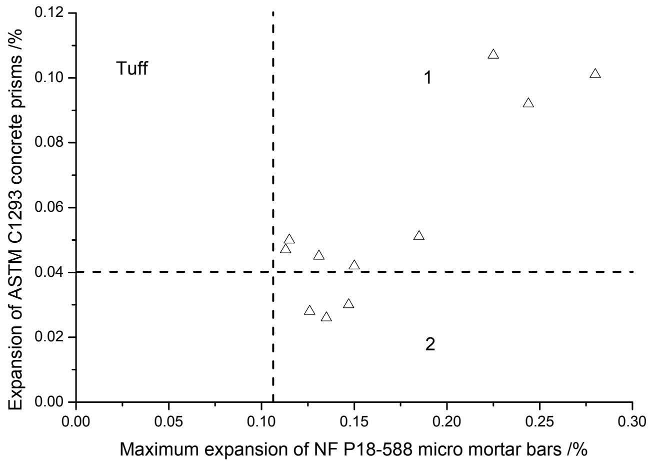

Figure 10: The maximum expansion of NF P18-588 micro-mortar bars vs expansion of ASTM C1293 concrete prisms for tuffs

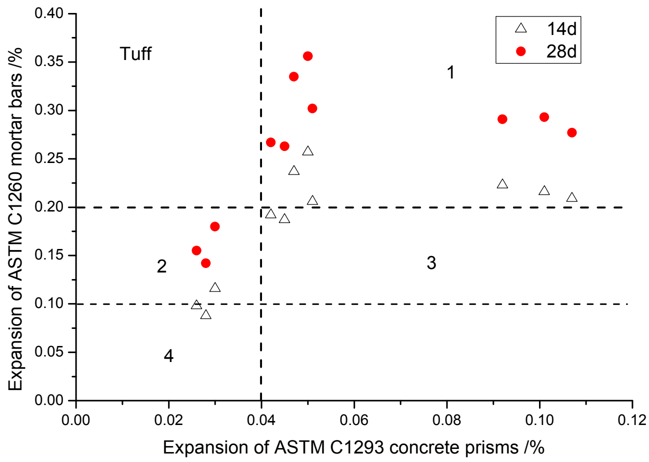

Figure 11: Relationship between expansions of ASTM C1260 accelerated mortar bars and ASTM C1293 concrete prisms for tuffs

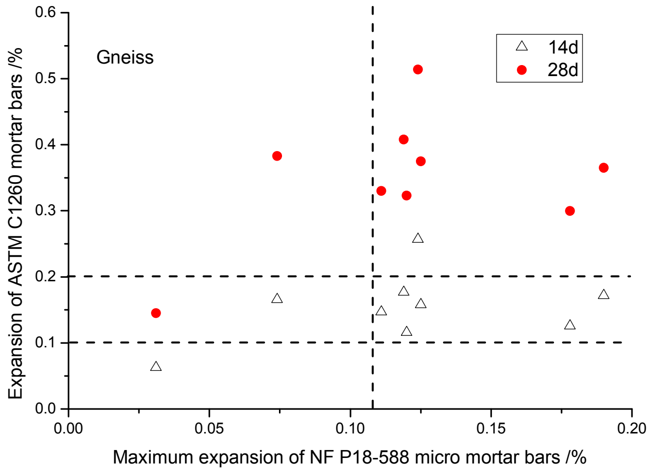

Fig 12: Relationship between the maximum expansion of NF P18-588 micro-mortar bars and expansion of ASTM C1260 accelerated mortar bars for gneisses

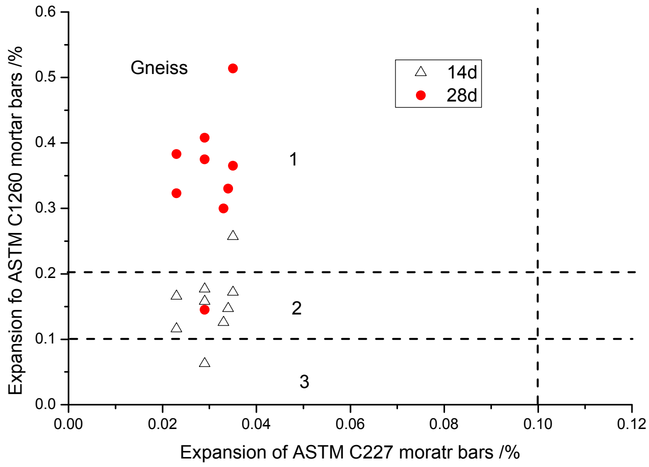

Figure 13: Correlation of expansion of ASTM C227 mortar bars and ASTM C1293 concrete prisms for gneisses

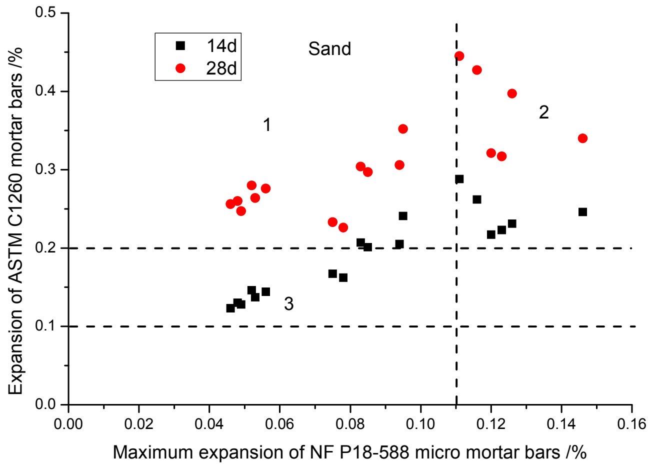

Figure 14: Relationship between the maximum expansion of NF P18-588 micro-mortar bars and expansion of ASTM C1260 accelerated mortar bars for sands