

論文の要旨

題目 Application of Porous Ceramic Aggregate Derived from Roof Tile Waste as an Internal Curing Agent to Structural Blast Furnace Slag Type-B Concrete
(内部養生材としての廃瓦の構造用高炉 B 種コンクリートへの適用性)

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In this study, the applicability of porous ceramic waste roof tile aggregate (PCA) as an internal curing aggregate to structural Portland blast furnace slag cement Type B concrete (BBC) that requires longer wet curing treatment at early ages was investigated. The adopted water to cement ratios (W/C) were 0.5 and 0.35. The investigation on the effects of PCA was carried out using both coarse and fine aggregate partial volume replacement with PCA. In the case of coarse aggregate replacement (PCCA), the replacement ratios were 0, 10%, 20% and 0, 10%, 20%, 30% for W/C=0.5 and W/C=0.35, respectively. In the case of fine aggregate replacement (PCFA), for comparison purposes, the amount of internal curing water was adjusted to be the same as in the case of PCCA, and the resultant replacement ratios were 0, 12%, and 24% for both W/Cs. The PCA was immersed in water for more than 7 days, and thereafter dried until surface dry condition, before being used in concrete. The factors considered in the investigation were water to cement ratio (W/C) and replacement ratio of PCA.

The investigated parameters together with the results obtained are as summarized below:

1. Investigation on the effect of internal curing with PCA on mechanical properties of plain BBC exposed to drying at the age of 7 days were carried out. The investigated parameters were the effects on compressive strength, splitting tensile strength, Young's modulus, fracture energy as well as the characteristic length of concrete. The results showed that the compressive strengths and splitting tensile strengths of the internally cured W/C=0.5 concretes improved only marginally compared to the reference concretes. However, in the case of W/C=0.35, the internal curing effect of PCA was effective in increasing the compressive strengths by 40% at maximum and splitting tensile strengths by 20% at maximum. The increase was particularly remarkable in the case of low replacement ratio of PCA at 10% PCCA. In the case of Young's modulus of the internally cured concretes, a decrease with increase in replacement ratio of PCA was observed. This decrease was at maximum 20% in the case of 30% replacement ratio. The internal curing effect of PCA was effective in increasing the fracture energies of concretes of BBC irrespective of the replacement ratio and W/C. This effect was particularly remarkable in the case of low replacement ratio of PCA at 10% PCCA and 12% PCFA. However, in the case of characteristic length, which is a parameter used to show the brittleness of concrete and is used in the estimation of flexural cracking strength to incorporate the tension softening properties of concrete, the increased splitting tensile strengths of the internally cured BBC resulted in decreased characteristic length of concretes.
2. Investigations of the effect of internal curing with PCA on flexural cracking properties of RC beams exposed to drying at the age of 7 days were carried out. Two RC beams of dimensions 200×250×2700mm, for each mixture proportion were prepared. The effective depth was 210mm and the tension reinforcement ratio was 1.36%. The flexural crack widths were measured on the length of the zone subjected to pure bending moment, which was fixed at 800 mm for all beams. The results of this investigation showed that the internal curing with PCA did not have significant effects on the flexural cracking moments of W/C=0.5 beams. However, in the case of W/C=0.35, the flexural cracking moment of the internally cured beams increased irrespective of the PCA replacement ratio, in the range of 20~40%.

The maximum crack spacing and maximum crack width in the case of W/C=0.50 were almost the same as those of

the reference beam. In the case of $W/C=0.35$, the maximum crack spacings of the internally cured beams were similar or slightly larger than the reference beam. However, the maximum crack widths of the internally cured beams were observed to decrease significantly compared to reference BBC. This tendency implies that the bond between concrete and steel in the case of internally cured RC beams was improved, thus resulting in smaller crack widths.

- Investigations on the effect of internal curing with PCA on shear capacity of RC beams exposed to drying at the age of 7 days were carried out. Two RC beams of dimensions $300 \times 305 \times 2300$ mm, for each mixture proportion were prepared. The effective depth was 250mm and the tension reinforcement ratio was 1.03%. The loading tests results showed that the PCA was effective in increasing the shear capacity of the internally cured RC beams in the case of $W/C=0.5$, by 11~13% at maximum. The increase in shear capacity was particularly remarkable in the low PCFA replacement ratio of 12%. In the case of $W/C=0.35$, the shear capacity was found to decrease with increase in PCCA replacement ratio, probably due to reduced shear transfer along the diagonal cracks. However, use of PCFA in $W/C=0.35$ RC beams resulted in an increase by 3% in the case of 12% replacement.

The estimate values of shear capacity of the RC beams using various estimation equations from various codes were found to be lower than the measured values, irrespective of the W/C and replacement ratio of PCA, thus showing a possibility of estimation of shear capacity on the safe side.

- Investigations on the effects of internal curing with PCA on the autogenous shrinkage of BBC and shear capacity of RC beams made using BBC cured under high temperature history (*high temp*) at early ages were carried out. A temperature history to simulate the conditions of mass concrete with a maximum temperature of 70 degrees was adopted. For comparison purposes, investigations were also carried out on BBC and BBC RC beams cured under room temperature (*normal temp*). The PCA replacement ratios investigated were 10% PCCA and 12% PCFA replacement ratios. The autogenous shrinkages were measured using strain gauges embedded at the center of $200 \times 320 \times 1000$ mm concrete specimens. In the case of the RC beams, two beams of dimensions $200 \times 320 \times 2300$ mm, for each mixture proportion were prepared. The effective depth was 250mm and the tension reinforcement ratio was 0.80%. The results on the autogenous shrinkage showed that the *high temp* values increased drastically with increase in control temperature, up to the peak temperatures, and thereafter decreased with decrease in control temperature, independent of W/C and PCA replacement ratio. When the specimens were removed from the control room, the *high temp* autogenous shrinkage values were generated at a higher rate than the *normal temp* values, independent of W/C and PCA replacement ratio. In the case of effect of internal curing with PCA, the PCA was effective in mitigating the autogenous shrinkage of the internally cured concretes, particularly in the case *high temp* concretes, compared to the effect on *normal temp* concretes.

The loading test results of the RC beams showed that the beams cured under high temperatures had lower shear capacity compared to those cured under normal room temperature, independent of the W/C and PCA replacement ratio. However, this decrease was clearly mitigated in the case of internally cured RC beams, compared to the reference beams. The shear capacity of the internally cured RC beams were found to increase compared to the respective reference beam, independent of the exposed temperature, PCA replacement ratio and W/C .

- Based on these investigations, this study showed the potential effects of PCA as an internal curing agent, and also showed that PCA can be applicable to both the plain BBC and the reinforced BBC. The application range was found to be from 10~30% replacement ratio of both fine and coarse aggregate in the case of plain BBC, while the replacement ratio of PCA in the range of 10~12% was found to be the most appropriate in improving the performance of reinforced concrete regardless of curing condition. In addition, based on the findings from this study, the PCA (Replacement ratio 12%) was successfully used in the construction of a box culvert for a highway in Western Japan.