CONCRETE RECYCLING

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ABSTRACT

Limbah benda uji beton yang tertimbun di Laboratorium Bahan dan Konstruksi, Fakultas Teknik Jurusan Sipil Undip setiap harinya mencapai kubikasi yang cukup tinggi. Bahan ini merupakan komponen limbah industri yang dapat mempengaruhi tata guna lahan dan merupakan pencemar lingkungan. Pada proses pembongkaran bangunan lama, volume limbah beton akan lebih besar lagi. Berbagai usaha telah dilakukan untuk mendaur ulang atau memanfaatkan bahan limbah beton. Salah satu alternatif yang dipandang baik secara struktur maupun dari segi ilmu lingkungan adalah mendaur ulang dan memakai kembali bahan agregat kasar yang berasal dari bahan beton. Sifat fisis dan mekanis bahan agregat ini berbeda dengan bahan agregat asli yang berasal dari pemecahan batu. Faktor-faktor yang sangat berpengaruh adalah kadar resapan yang tinggi, adanya sisa-sisa mortar yang menempel pada agregat dan variasi kualitas bahan dasar yang sulit ditentukan secara tepat. Tulisan ini membahas perkembangan paling dini dalam bidang daur ulang agregat. Hasil-hasil penelitian yang dilaksanakan oleh Laboratorium Bahan dan Konstruksi, Fakultas Teknik Jurusan Sipil Undip akan di evaluasi secara singkat.

***Kata kunci** : Agregat Daur Ulang (RCA), Kuat Tekan, Sifat-sifat Agregat, Ilmu Lingkungan*

INTRODUCTION

Concrete has been widely known as a tough and durable building material. However, recent issues on *Sustainable Concrete Technology* has placed concrete in another light. *Construction and Demolition Waste*, so called as *CDW* will arises another problem. Waste and Directive keys now put a stressing factor on: *Cleaner Technology; Recycling, Reuse and Recovery of Waste (R3) and Management and Planning of CDW Handling.* The Construction and Material Laboratory, Diponegoro University alone produces around 20 test cylinders daily, equivalent to 10.5 m^3 of concrete waste (Figure 1). The removal of this waste cost up to a million rupiah per dump truck, and still the waste used only as land fill on building sites.

Figure 1. Used Test Cylinders

ENVIRONMENTAL IMPACT OF CONCRETE WASTE

A large amount of waste rubble, largely concrete, is produced annually. In Indonesia the majority of this waste is sent to landfills while in other parts of the world this material is recycled as *Recycled*

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Concrete Aggregate (RCA). When sending waste concrete to landfills in Indonesia will involve only the cost of transportation, in Europe for example, dumping fees will rise to US$ 20 – 50 per ton. *(Lauritzen, 2004)*

The impact of concrete waste on the environment *D* can be expressed in a formulation *(Mehta, 2001);*

D = f(P x I x W) .... (1)

Where *P* is the population, *I* the index for industrial and urban growth and *W* express the degree of community unawareness to natural resources conservation. Concrete waste will strongly influence *I* index and is a direct function of population growth *P*. In North America, Europe and Japan only, two-thirds of CDW consist of concrete and masonry. The reuse and recycling of this waste material will increase natural resources conservation.

SOLUTIONS TO REDUCE ENVIRONMENTAL IMPACT

Reducing the environmental impact of construction industry has become an important issue in the late one decade. Regarding concrete structure, the impact has occurred since the mining process of its basic materials. The following are some ways to reduce its environmental impact.

1. *Making more durable concrete with longer lifetime*.
   Nowadays most buildings are designed to have a lifetime of 50 years. However, the fact is that most building are starting to deteriorate at age 20. This is mainly caused by the instant speed-up of hydration process in mortar cement usually required to speed up construction work. This fast hydration process will produce high internal stresses in the concrete leading to early failure. This phenomenon did not occur in buildings from the roman era which still can be observed until to date, and stood for more than thousands of years. Making more durable buildings with a lifetime of 500 years will reduce the waste significantly.
2. *Cement Conservation*.
   Cement production is known to contribute to 7% of all CO_2 into the atmosphere, increasing the greenhouse effect. In addition, cement production also contributes to deforestation and topsoil lost due to large quantity mining of its materials such as limestone, clay and fuel. Reducing cement amounts in concrete will contribute significantly to the environment. One alternative to reduce cement in concrete is the use of alternate pozzolanic materials such as fly ash and silica fume. Researches have showed that the use of fly ash and/or silica fume as replacement of some cement portion will improve the quality of concrete.
3. *Water Conservation*.
   Production of concrete uses tons of water everyday. Partly is used for washing the mixer and other parts are used for concrete mixing. Theoretically, the hydration process of cement only requires about 30% of the cement mass, which means that majority of water is needed for increasing the workability. For this, using *recycled water* and *water-reducing admixture* to control water usage will be beneficial.
4. *Aggregate Conservation*.
   Aggregate conservation can be done by using aggregates from recycled concrete. Concrete waste from building demolitions are usually exploited as landfill. Upgrading the waste by re-using it as aggregate in new concrete is a challenge. Since this material comes from different sources with a variety in original strengths, using *recycled concrete aggregate* (*RCA)* requires a good understanding of this material. The following sections in this paper will discuss this topic in more detail.

DEMOLITION PROCESS

The physical performance of RCA is further influenced by demolition methods. The most used concrete demolition methods are: *hydraulic breakers (crushers); blasting; chemical splitting; diamond disc saw cutting; thermit lance and abrasive water jet.* The method chosen greatly depends on the type of concrete structure being demolished and its environment *(Fig. 2 and 3)*. Hydraulic breakers are suitable in areas where a low noise and vibration level is required. Blasting is far most the most popular between all the methods, followed by chemical splitting. *(Kasai, 1986)*

Figure 2. Blasting of Concrete Structures (Kasai, 1986)

Figure 3. Chemical Splitting (Kasai, 1986)

RCA obtained from the demolition process will only be attractive when the material is competitive to natural sources, both in terms of quality as well as economically.

Reclaiming the RCA is by separating the solid material from the cement mortar. The crushed concrete is disposed in a washbasin, and then the aggregate is separated from the *water-cement slurry*. This can be done by several technologies. The most straight forward method is washing the material with water. The RCA then can be screened and the water can be processed for further use

PROPERTIES OF RECYCLED CONCRETE AGGREGATE

The origin of concrete waste and its original concrete properties largely influence the potential of RCA. CDW originating from rigid pavement structures, for example, will contain *asphalt residue, joint sealant and sub base material*. CDW from building structures will contain other contaminations such as *roof sealants, floor tiles and waterproofing additives*.

Research work has been performed to study the behaviour and characteristics of concrete made with RCA as compared with concrete using natural aggregates *(Abou-Zeid, 2005; Banthia, 2000; Tavakoli, 1996; Rashwan, 1997).*

RCA is classified in:

1. Clean coarse aggregate with small amount of mortar attached to the aggregates on one or more spots
2. Coarse with a thin film of old cement mortar covering the major part of aggregate
3. Coarse aggregates with a thick layer of old paste, ca 2 – 3 mm
4. Coarse aggregate with a lump of old cement mortar on one site
5. Particles consisting of only old mortar
6. RCA with contaminations originating from the old structure.

One of the major differences between natural gravel and RCA is that RCA generally *will not meet the gradation requirements*.

Figure 4. Original Aggregate from Stone Crushers

Figure 5. Recycled Coarse Aggregate (Construction & Material Laboratory, UNDIP 2006)

RCA produced by a crushing process have good shape but a low specific gravity and a high absorption degree as compared to original aggregates *(Fig. 4 and 5).* Studies also showed that multiple recycling will increase this absorption level. While natural gravel having absorption levels ranging from 1 – 2, RCA's absorption level is usually above 3.5. This high level can be explained due to the presence of the old porous cement mortar attached to the RCA.

A method to accomplish the amount of attached mortar is by performing the *Los Angeles Abrasion Test*. The loss in fine particles under the impact of Los Angeles' loads can predict the ratio of cement factor in the original concrete. This same test can also provide information to the overall toughness of the aggregates.

Table 1. shows the properties of RCA from used test samples if compared to original aggregates from *Pudak Payung*.

Table 1. Physical Properties of Aggregates
(Construstion and Material Laboratory, Diponegoro University, 2006)

	Density (gr/cm^3)	SSD Density (gr/cm^3)	Water Content (%)	Absorption (%)	Fine Particles (%)	Abrasion (%) (Los Angeles)	Impact Test (%)
Pudak Payung	2.709	2.715	0.76	3.20	0.16	23.3	15.84
RCA	2.445	2.458	4.85	4.62	0.77	30.01	25.51

The test result confirm the conducted research work and it is seen that density of RCA is lower while its absorption rate as well as its Fine Particles content is much higher as compared to the Pudak Payurng aggregate.

As for fresh concrete mixes, this high absorption nature will result in a higher demand of *Water Cement Ratio* combined with a decrease in workability. Tests on concrete with both coarse and fine RCA from US State Highways *(Foster, 1986)* resulted in a harsh, nearly unworkable mix.

On the other hand the attachment of old mortar will make the shape of RCA rounder, thus beneficial the mixing process of fresh concrete. However, due to this round form, interlocking between cement mortars will be lower resulting in a lower concrete strength performance *(Fig. 6.).*

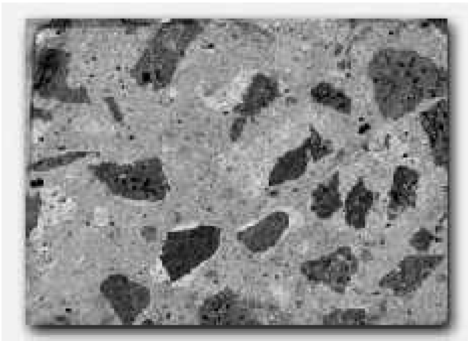

Figure 6. Cross Section of Recycled-Concrete Aggregate (Shayan, 2003) show the attached old mortar

Properties of *recycled-aggregate concrete* are further influenced by the RCA properties such as *size, strength, shape, composition and impurities*.

Based on the RCA proportion in concrete, *recycled-aggregate concrete* can be classified into two. The first is *"partial replacement",* which is using RCA as either coarse aggregate or fine aggregate only. The next is *"total replacement"*, which replace both coarse and fine aggregate with RCA.

Abu-zeid's research work (*Abou-zeid, M. N., Shenouda, S. L., McCabe, S. L. and El-Tawil, F. A., 2005*) compared the behaviour of *recycled-aggregate concrete* for both partial and total replacement of aggregates, with conventional concrete. Effects of recycled aggregate age is also studied by comparing concrete properties originating from old building demolition, and newly recycled aggregate, crushed at 14 to 21 days of concrete age. Their study showed that RCA from old buildings results in a better performing concrete rather than the concrete using newly crushed RCA.

On the other hand, research work of Rashwan *(Rashwan, 1997)* proved that RCA crushed and used in a short period of time, will provide advantage above RCA that undergo a long storage time after crushing.

The result showed that density of *recycled-aggregate concrete* ranges from 2070 kg/m^3 to 2190 kg/m^3, which is lower than that of conventional concrete. Reduction in the unit weight will increase, as the RCA content increases.

All mixtures are designed with a slump in the ranges of 65 to 85mm. However, concrete mixture with RCA performs a lower slump which range, from 20 to 60mm. The fresh concrete mixed at the Construction and Material Laboratory, Undip showed a significant differential value for the same mix proportion of aggregates (Figure 7 and 8).

Figure 7. Slump of Ordinary Aggregate Mix

Figure 8. Slump of RCA Mix

Comparison of the concrete compressive strength at 28 days with a cylinder specimen shows that *recycled-aggregate concrete* has a slightly less compressive strength, range from 26 to 32.6 MPa, while conventional concrete's strength ranges from 28.5 to 35.7 MPa. Here, the *"total replacement"* exhibits the lowest compressive strength with a value below 30MPa for all specimens.

Regarding the flexural strength, the research implied that the flexural strength is quite similar for all concrete. This may be because of a better bond of RCA to the cement mortar than that in conventional concrete.

Observing the compression and tensile strength relationship it was shown that the pattern slightly deviates from its typical relationship. Therefore, the relation between compression strength obtained by cylinder testing and tensile strength from the splitting test as well as flexure test need to be modified.

Studies showed that the strength characteristics of the concrete with RCA are also highly dependent on the strength of original concrete, the ratio of coarse to fine aggregate in the original concrete and the size of the coarse aggregates. *(Tavakoli, 1996).*

HIGH STRENGTH RECYCLED-AGGREGATE CONCRETE

Generally, concrete made with RCA has a compressive strength of about 32 MPa, which limits the use of this concrete. Next, other problem are high water demand and low workability, resulting in reluctance of engineers in using this concrete.

Designing a high strength concrete using RCA should therefore consider its material properties carefully in order to obtain the design strength. In this case more attention should be addressed to RCA used for both coarse *and* fine aggregate.

Coarse aggregate should be cleaned from its contaminants such as bricks, ceramics, plaster, metal, plastic, and wood, which can give adverse effect to concrete properties. Recycled-aggregate crushed from high strength concrete structure will be preferable above low strength concrete. In general, effect of PCA to concrete can be predicted and examined from its water absorption and density pattern, whereas high water absorption and low density will donate to lower strength concrete.

Shayan et al, *(Shayan, 2003),* determine the RCA water absorption to be 4.7% in saturated surface dry (SSD) samples. Density of RCA is determined to be 2557 kg/m^3, which is lower than density of natural aggregate from crushed natural granite and basalt being 2650 and 2950 kg/m^3. These lower properties are due to the porous mortar cement that wraps the aggregate.

Fine aggregate has a fines modulus of approximately 2.44 with a composition mainly consisting of sand and cement paste. Aggregate density is about 2332 kg/m^3, lower than that of natural sand which usually has a density of around 2650 kg/m^3. Water absorption in fine RCA is quite high and reaches 6.3%.

Fly ash and silica fume is used to improve concrete properties, reduce the porosity as well as increase the compressive strength. Test result shows that concrete made from recycled aggregate is able to reach a compressive strength of 50 MPa.

CONCLUSION

1. The use of RCA both as coarse or fine aggregate can contribute significantly to reduce environmental impact of concrete waste
2. The overall quality of *recycled-aggregate concrete* is highly influenced by the origin of RCA
3. The present of attached mortar will increase the absorption level, and therefore increase the water demand of *recycled-aggregate concrete*. Workability is influenced negatively by this RCA nature
4. Unit weight of RCA is slightly lower than natural aggregate, resulting in a concrete with a lower density as compared to conventional concrete
5. RCA was shown to perform better when used as coarse aggregate rather than fine aggregate
6. The typical *Compression-Flexure-Tensile* relationship of conventional concrete, has to be modified for *recycled-aggregate concrete*
7. RCA originating from old structures will result in a better performing *recycled-aggregate concrete* as compared to concrete using newly crushed RCA, on the other hand the shorter the crushed RCA is stored, the larger its advantage is compared to long-stored RCA

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