A Study on Strength and Durability of Mortar Using Low-Quality Recycled Fine Aggregate with Accelerated Carbonation

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Abstract. Recycled aggregate produced from demolished concrete and waste fresh concrete are classified into three types of quality using the density in oven-dry condition and water absorption ratio in Japan. Among the three types, compared to medium and high quality recycled aggregate (M and H), low quality recycled aggregate (L) can be produced with less energy and cost, and reduces the generation of fine powder by-product. However, concrete made from L have problems are it has lower strength and greater length change due to drying shrinkage. When considering the widespread use of L, these must be improved with less cost. For these modifications, we have been investigating the use of CO_2 gas for accelerated carbonation technology. This technology focuses on the carbonation mechanism of concrete and blows CO_2 gas on recycled aggregate to carbonate the cement paste that are attached mortar. It has been found that the physical properties of recycled fine aggregate are greatly improved using this technology. Therefore, to investigate the effect of recycled fine aggregate with accelerated carbonation on the hardened samples, we conducted tests on mortars made from that fine aggregate. It has shown that mortar has improved strength and durability due to the reduction of mortar voids attached on recycled fine aggregate. Especially, we reported that there was a large improvement in the out of specification of L (outside of L). There is a difference in amount of fine powder. L contains 3% fine powder, while outside of L contains 12%. We considered that the fine powder influenced the hardened samples. Therefore, in this study we focused on the granularity, such as fine powder of low quality recycled fine aggregate and conducted tests on mortar to compare the difference in the effect of accelerated carbonation modification technology.

Keywords: Recycled fine aggregate; Accelerated carbonation technology; Fine powder; Granularity

1. INTRODUCTION

Carbon neutrality, which aims to reduce greenhouse gas emissions to zero as a whole, is being promoted on a global scale. In Japan, various efforts are being made to achieve carbon neutrality by 2050. In the concrete field, studies are being conducted to reduce the use of cement, which emits a large amount of CO_2 during production, and to fix CO_2 using carbonation mechanisms in concrete and aggregates. On the other hand, the use of recycled aggregate produced from dismantled concrete masses is also important for a recycling-oriented society such as carbon neutral. Recycled aggregate is classified into three types, H, M, and L, in descending order of quality. The classification method is based on differences in quality resulting from the condition of the original concrete demolition material and the processing method. It is also known that low-quality recycled aggregates have low strength and durability when used in concrete, although energy and cost during production are low. The carbonation of such low-quality recycled aggregate can adsorb and fix CO_2, which may help to achieve carbon neutrality. Furthermore, the density increases and the water absorption rate decreases. In addition, it has been found that the strength of cured bodies using these materials is greatly improved when low-quality recycled fine aggregate or recycled fine aggregate of poorer quality is used, and the air permeability coefficient is improved for recycled fine aggregate of poorer quality. Each of these aggregates has a different particle size distribution, and among them, the poor quality fine aggregate has a large amount of fine particles, which suggests that the difference in particle size is the key to the improvement effect of carbonation. Therefore, in order to compare which particle size should be carbonated to obtain a greater improvement to the hardened samples, this study examined the effect of different particle sizes of aggregate on the strength and permeability of mortar.

2. OUTLINE OF EXPERIMENT

2.1. Materials Used and Mix Proportions

In this study, mortar was made to study the effect of carbonating the fine aggregate. The mortar was formulated with a water cement ratio 50% and a constant cement: fine aggregate ratio 3.0. The cement used was Ordinary Portland Cement. The physical properties of the recycled fine aggregate used in this study are shown in Table-1. In this study, L-class recycled fine aggregate(LS) and it was carbonated(LSC) were used. The carbonated fine aggregate was placed in an accelerated carbonation system for one week at a temperature of 20°C, relative humidity of 60% and CO_2 concentration of 5%. Figure-1 show the improving effect of dry density and water absorption rate of recycled fine aggregate by accelerated carbonation. A treatment of fine aggregate used in the mortar is shown in Figure-2. The recycled fine aggregate was sieved into five particle sizes. Then, in order to reduce the difference in the effect of the mass of each particle size, mass ratio equalized by 20%. In (1) to (5), each particle size range was partially carbonated and the effects of different fine aggregate particle sizes on the strength and permeability of the mortar were investigated. Then, the transition zone thickness, which is known to affect strength and permeability, was examined. The whole grain unmodified and the whole grain carbonated were also prepared at the same time to compare the different effects on the mortar.

Sample name	Surface dry density (g/cm^3)	Absolute dry density (g/cm^3)	Water absorption rate (%)	Amount of fine particles (%)
LS	2.24	2.00	12.01	8.60
LSC	2.31	2.13	8.47	

Table-1 Physical properties of recycled fine aggregate

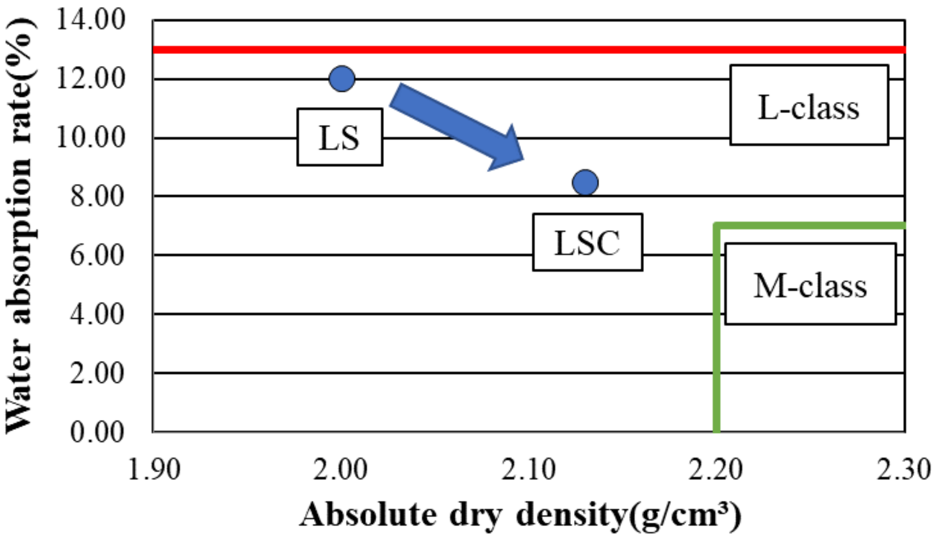

Figure-1 Improving effect of dry density and water absorption rate of recycled fine aggregate

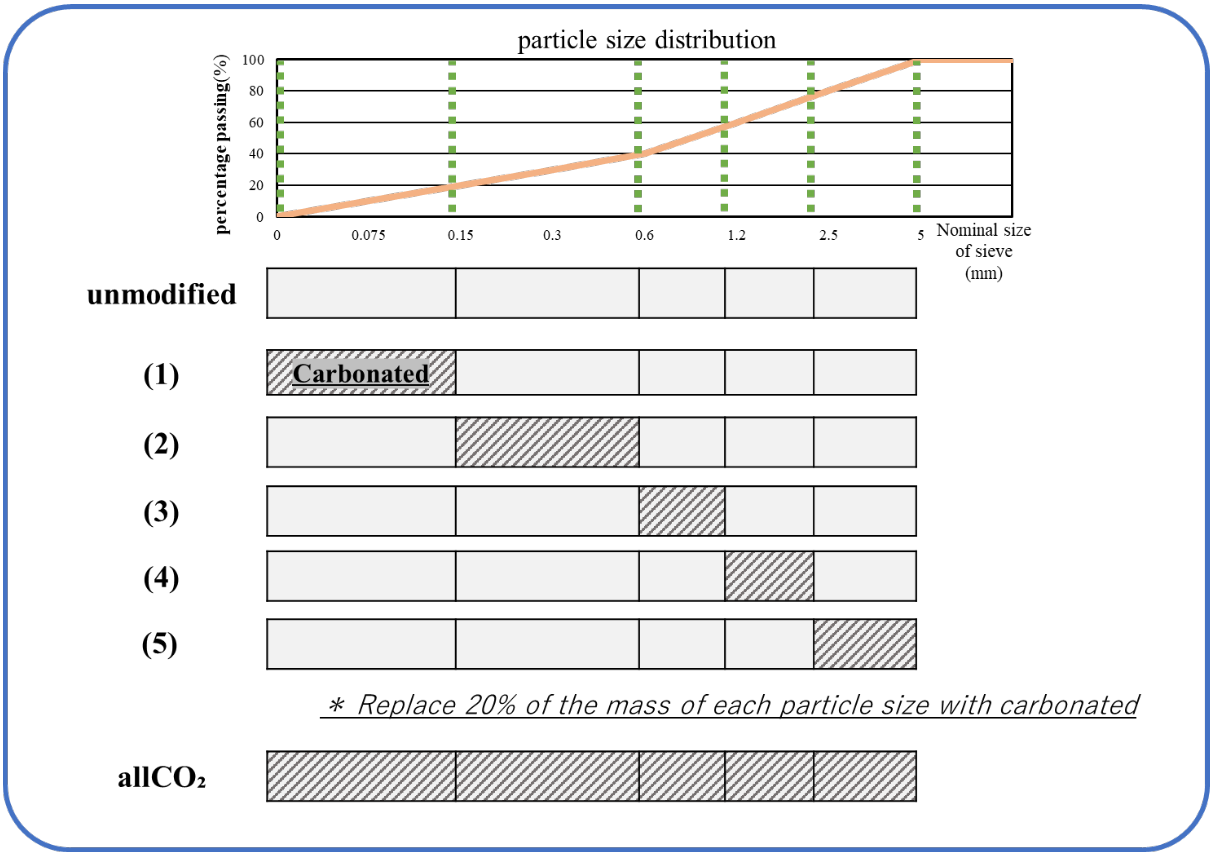

Figure-2 Mixture name and Fine aggregate used in mortar

2.2. Test Items and Test Methods

2.2.1 Compressive strength test

Mortar bars of 40 × 40 × 160 mm were used, and the test was conducted in accordance with JIS R 5201 at 28 days curing in top water.

2.2.2 Air permeability test

A cylindrical specimen of φ100 × 25mm cured in water for 28 days was placed in a drying oven at 40°C until its mass became constant, and the test was conducted. Air was allowed to permeate through the material at a pressure of 0.1 MPa in an air permeability testing chamber. The amount of air permeation was measured by the water displacement method using a measuring cylinder, and the permeability coefficient was calculated from the following equation (1).

$$K = \frac{2LP_1}{(P_1^2 - P_2^2)} \cdot \frac{Q}{A} \tag{1}$$

K: Air permeability coefficient ($cm^4/N \cdot s$), L: Specimen thickness (cm), P1: Loading pressure(N/mm^2), P2: Outflow side pressure (N/cm^2), Q: Amount of air permeability (cm^3/s), A: permeable area (cm^2)

2.2.3 Vickers hardness test

The test was conducted using pieces of the specimen after the compression test. The piece surface was finished on a turntable using abrasive paper #120~1200, and the Vickers hardness of the fine aggregate interface was measured with a vickers hardness tester (load: 0.9807N, test force: 10μm/s). From 3~4mm size aggregate easily recognized as aggregate ten points were measured at 20 μm intervals from the edge of the fine aggregate, and the approximate interfacial transition zone thickness was calculated from the Vickers hardness measurements.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength Test

Figure-3 shows the results of compressive strength test. No significant change in compressive strength was observed in the cases (1) to (5) where the particle size of fine aggregate was partially carbonated. On the other hand, there was a significant improvement in allCO_2. The reason may be that the partial carbonation is only 20% by mass of the total aggregate, and the remaining unmodified parts are more affected by porosity and brittleness.

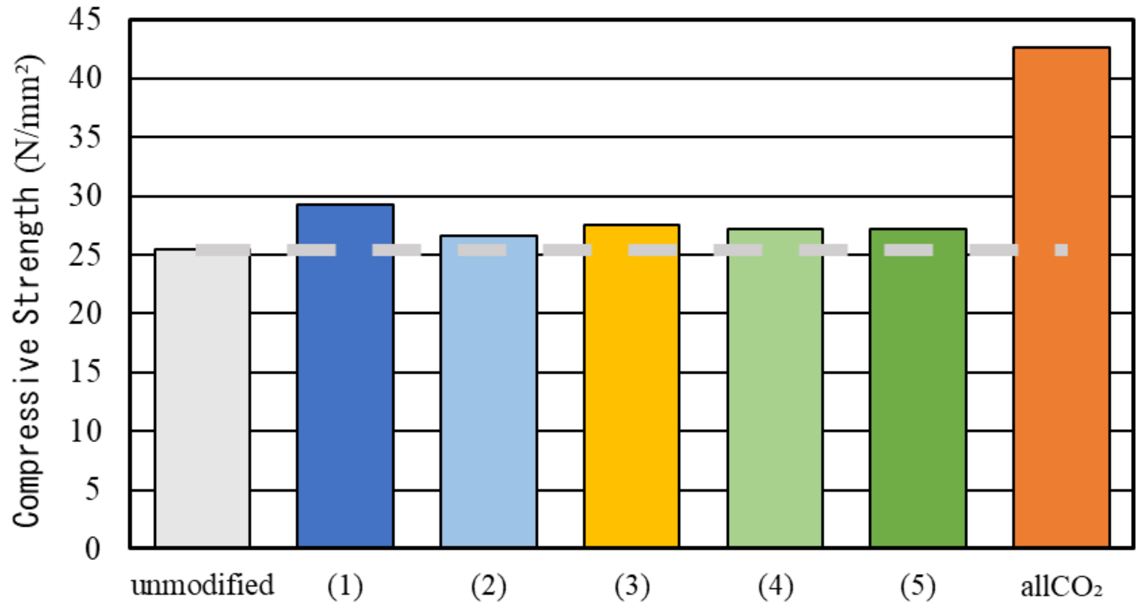

Figure-3 Compressive strength

3.2. Air Permeability Test

Figure-4 shows the results of air permeability test. Air permeability tends to be improved when carbonating the fine grain range as in (1) and (2). However, compared to the improvement effect of allCO_2, it is found to be small. This suggests that partial carbonation of aggregate particle size improves the air permeability of mortar in the smaller diameter particle size range, but the improvement is smaller than that of forced carbonation of the entire particle size. By the way, since the air permeability of the hardened material depends on the structure of the interfacial transition zone, we think that the improvement mechanism of the interfacial transition zone may be different for each grain size.

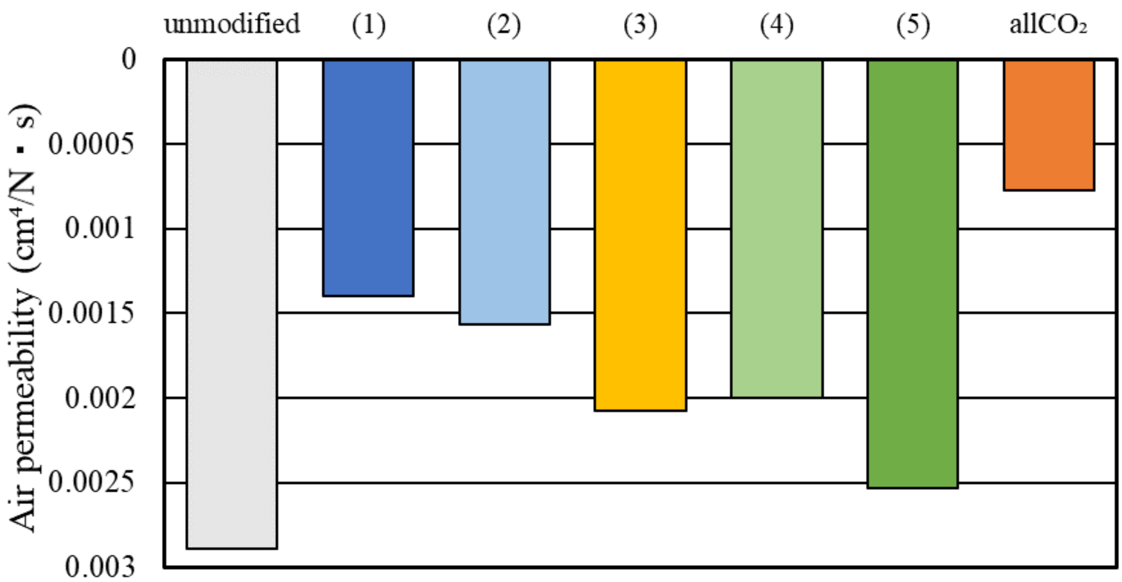

Figure-4 Air permeability

3.3. Vickers hardness Test

3.3.1 Test results

Figure-5 shows the results of Vickers hardness test. Based on the discussion in the air permeability test, the interfacial transition zone thickness was calculated from the vickers hardness test. In this section, the results for the carbonated particle sizes of (2), (3), and (4) had similar slopes, so only the results for the particle size of (3) are shown. All proportions are higher than 80 N/mm^2 up to around 40μm, suggesting that it is not the interfacial transition zone, but the aggregate or adhesion paste. In the case of the finer grain size (1), the interfacial transition zone was improved at a distance from the aggregate. In the case of coarse grain size (5), the interfacial transition zone was improved near the aggregate compared to the others. These results suggest that the mechanism of improvement of the interfacial transition zone varies depending on the particle size of carbonation. By the way, we consider that the reason why there was almost no improvement in (2), (3), and (4) was because the aggregate particle size measured for the interfacial transition zone thickness was about 3~4 mm, which was not modified in (2), (3), and (4).

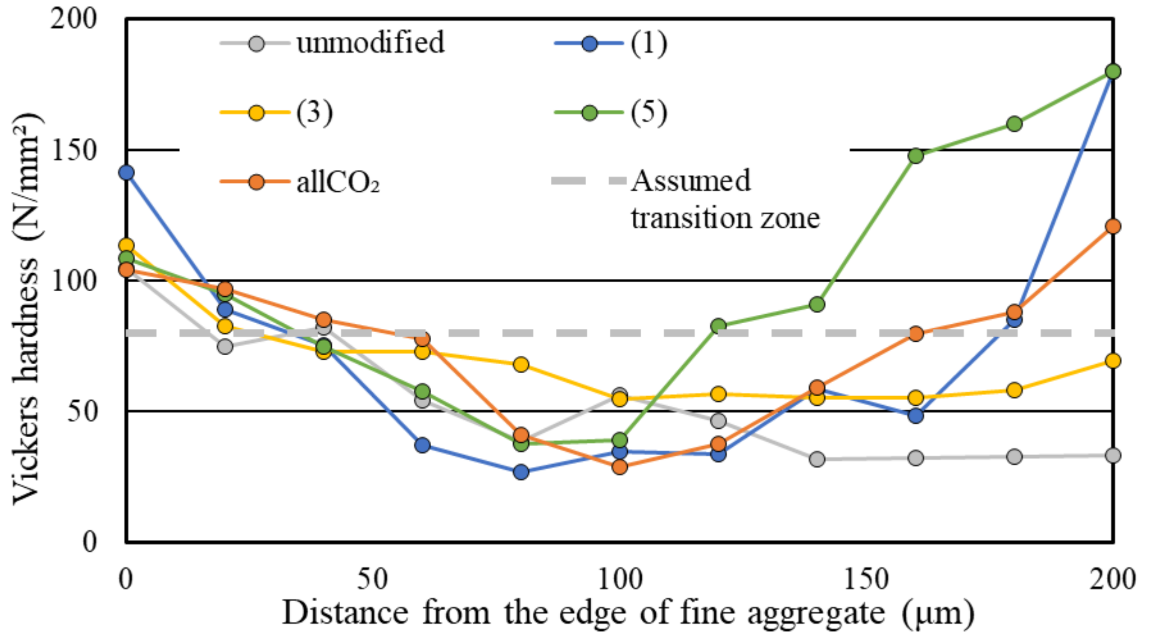

Figure-5 Vickers hardness

3.3.2 Discussion

Figure-6 shows the images of transition zone improvement mechanism. In the case of carbonation of fine-grained (1), we believe that the fine-grained content is converted to almost pure $CaCO_3$ by carbonation, which improves the interfacial transition zone by promoting hydration at the cement paste interface. On the other hand, we consider that carbonation of coarse-grained (5) improves the transition zone by modifying the adherent paste around the aggregate and reducing the amount of water that exudes due to lower water absorption. In short, although the measured interfacial transition zone thickness of the allCO_2 was thicker than (5), the actual interfacial transition zone thickness is expected to be more improved because both of the above improvement effects occur. Therefore, permeability is more improved.

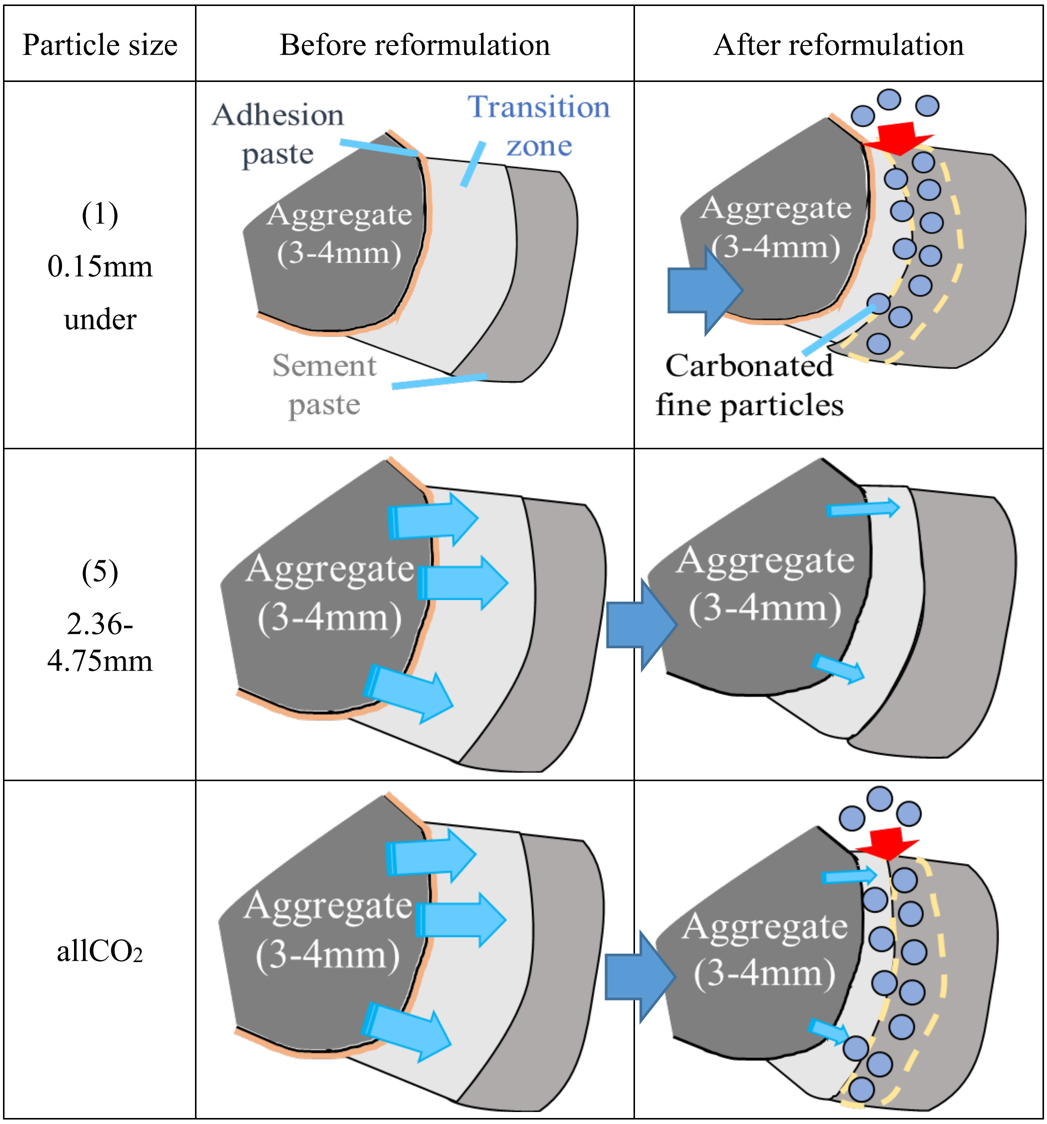

Figure-6 Images of transition zone improvement mechanism

4. CONCLUSIONS

(1) In the case of accelerated carbonation of a partial grain size range, there was little improvement in compressive strength under any condition. There was no significant effect of any of the particle size ranges (1) to (5). On the other hand, the smaller the particle size, the better the improvement of air permeability was observed.

(2) Although the smaller the particle size range, the better the air permeability of the mortar, carbonation of all particles has the greatest improvement in both strength and air permeability.

(3) The improvement mechanism of the transition zone depends on the grain size. The finer particles are themselves converted to $CaCO_3$ by carbonation. to $CaCO_3$, which improves the transition zone. The coarser grains are considered to have modified the adhesion paste by carbonation and to have improved the transition zone.

ACKNOWLEDGEMENTS

This result was obtained as a result of the work (JPNP16002) commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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