Form 2

**Dissertation Abstract**

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| Dissertation title | **Influence of moisture content on permanent deformation and particle breakage of recycled concrete aggregates** (リサイクルコンクリート材の変形と破砕に水分量が与える影響) | | |


Abstract

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The objective of the current study is to focus on the utilization of recycled construction materials with special focus on recycled concrete aggregates. The main aim is further sub-divided into sub-objectives. The sub-objectives include to utilize the recycled concrete aggregates as a pavement material taking into consideration the environmental factor (moisture content in this study) as a controlling feature to the long-term performance.

Looking at the problem currently world especially the developing countries are facing currently is the massive generation of construction waste but unused. On the other hand due to expansion of infrastructure due to future developments the demand of natural resources is peaking causing damage to environment and social life. To overcome the above issues recycling is currently the best way to manage the large amounts of construction and demolition waste (CDW) generated by demolishing works of existing infrastructure and from natural disasters. With a rapid increase in CDW generation, the demands for CDW recycling and sound waste management including suitable recycling policies and legislations are being advocated worldwide. The utilisation of recycled materials as well as industrial by-products in construction works and infrastructure development has many advantages by minimising the use of natural resources and reducing carbon dioxide emission, and for sustainable development and green growth of cities. The use of recycled concrete aggregates (RCA) being the larger part of construction and demolition waste directly contributes to the increase of recycling, and the use of RCA in geotechnical engineering applications has been increasing.

In road pavement systems, recycled granular materials including RCA are widely used to construct base and subbase courses. The base and subbase courses must withstand overburden and traffic loads above the courses, to mitigate failure of the surface pavement layer, and to spread the loads to subgrades in a safe manner in various environmental conditions. One of the principal objectives of road pavement design is to minimise the growth of permanent deformation in the pavement system because the existence of permanent deformation can be recognised as a first step to pavement distress.

Fewer studies have been devoted to the assessment of permanent deformation, especially the effects of moisture content (*m.c.*). A small increase of *m.c.* increased the development rate of permanent deformation without the generation of excess pore water pressure due to the lubricating effect of water in natural granular materials. With regards to the long-term durability of granular materials, the occurrence of particle breakage under dynamic loading is also a critical aspect. The particle breakage induced during the loading process continuously

changes the grading of granular materials and significantly affects mechanical and hydraulic properties. The particle breakage can strongly relate to grain size distribution, void ratio, and shape and hardness of individual particles, and that the amount of particle breakage increased in the granular materials with uniform and angular grains and with increasing confining pressure. This study, therefore, aimed to investigate the permanent deformation and particle breakage characteristics of RCA with different *m.c*.

Different series of laboratory tests including compaction, static triaxial test and cyclic triaxial test were conducted to investigate the long-term performance of RCA as pavement base material. The material used in this study was collected from a crushing plant in Japan and particle size distribution was graded according to RM-30, suggested by Japan Road Association standards. The optimum moisture of the material lies around 10% with approximate maximum dry density of 1.88 g/cm$^3$. As mentioned earlier, to estimate the breakage of RCA particles research was divided into different parts. In the first part, compaction tests were conducted to simulate the construction phase. Five different moisture contents were used ranging from 5.4~15%.

To estimate the particle breakage of RCA, commonly used Marsal's breakage index, $B_g$ was used. However, the limitation of this index is that it does not capture the actual or absolute breakage that happens in specific size range but it gives overall breakage tr end. To overcome this coloring technique was introduced in this study to trace the part icle sizes which are more prone to breakage. Results of the compaction tests indicate t hat $B_g$ shows decreasing trend with increasing moisture content. The possible reason to explain this trend is that on the wet side moisture act as a buffer to reduce the partic le breakage, whereas on dry side due to increased inter-particle friction due to less moi sture crushing of the particle happens causing increased breakage. Colouring technique r esulted in the identification of particle size range of 9.5~4.75 mm contributing more to the breakage. The increment in fines also increased due to contribution from top size ranges. In the next part, RCA samples were subjected to cyclic loading to assess the lo ng-term performance with different compaction moisture contents under three confining p ressures 40, 70 and 100 kPa. The samples were subjected to 4000 loading cycles under corresponding deviatoric stress. After the cyclic loading the breakage of the RCA tested was also calculated. The results of the cyclic loading showed that increasing moisture co ntent cause increased permanent strain. The maximum strain development happened in th e initial few cycles in all tests. However, in less moisture content cases, after certain nu mber of cycles the strain development stabilised. Whereas in case of higher moisture co ntent (11.6%) the deformation kept on increasing with increasing number of loading cycl es. This suggests that increased moisture content act as a lubricating agent in the materi al matrix causing large increase in permanent strain, apparently due to the lubricating eff ect of water in a granular assembly. The same has been reported in the literature. The breakage results under cyclic loading show overall decreasing trend if the breakage durin g compaction is considered. The least breakage in that case is observed near to optimu m moisture zone. There is an increasing trend in breakage observed after optimum moist ure zone at higher moisture content. To observe this difference from compaction results, the post compaction breakage was separated. The post compaction breakage or absolute breakage under cyclic loading show increasing trend with moisture. This indicates that during cyclic loading the breakage of the particles is not much influenced by the moistu

re. Also, the major portion of the breakage happens during the compaction stage. The results of the colouring method after cyclic loading indicated that the same particle size range (9.5~4.75 mm) contributes more to the breakage. In the final series of the tests to moisture content was varied from compaction moisture by infiltrating and drying the sample to target moisture contents before and after certain number of loading cycles. Results apparently show that moisture does affect the deformation characteristics of RCA. However, the breakage was less affected in this case. The findings of the study are a step forward towards the understanding of the mechanisms affecting the long-term performance of recycled materials to be used in engineering applications and sustainable society.