# RECYCLED AGGREGATE FROM CONCRETE WASTE FOR HIGHER GRADES OF CONCRETE CONSTRUCTION

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# Recycled Aggregate from Concrete Waste for Higher Grades of Concrete Construction
# 再生混凝土骨料應用於較高階混凝土建築

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# ABSTRACT

Owing to shortage of space for land reclamation in Hong Kong, it is difficult to dispose tons of concrete waste generated daily from construction activities. This research aims to adopt Recycled Aggregate (RA) from concrete waste for higher grades of concrete construction. The three parts study is divided. The first part investigates the waste management and recycling in the construction industry by providing methods in managing the waste problems created by the local construction industry. Telephone-interview to the recycling firms, site visits to Construction and Demolition (C&D) sites and Tuen Mun Area 38 recycling plant are conducted in order to examine the difficulties encountered in the recycling market. It is also examining the technology on construction waste recycling; ten material recycling practices are studied, including: i) asphalt; ii) brick; iii) concrete; iv) ferrous metal; v) glass; vi) masonry; vii) non-ferrous metal; viii) paper and cardboard; ix) plastic; and x) timber. Among various types of waste sources, concrete waste was found to be the major proportions between them. Adoption of RA from crushing the demolished concrete wastes thus becomes a burning issue. However, the use of Recycled Aggregate Concrete (RAC) to higher grade applications is rarely reported because of its poor compressive strength and high variability in mechanical behaviour. The benefits, difficulties, and recommendations in adopting RAC are thus explored and reported.

The second part includes experimental works for examining the characteristics of RA and the properties of RAC. There are six groups of experimental works in investigating the characteristics of RA, namely: i) particle size distribution; ii) particle density; iii) porosity and absorption; iv) particle shape; v) strength and toughness; and vi) chemical composition. The properties of twelve RA samples and their correlations are explored. As the properties of RA are the main criteria to define their construction applications, classification system is developed, and aided with two new innovative testing techniques: i) Timely Assessment of Water Absorption (TAWA) for measuring the water absorption rate of RA without changing the behaviour of the original RA; and ii) Classification System on Cement Mortar Remains (CS*Cement*) for measuring the amount of cement mortar attached to RA. For the production of RAC, eight groups of experimental works

used to compare the improvement of Two-Stage Mixing Approach (TSMA) with traditional mixing approach, namely: i) workability; ii) density; iii) strength; iv) rigidity; v) scale of pH; vi) deformation; vii) permeability; and viii) micro-structural crystallization. Three issues can be summarized from the experimentation: i) RA replacement ratio is directly affected the performance of RAC; ii) On the same RA substitution, Two-Stage Mixing Approach (TSMA, $TSMA_{p1}$, $TSMA_{p2}$, $TSMA_{s}$ and $TSMA_{sc}$) can help to improve the quality of RAC in comparison with the traditional mixing approach; and iii) Some experimentation highlighted the optimal situation occurs for TSMA at 20% RA substitution. Based upon the experimental works, improvement in quality of RAC was achieved after adopting TSMA. The effects for TSMA can be attributable to the porous nature of RA and hence the pre-mix process can fill up some pores and cracks, resulting in a denser concrete, an improved interfacial zone around RA and thus a higher strength in comparison with the traditional mixing approach. TSMA is thus intended for improving the quality and hence lowering its strength variability. This part of research also includes the optimization of the RA replacement ratio by using TSMA. The uses are suggested the ranges of RA replacement ratios on 20~45%, 55~70% and 80~95%. Since the quality of RA varies from site to site, a lower replacement ratio of RA can reduce the risk. The result suggests to adopt 20~45% RA replacement ratio for the production of RAC. It confirms the conservation decision in recommending 20% RA substitution by the Architecture Services Department and the Buildings Department of the Hong Kong Special Administrative Region.

The final part proposes a guidance note on RAC in order to provide an effective methodology for enhancing the performance of RAC and opening up a wider scope of RAC applications, which aims to: i) highlight the potential reduction on the quality of RAC in adopting various RA proportion; ii) classify the characteristics of RA for various construction applications; and iii) suggest the use of TSMA for the production of RAC to benefit the gain of mechanical properties. Furthermore, the industrialization of concrete waste recycling activities is also explored by the development of a mobile crusher. The mobile crusher aims to remove the difficulties encountered in the centralized recycling plant, which can also retain the quality of RA from a known source of concrete wastes and enhance their applications.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| $2CaO.SiO_2$ | Dicalcium Silicate |
| $3CaO.Al_2O_3$ | Tricalcium Aluminate |
| $3CaO.SiO_2$ | Tricalcium Silicate |
| $4CaO.Al_2O_3.Fe_2O_3$ | Tetracalcium Aluminoferrite |
| *Al* | Aluminum |
| *AIV* | Aggregate Impact Value |
| *BD* | Buildings Department |
| $C_2S$ | Dicalcium Silicate |
| $C_3A$ | Tricalcium Aluminate |
| $C_4AF$ | Telracalcium Aluminoferrite |
| $C_3S$ | Tricalcium Silicate |
| *C&D* | Construction and Demolition |
| $Ca(OH)_2$ | Calcium Hydroxide |
| $CaO.SiO_2.H_2O$ | Calcium Silicate Hydrate |
| *Cap.* | Chapter |
| *CED* | Civil Engineering Department |
| *CH* | Calcium Hydroxide |
| *CRA* | Coarse Recycled Aggregate |
| CS*Cement* | Classification System on Cement Portion Remains |
| *CSH* | Calcium Silicate Hydrate |
| *DSC* | Differential Scanning Calorimetry |
| *EPD* | Environmental Protection Department |
| *FRA* | Fine Recycled Aggregate |
| *GRNN* | General Regression Neural Network |
| *GMDH* | Group Methods of Data Handling |
| *HA* | Housing Authority |
| *HCP* | Hardened Cement Paste |
| *HDPE* | High-Density Polyethylene |
| *ITZ* | Interfacial Transition Zone |
| *MLP* | Multi-Layer Perceptron |
| *NENT* | North East New Territories |

| | |
|---|---|
| *NMA* | Normal Mixing Approach |
| *PE* | Polyethylene |
| *PET* | Polyethylene Terephthalate |
| *PP* | Polypropylene |
| *PS* | Polystyrene |
| *PVC* | Polyvinylchloride |
| *RA* | Recycled Aggregate |
| *RAC* | Recycled Aggregate Concrete |
| *RBN* | Radial Basis Network |
| *SAR* | Special Administrative Region |
| *SEM* | Scanning Electron Microscopy |
| *SENT* | South East New Territories |
| $SiO_2$ | Silicon Dioxide |
| *SSD* | Saturated and Surface-Dried |
| *TAWA* | Timely Assessment of Water Absorption |
| *TFV* | Ten Percent Fine Value |
| *TSMA* | Two-Stage Mixing Approach |
| $TSMA_{p1}$ | Two-Stage Mixing Approach$_{\text{(proportional-1)}}$ |
| $TSMA_{p2}$ | Two-Stage Mixing Approach$_{\text{(proportional-2)}}$ |
| $TSMA_{s}$ | Two-Stage Mixing Approach$_{\text{(silica fume)}}$ |
| $TSMA_{sc}$ | Two-Stage Mixing Approach$_{\text{(silica fume and cement)}}$ |
| *WENT* | West East New Territories |
| *WRFP* | Waste Reduction Framework Plan |

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