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Shrinkage and Durability of Cement Mortars with Recycled Aggregates

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ABSTRACT

In recent years, the rapid growth of economy and urbanization process in China resulted in the massive construction and demolition wastes (C&DW). The reutilization of C&DW as recycled aggregates (RA) fully or partially to replace natural aggregates is an effective way to solve the environmental and economic problems caused by C&DW. The properties of cement mortars could be influenced by recycled fine aggregates due to their high absorption and the quantity of fine particles. This paper presents the main results of the research to explore the effect of recycled aggregate (RA) on shrinkage and durability properties of masonry mortars. Four strength levels of mortars were designed to be M5, M10, M15 and M20. The percentage of replacement of natural aggregate by RA was controlled at 0%, 30%, 50%, 70% and 100%. The shrinkage, the water loss, the water absorption and the freeze-thaw resistance were measured to evaluate the properties of mortars, and the SEM analyzation was carried out to study the microstructure of mortars. Some conclusions have been found based on results of experiments. The shrinkage and the water loss increased when the replacement percentage of RA increased in all strength levels mortars. The water absorption of mortars increased with the increasing of RA content either. A better freeze-thaw resistance of mortars with higher RA replacement percentage and higher strength level was presented, and the maximum freeze-thaw cycles reached to 75 cycles. More microcracks were found in interfacial transition zone (ITZ) in mortars with high replacement percentage of RA, resulting in the weak ITZ.

1. INTRODUCTION

Recently, the rapid growth of economy and urbanization process results in the massive waste of construction and demolition (C&DW). Furthermore, a large number of old constructions are approaching their designed service life. In China, the amount of C&DW has achieved to 30% to 40% of the total urban solid wastes[1]. The CO_2 emissions during concrete production processes is mainly derived from the use of ordinary Portland cement with the increasing rate of 80% to 90%[2]. The reutilization of C&DW has been a serious environmental and economic problem which the construction industry is endeavouring to solve[3, 4]. Hence, it will be an effective way to utilize C&DW as recycled aggregate (RA) fully or partially to replace natural aggregate (NA).

Recycled aggregate concrete (RAC) has attracted lots of attentions since 1990s, and many effects of replacement percentage and type of RA on the durability of RAC has been found. Most results showed that the strength loss of RAC was not so obvious for concrete with less than 30% NA compared with conventional concrete[5-7]. For recycled aggregate mortar (RAM), the fine recycled aggregate was used rarely due to its high absorption and quantity of fine particles. In this regard, the workability of fresh mortar and mechanical properties of hardened mortar has been investigated[8-12]. Reference [8] and [9] reported deterioration in mechanical strength of mortar with increasing replacement percentage of RA. Ledesma also got the conclusion that the compressive strength and the flexural strength of mortar with substitutions of 50% RA was acceptable[10]. Zhao got some conclusions that both the slump and the compressive strength of concrete containing dried RA was higher than that containing saturated RA, and it attributed to that the thin ITZ of concrete with dried FRA could improve the ITZ strength[11]. It is found that the mechanical properties of RAM in lab was significantly different with that in practical programs and it was due to more impurities in RA than that in NA and weaker ITZ[12].

Despite of the use of RA has been studied in construction materials, and there is still lack of durability behavior of cement mortars. This paper focused on the shrinkage and durability of RAM. The shrinkage and durability of hardened mortar, including the water absorption, water loss and freeze-thaw resistance and microstructure analyzation by scanning electron microscope, with different designed strength levels has been investigated at the age of 28-days. The replacement percentage of NA by RA was designed to be 0%, 30%, 50%, 70% and 100%.

2. EXPERIMENTAL PROGRAM

2.1. Materials

Ordinary Portland Cement (P·O 42.5) was used in accordance with China National Standard GB/175-2009, and Table 1 and Table 2 summarized the chemical and physical properties of cement. River sand with the fineness modulus of 2.9 was employed as the fine NA.

Table 1. Chemical properties of cement.

SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	Na_2O(eq) (%)
20.3	64.1	4.8	2.88	2.41	2.11	0.82

Table 2. Physical properties of cement.

Initial Setting time (min)	Final Setting time (min)	Tensile strength (MPa)		Compressive Strength (MPa)	
		3d	28d	3d	28d
190	250	4.2	6.5	21.7	43.2

2.2 Mix proportions

Four strength levels (M5, M10, M15, M20) were designed, and the replacement percentage of NA by RA was controlled to be 0%, 30%, 50%, 70%, 100%. The mix proportion details were shown in Table 3.

Table 3. Mix proportions of mortars.

Mix Number	Cement (kg/m^3)	NA (kg/m^3)	RA (kg/m^3)	Water (kg/m^3)
M5	230	1398	0	287
M5-30%	230	979	419	287
M5-50%	230	699	699	287
M5-70%	230	419	979	287
M5-100%	230	0	1389	287
M10	272	1398	0	298.6
M10-30%	272	979	419	298.6
M10-50%	272	699	699	298.6
M10-70%	272	419	979	298.6
M10-100%	272	0	1389	298.6
M15	323	1398	0	303.6
M15-30%	323	979	419	303.6
M15-50%	323	699	699	303.6
M15-70%	323	419	979	303.6
M15-100%	323	0	1389	303.6
M20	393.6	1398	0	315
M20-30%	393.6	979	419	315
M20-50%	393.6	699	699	315
M20-70%	393.6	419	979	315
M20-100%	393.6	0	1389	315

2.3 Specimen preparation

All dry materials were uniformly mixed for 150s. Water was then slowly added into the mixer, and the mortar was mixed for 3 minutes. The fresh mortar was cast into molds and vibrated for 30s. The specimens were placed in curing room once being demolded. Several of test would be operated at corresponding age. For all tests, 3 specimens for every mix proportion were prepared, and the average value of 3 specimens was reported.

2.3.1. Shrinkage and Water loss. As the JGJ/T 70-2009 described, the specimens for shrinkage and water loss test were placed in the special condition (temperature 20℃, relative humidity 60%) after 7-day standard curing (temperature 20 ℃ , relative humidity 100%). The length and mass of specimen was recorded as the original length and mass. Then the length and mass were measured after 3 days, 7 days and 28days. The shrinkage strain and water loss of mortar could be calculated as the equation (1) and (2).

$$\varepsilon_{at}=(L_0-L_t)/L_0 \qquad (1)$$

where ε_{at} means the shrinkage strain at time t (unit: day); L_0 means the original length of specimen; L_t means actual length of specimen at time t.

$$W=(m_t-m_0)/m_0 \qquad (2)$$

where W means the water loss at time t (unit: day); m_0 means the original mass of specimen; m_t means actual mass of specimen at time t;

2.3.2. Freeze-thaw test. In accordance with the Chinese standard JGJ/T 70-2009, the specimens for freeze-thaw test were cured in curing room for 26 days, and then cured in the water for 2 extra days. The specimens were placed in rapid freeze-thaw equipment after 28 days curing. Test would be stopped when the mass loss exceeded 5% of original mass. The mass loss was measured according to the equation (3).

$$\Delta m_m=(m_0-m_n)/m_0 \qquad (3)$$

where Δm_m means the mass loss after n freeze-thaw cycles, m_0 means the original mass before freeze-thaw cycles but after immerging, m_n means the mass after n freeze-thaw cycles.

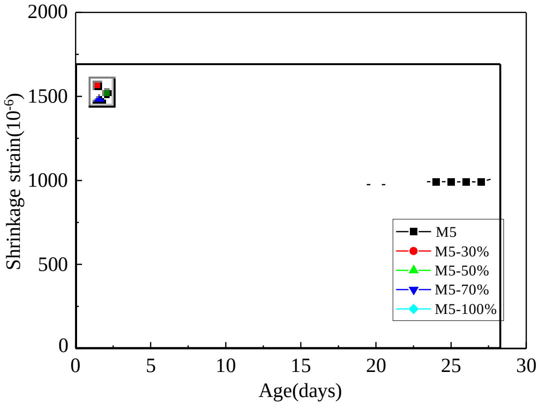
2.3.3 SEM analyzation. The samples for SEM analyzation were cut from the center location of the specimens to avoid carbonation.

3. TEST RESULTS AND DISCUSSION

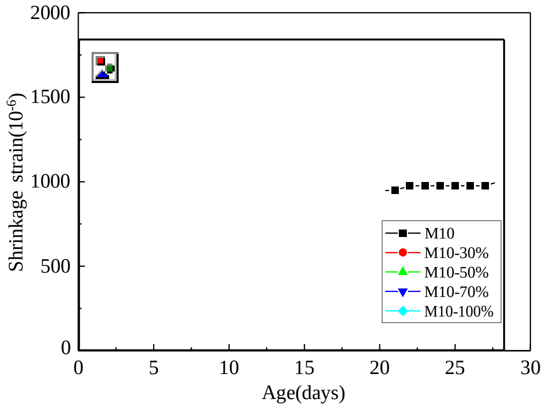
3.1 Shrinkage

In Figure 1, the shrinkage ratio as a function of the age exhibited the effect of replacement percentage on shrinkage property of RAM. The same as traditional mortar, the shrinkage of RAM increased with age. And the higher replacement percentage, the greater shrinkage of RAM. It could be found that the shrinkage difference between different replacement percentage was least for M20 group compared with M5, M10 and M15, and the shrinkage ratio of replacement percentage of 100% was 1.38 times of that of replacement percentage of 0% at 28-day age. But it was 1.64 times, 1.86 times and 1.57 times for M5, M10 and M15, respectively.

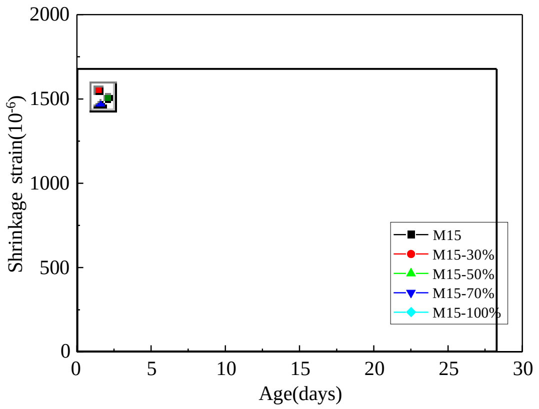
The shrinkage tested in the paper was mainly from drying shrinkage because it was tested after 7-day curing ages. It was concluded that drying shrinkage was close connection with internal water amount of mortar. The water absorption of RA was more than that of NA, which caused more shrinkage strain when replacement percentage increased.



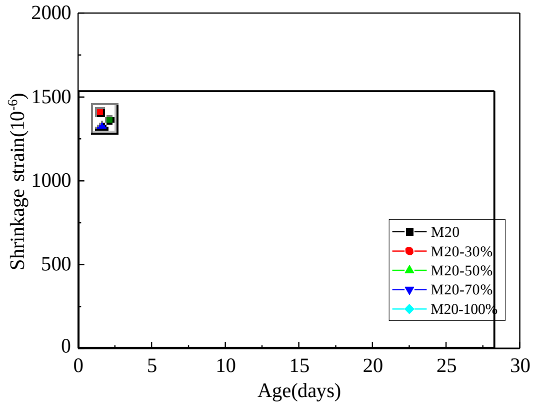
a) M5



a) M10



c) M15

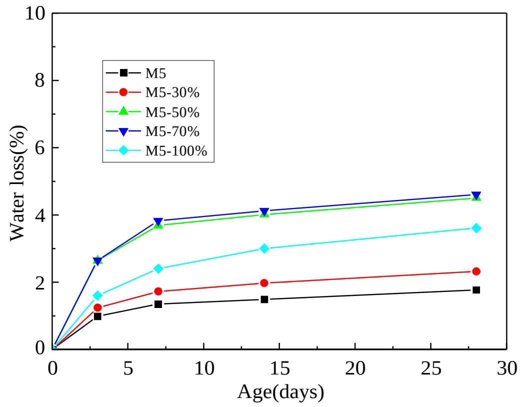


d) M20

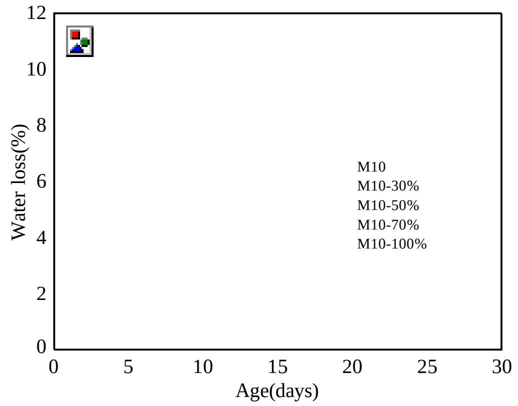
Figure 1. Shrinkage of RAM with different strength levels.

3.2 Water loss

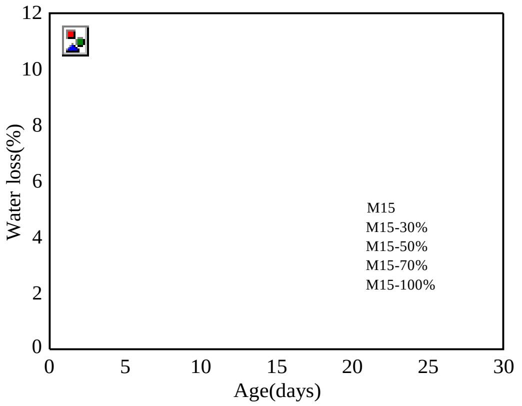
The water loss was tested at the same time with the shrinkage strain, and Figure 2 showed the water loss as a function of ages. It could be found that water loss increased with the increasement of RA replacement percentage. It is similar to the shrinkage that the water loss between different replacement percentages was the least for M20 group compared with M5, M10 and M15, and the water loss of replacement percentage of 100% was 1.48 times of that of replacement percentage of 0% at 28-day age. But it was 2.04 times, 3.59 times and 1.53 times for M5, M10 and M15, respectively, and M15 had the greatest effect as above values showed.



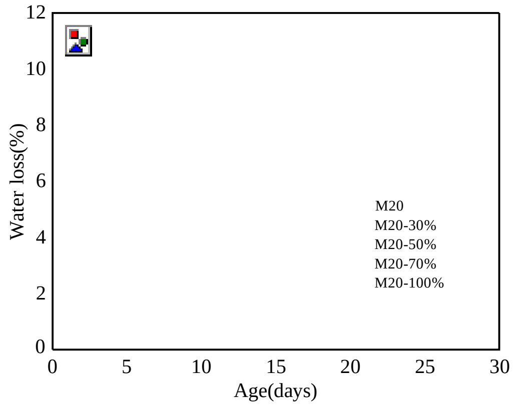
a) M5



b) M10



c) M15



d) M20

Figure 2. Water loss of RAM with different strength levels.

3.3 Water absorption

Figure 3 showed the water absorption of RAM at 28-day age. For all groups of RAM, the water absorption increased when the replacement percentage increased. But it seemed that the water absorption for all groups of RAM was nearly the same. The water absorption was about 13% for replacement percentage of 0%, about 14% for replacement percentage of 30%, 16% for replacement percentage of 50%, 17.5% for replacement percentage of 70% and 19.5% for replacement percentage of 100%. The less RA caused the lower water absorption of RAM.

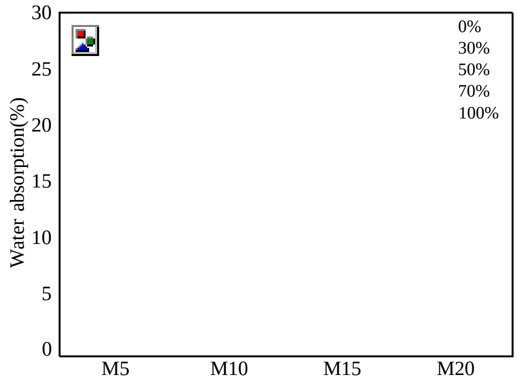
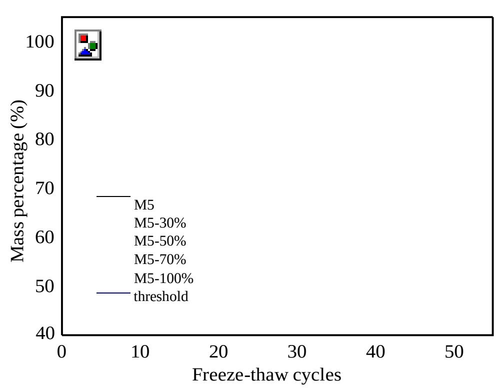


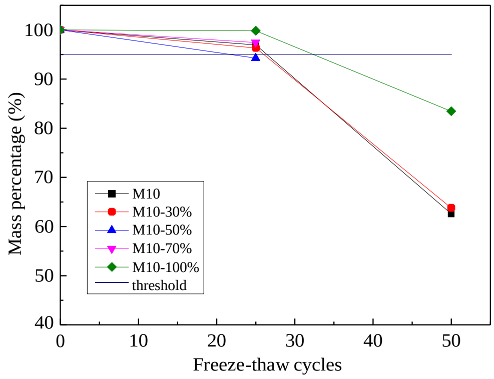
Figure 3. Water absorption of RAM with different strength levels.

3.4 Freeze-thaw resistance

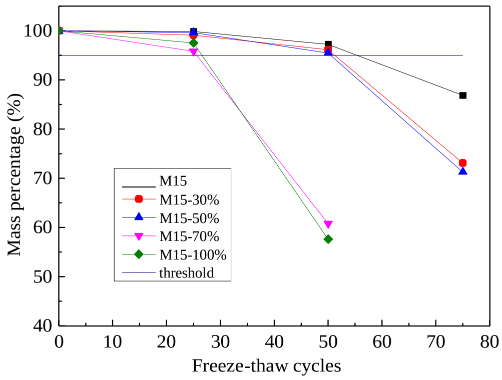
Figure 4 exhibited the mass percent of RAM as a function of cycles of freeze-thaw test. The trending of freeze-thaw resistance of RAM with different designed strength level showed very different results. In the freeze-thaw test, the mass of all RAM decreased with freeze-thaw cycles. The critical value of failure for freeze-thaw cycle test is that RAM lost 5% of original mass. For M5 group RAM, the mortars with the RA replacement of 30% and 50% achieved the threshold at 25 cycles, and those with the replacement of 0%, 70% and 100% achieved this threshold at 50 cycles. M10 group RAM has the similar trend to M5 group. The mortars with the RA replacement of 50% and 70% achieved the threshold firstly at 25 cycles, and then those with the replacement of 0%, 30% and 100% failed at 50 cycles. M15 and M20 groups had better free-thaw resistance than M5 and M10 groups. For M15 group, the mortars with the replacement of 70% and 100% achieved critical value of failure at 50 cycles, while those with the replacement of 0%, 30% and 50% lost service performance at 75 cycles. But M20 group had the opposite result to M15, the mortars with the RA replacement of 0% and 30% presented failure firstly at 25 cycles, and those with the RA replacement of 50% failed at 50 cycles, and mortars with the 70% and 100% RA lost service performance finally at 75 cycles.



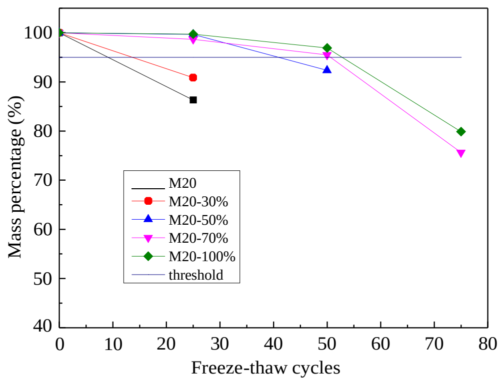
a) M5



b) M10



c) M15

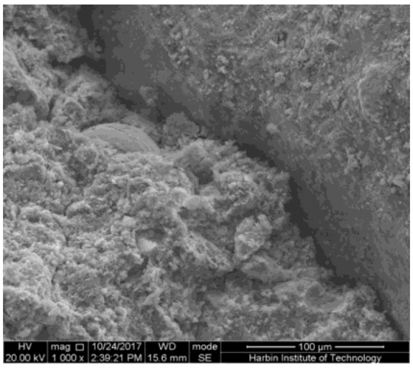


d) M20

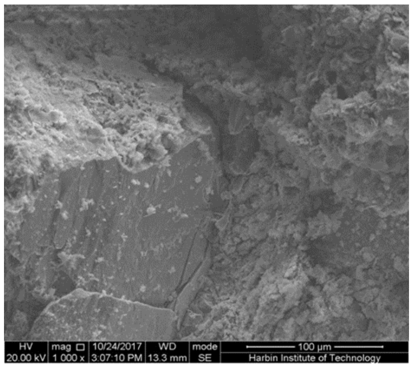
Figure 4. Mass percentage of RAM as a function of freeze-thaw cycles.

3.5 SEM analyzation

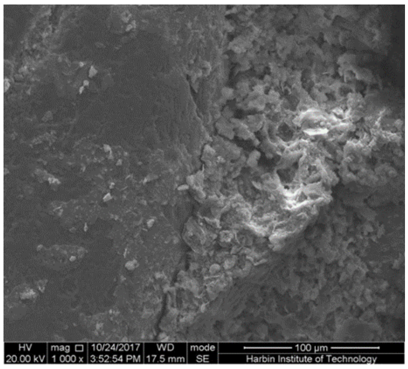
Figure 5 showed the morphology of the interfacial transition zone (ITZ) of both NAM and RAM. The replacement of RA was 100%. More microcracks were found in ITZ in high replacement percentage RAM. That was the reason that RAM presented the weak ITZ when more recycled aggregate was added into mortars.



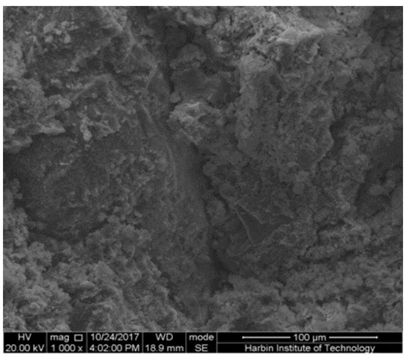
a) M5 (NAM)



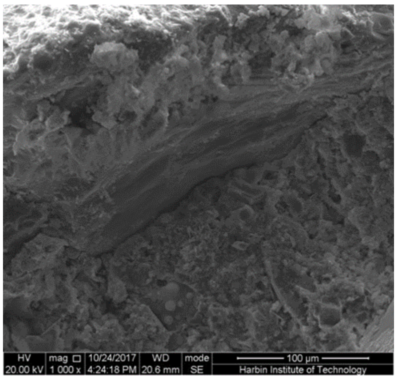
b）M5 (RAM)



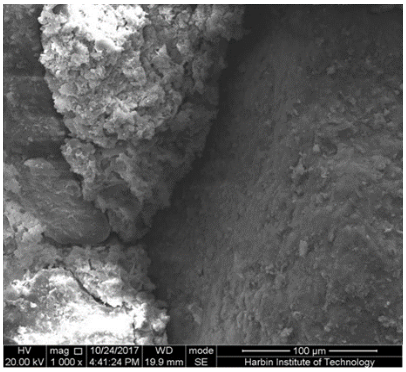
c) M10 (NAM)



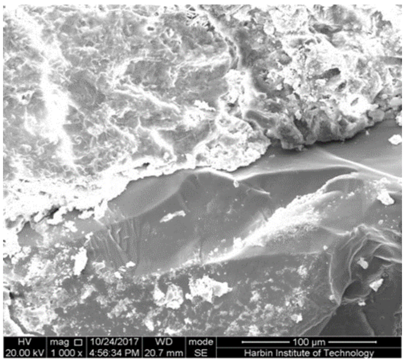
d）M10 (RAM)



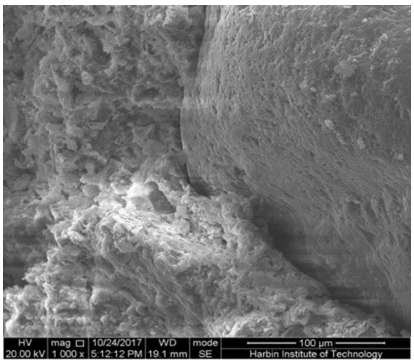
e) M15 (NAM)



f）M15 (RAM)



g) M20 (NAM)



h）M20 (RAM)

Figure 5. Microstructure of ITZ in NAM and RAM.

4. CONCLUSIONS

Based on the above experimental results and discussions, some conclusions could be drawn below:

(1) The shrinkage, the water loss and the water absorption were all positively correlated with replacement percentage of NA by RA. And freeze-thaw resistance of mortar became worse when the RA replacement percentage increased.

(2) The SEM images showed more micro crack in ITZ area of RAM with high replacement of RA. It was the reason for that the mechanical properties of those mortars decreased.

ACKNOWLEDGMENT

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