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DEVELOPMENT OF HIGH QUALITY RECYCLED AGGREGATE BY PHYSICAL TREATMENT USING PHOSPHORIC ACID (H_3PO_4)

BY

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We hereby declare that we are the sole author of this thesis. This report has been performed by us and any part of it has not been submitted else where for the award of any degree or diploma.

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Abstract:

Recycled aggregate consists of the original aggregate and cement mortar layer remaining of the old concrete. Physical and mechanical properties of recycled aggregate dependent on the properties, as well as on the quantity of remaining mortar. Removing and strengthening the adhered mortar are the two main methods for improvement the properties of recycled concrete aggregate. In this study, how the quality of recycled aggregate can be improved by surface treatment is studied. From the study it is fund that after surface treatment, the quality of recycled aggregate enhanced significantly.

Key words: Physical treatment, Bonded mortar, Quality of Recycled Aggregate.

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Up and above anything else, praises are due to Almighty Allah alone, the omnipotent, and the omnipresent. The most merciful and most compassionate. And after Almighty Allah to his Prophet, Hazrat Muhammad صلى الله عليہ وآلہ وسلم the most perfect and exalted, who is forever a source of guidance and knowledge for humanity as a whole.

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Chapter 1

Background, Objectives, and Flow Diagram of the Study

1.1 Background of the Study

The ambition of reducing the use of natural materials in construction and the aim of reducing the environmental impact of the concrete industry has recently driven Europe to adopt a policy that strongly promotes the use of recycled aggregates in concrete production. The European Directive n.98 of 19/11/2008 [1] calls on member states to take ''the necessary measures to promote the reuse of products and the preparing measures for re-use activities, particularly by promoting the establishment of economic tools and criteria about tenders, quantitative targets or other measures''. Particularly, it specifies that preparations for re-use, recycling and other types of recovery of material, including construction and demolition waste, shall be increased up to at least 70% (by weight) by 2020 [2]. Recycled Concrete Aggregate (RCA), derived from Concrete & Demolition waste generally consists of natural coarse aggregate and adhered mortar which makes it porous due to high mortar content, inhomogeneous and less dense [3,4]. The volume of the residual mortar in RA varies from 25% to 60% according to the size of aggregate [5]. Some researchers have reported in their studies that around 20% of cement paste is found attached to the surface of RA for particle size range from 20 to 30 mm [6, 7]. What is specific for RCA is a presence of several types of interfacial transition zone (ITZ) - between the ''old'' and ''new'' compounds, that may play a key role in the internal microstructure of a concrete (Figure 1). Therefore, it will facilitate the applications of RCA if the adhered cement mortar can be enhanced. Removing and strengthening the adhered mortar are the two main methods for enhancing the properties of RCA. On this background to improve the quality of brick recycled aggregate, this study is planned.

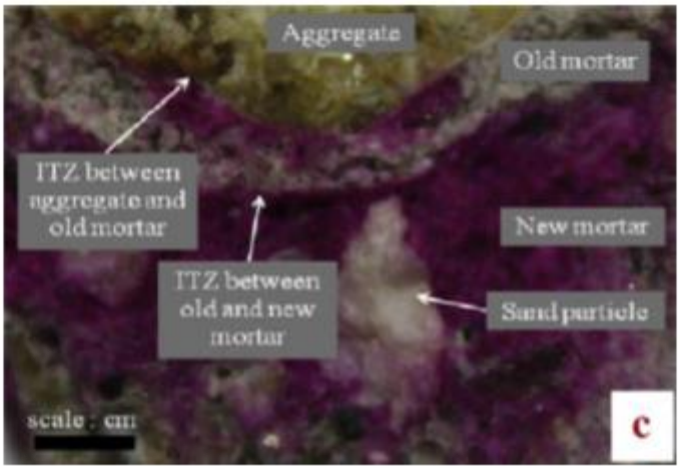

Figure 1. Sectional view of RCA [18]

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1.2 Commonly used treatment methods

There are several treatment methods to improve the quality of recycled aggregate. Depending on the nature of recycled aggregate the treatment methods differ. All these methods discuss below are commonly used for treating recycled aggregate made from stone. So using these methods for brick recycled aggregate also could be useful.

1.2.1 Mechanical treatment method

The adhered mortar can be separated as much as possible from the natural aggregate using crushing and ball – milling. It is a simple and popular treatment which has a lot of variations. However, during mechanical grinding recycled concrete aggregate could be damaged (micro – cracks by grinding).

Autogenous cleaning [2] - with this process RCAs are placed in a rotating mill drum and collide against each other while removing pieces of attached mortar. The mill drum, 30 cm in diameter and 50 cm in depth (Figure 2), was filled up to 33% with ‘‘raw’’ recycled aggregates and the rotation rate was imposed to 60 rotations for minute. After the autogenous cleaning process, aggregates were cleaned with water and subsequently dried to remove all the produced fine remainings and impurities. The results of autogenous cleaning, showed a progressive decrease of the water absorption capacity, with increasing durations from 2 to 10 or 15 min. The results highlight that after the autogenous cleaning, the amount of absorbed water was reduced by 50% and 20%, the amount of fine particles increased. Furthermore, uncleaned recycled aggregates show an attached mortar content equal of about 30% while the aggregates cleaning led to a decrease of the attached mortar up to about 15%.

Figure 2. The mill drum [2]

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Heat treatment method [8,9] - The coarse recycled concrete aggregate samples were heated at four different temperatures: 250˚C, 350˚C, 500˚C and 750˚C for a period of one hour in a conventional electric oven. The use of heat treatment method is successful in improving various physical properties including water absorption, specific gravity, porosity and freezing and thawing. However, it is recommended to use this method at temperatures between 300˚C and 350˚C because of the noticeable negative effects of higher temperatures on coarse recycled concrete aggregate characteristics. The aggregate suffers from thermal expansion followed by internal stresses due to exposure to high temperature between 400˚C and 600˚C. Whereas there is serious microcracking of the cement matrix when the material is exposed to a higher temperature range between 600˚C and 800˚C resulting in degradation, breakdown and mass loss of aggregate.

1.2.2 Pre –soaking in water (Pre-Saturation)

The results obtained in [10] verified that if recycled aggregates are immersed in water for short intervals the consistency of the fresh recycled concrete improved at the expense of an insignificant decrease in the compressive strength. This loss ranged from 11%, for the 3 min soaking period, to 13%, for 5 min pre-saturation interval.

1.2.3 Pre-soaking in acid

The hydration products of cement in hardened paste can be dissolved in acid solution. The procedure [11] is first to soak the recycled aggregate in an acidic environment at around 20˚C for 24 h and then watering with distill water to remove the acidic solvents afterward. Before concrete mixing, 24 h water soaking of recycled aggregate is stipulated. Three acidic solvents are experimented: hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) with concentration of 0.1 mole which can provide a suitable acidic environment for the aggregate to remove the old cement mortar and will not lower the aggregate quality. Experimental results show that the values of water absorption of the pre-treated RA have been significantly reduced with improved mechanical properties for the recycled aggregate concrete. Meanwhile, the alkalinity of recycled aggregate concrete, chloride and sulphate contents of recycled aggregate have not been adversely affected. In the procedure shown in [12], the coarse recycled concrete aggregates were kept immersed in HCl with a molarity of 0.5 mole for 24 h. The container was occasionally shaken to ensure a more efficient reaction of the acid in the degradation of weak mortar. After the immersion, the aggregates were watered with distilled water and drained, and then impregnated with calcium metasilicate ($CaSiO_3$) solution for 24 h. The purpose of this step was to coat the surface of coarse recycled concrete aggregate with calcium metasilicate particles to refill the pores and cracks throughout its physical surface. Simultaneously, the present calcium metasilicate particles that was used to coat the recycled concrete aggregate surface would be dissolved during mixing and are

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expected to function as a filler with the product of cement hydration for the densification of the interface structure, which improves bond strength at contact between the aggregate surface and the cement matrix.

In [9] the coarse recycled concrete aggregate was soaked in an acidic solution composed of hydrochloric acid (HCl) (37%) and acetic acid (C2H4O2) (99.7%) at a low concentration of 0.1mole for 24 h at room temperature around 20˚C. In [13] the aggregates were submerged in HCI (hydrochloric acid) solution at 0.1 molarity for 24 h at 20˚C. After then, they were submerged in distilled water in order to remove acidic solution. The second method at the same paper was that the aggregates were submerged in water glass (Na2O·nSiO2 sodium silicate) for 30 min. After then, they were held in suspension for 10 min to provide leakage of excess water glass from the aggregates which were taken out of the solution and then dried in oven for 1 h by preventing bonding the aggregate particles. The use of HCl concentration at 0.1 molarity has the potential to remove the loose adhered mortar and certain loose substances on recycled concrete aggregate surface as demonstrated by the SEM analysis. The properties of recycled concrete aggregate such as density and water absorption have improved after HCl treatment as compared to untreated recycled concrete aggregate. Water glass treated aggregates considerably reduce the water absorption providing the minimal value compared to the other treatments applied. The SEM analysis has demonstrated that new ITZs in SCCs containing treated recycled concrete aggregate provide less porous, more dense and connected microstructure [14]. The study [14] include assessing the influence of different acid concentrations and durations of treatment on the physical and mechanical properties of coarse RCA, as well as effects of using treated aggregate on concrete's compressive strength. Three types of acid molarity, 0.1, 0.5 and 0.8 mole, of HCl were used in this study. The aggregates were immersed in acidic solvents for 1, 3, and 7 days. The use of low concentration HCl has the potential to remove the loose adhered mortar on RCA surface. The results show a linear correlation between the amount of mortar loss with the increase of the molarity of acid. However, the immersion time of RCA with acid did not have significant influence on the amount of mortar lost. The results indicate that incorporating concrete mix with treated RCA at a proportion of up to 45% achieves the optimum strength in the mix design of concrete compressive strength

Properties of recycled aggregate	Sizes of aggregate	Before pre soaking treatment	After pre-soaking treatment		
			HCl	H_2SO_4	H_3PO_4
Water absorption (%)	20 mm	1.65	1.45	1.48	1.53
	10 mm	2.63	2.31	2.37	2.41
Chloride content (%)	20 mm	0.0016	0.0025	0.0001	0.0001
	10 mm	0.0012	0.0056	0.0001	0.0001
Sulphate content (%)	20 mm	0.0025	0.0076	0.1090	0.0110
	10 mm	0.0025	0.0082	0.1040	0.0109
Value of pH	20 mm	10.46	9.07	8.95	8.55
	10 mm	11.63	9.34	9.35	9.33

Table 1: Properties of recycled aggregate before and after pre-soaking treatments [11]

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1.2.4 Two-stage mixing approach

In order to improve the quality of recycled aggregate concrete, a mixing method: two stage mixing approach (TSMA) was developed by Tam et al. [15], which divides the mixing process into two parts and proportionally splits the required water into two parts which are added after mixing one part with fine and coarse aggregate and cement; while the normal mixing approach only puts all the ingredients of concrete and mix them. In TSMA, during the first stage of mixing, the use of half of the required water for mixing leads to the formation of a thin layer of cement slurry on the surface of RCA which permeates into the porous old cement mortar, filling up the old cracks and voids. In the second stage of mixing, the remaining water is added to complete the cement hydration process. Improvement of strength can be achieved up to 21.19% for 20% of RCA under 28-day curing conditions using TSMA.

1.2.5 Three step method

The method was divided into three steps: rough crushing of the concrete, thermal treatment of the crushed concrete to separate the paste from the aggregates and chemical attack of the remaining attached paste with salicylic acid. Two variants were tested for the thermal treatment: a soundness test (ST) consisting in apply cycles of freezing (-17˚C) and heating (+60˚C) of the sample immersed in a 26% Na_2SO_4 solution, and liquid nitrogen – microwave heating cycles (LNMO). These two methods showed similar efficiency, i.e. a direct recovery rate of 84% of clean aggregates of the size class 4/20 mm (52% recovered compared to 62% of 4/20 mm aggregates initially present in the concrete). The soundness test was kept in the final method due to its easier application in the laboratory. The chemical treatment of the remaining aggregates covered by cement paste by means of salicylic acid successfully dissolved the paste, with an efficiency of around 67–69%. Only thin layers of paste remained on the 31–33% of final aggregates (size classes 0/1 and 1/4 mm). The overall efficiency of the three-step method, evaluated by comparing the amounts of recovered aggregates and natural aggregates, reached 90– 92% on quartzite and siliceous limestone aggregates, respectively

1.2.6 Self-healing method

Self healing process was achieved by immersing the recycled aggregates in water for 30 days. This period gives good chance to the unhydrated cement particles to react again with water to enhance the properties of concrete particles. The efficiency of this process to enhance the mechanical properties of hardened concrete had been documented [17].

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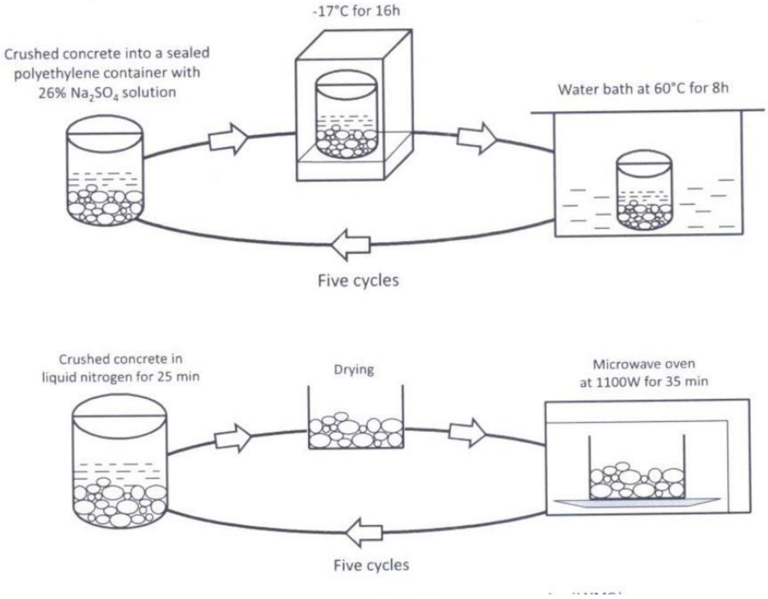

Figure 3: Three step method: soundness test and liquid nitrogen – microwave heating cycles [16]

1.2.7 Mineral admixture solution

Some approaches like surface coating of recycled concrete aggregate with low w/c ratio paste or by impregnating it in silica fume solution or in other mineral admixture solution also helped in healing the pores or cracks present in RCA. Impregnation of the RCA with a solution of silica fume or any other mineral admixtures helps in penetrating the silica fume particles into the cracked and loose layer of this aggregate. Due to the filling effect of silica fume, it helps in improving the ITZ during the hardening process of concrete. Furthermore, the pozzolanic reaction of silica fume with Ca(OH)2 produces secondary C–S–H gel which in turn strengthened the weak structure of the RA to form an improved zone, penetrates from the RCA through the residues of the old cement paste into the new cement matrix. Silica fume treatment at early age has a stronger effect on filling than the pozzolanic reaction, which is known to develop more slowly. The similar effect is also shown by other pozzolanic substances like GGBS, fly ash etc. This ultimately helps in improving the performance of recycled aggregate concrete regarding strength and durability [13,17-23].

1.2.8 Polymer emulsion

Silicon based additives are emulsions composed of alkylalkoxysilanes (silane), poly diorganosiloxanes (siloxane) or both of them. The treatment process can be simple impregnation (the aggregate samples were impregnated by each polymer solution for 5 min, then dried at room temperature maintained at 20˚C and about 50% relative

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humidity (RH) for 24 h, then in ventilated oven at a temperature of 50±5˚C until the difference in mass during 24h is less than 0.1%) and double impregnation and heat treatment process: the aggregate samples were impregnated by soluble sodium silicate for 3 min followed by drying for 20 h at room temperature maintained at 20˚C and 50% relative humidity (RH), then the samples were again impregnated in each polymer solution (different siloxane/silane emulsions) for 5 min followed by drying during 24 h in a room maintained at 20˚C and in ventilated oven at a temperature of 50±5˚C until the difference in mass is less than 0.1%. The results showed that these kinds of treatment emphasize the formation of polymeric film in pore network. This film allows the significant reduction of water absorption capacity. The film formed is efficient and resistant in alkali environment. Few amount of poly merbased treatment is necessary to achieve the water repellent performance [24].

1.2.9 Calcium carbonate biodeposition

The method of bio deposition of calcium carbonate (Figure 5) conducted through the participation of Sporosarcina pasteurii bacteria, should constitute an alternative method. Bio deposition, as opposed to other concepts, is a natural method and, in principle, makes less severe with the environment, because all the components used for cultivating the substrates as well as and the strain itself, naturally occur in the environment. The bio deposition concept is based on the ability of bacteria to precipitate calcium carbonate on the outer surface of the cell wall, due to occurrence of negative zeta potential of adequate strength. Bio deposition process has been described as follows:

Sp.cell + Ca2+ → Sp.cell-Ca2+

CO(NH2)2 → 2NH4 + + CO32-

Sp.cell-Ca2+ + CO32- → Sp.cell – CaCO3

S. pasteurii cell (Sp. cell) can attract Ca ions (Ca2+), which react with carbonate ions CaCO3 2- originating from urea (CO(NH2)2) hydrolysis. Simultaneously, ammonia ions NH4 + increase pH value in surrounding medium which improves calcite precipitation efficiency. The results showed that this procedure led to reduction in the water absorption of aggregate and this was even more effective when finer fractions derived from inferior quality concrete were used [25].

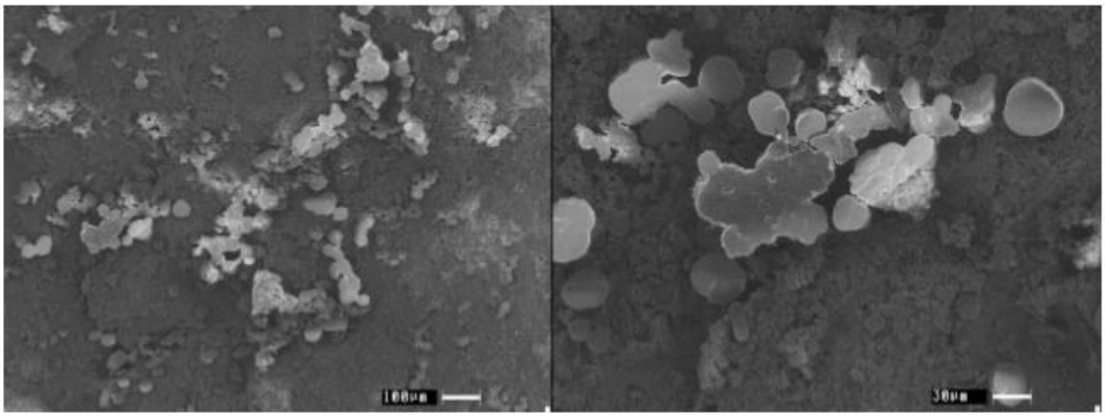

Figure 4. Scanning electron micrograph of recycled aggregate grain (w/c = 0.45,fraction 12/16 mm) after bio deposition treatment [25]

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1.2.10 Carbonation

In consideration of the constituent of the old cement mortar adhering to the surface of RCA, improving the low quality of RCA through accelerated carbonation is possible to some extent because the calcium hydroxide, which is one of the main cement hydration products in the old cement mortar adhering to the surface of RCA, can react with carbon dioxide accompanied by an increase in solid volume, which is formulated by the following reaction: Ca(OH)2 + CO2 = CaCO3 + H2O

The other hydration products, such as CSH (calcium silicate hydrate gel), also appears to be converted to calcium carbonate, water and a modified CSH gel with a lowered Ca/Si ratio or a higher degree of polymerized silica gel. For the reinforced concrete structure, natural carbonation can reduce the alkalinity of concrete leading to corrosion of steel reinforcement, and thus can limit the lifetime of reinforced concrete structures. However, the most direct consequence of carbonation is decrease in pore volume of concrete. The experimental results confirmed that the CO2 curing process can densify the mortar adhered on the RCA. After the CO2 curing process, there was a significant reduction in water absorption and porosity of the RCA. Owing to the large specific surface area, RCA with smaller particle sizes was more easily to be carbonated. The moisture content of RCA significantly influenced the carbonation percentage since the dry matrix could not provide sufficient water for the carbonation reactions and the pores in the water saturated matrix was filled with water blocking CO2 penetration. Furthermore, the carbonation process proceeded rapidly within the first 2 h but slowed down sharply after that [26-30].

1.3 Objectives

The main objectives of this study are

- To improve the quality of brick recycled aggregate by using physical treatment method.
- Evaluate the effect of individual treatment method by using H_3PO_4 acid.
- Identify the appropriate treatment method to treat brick recycled aggregate.

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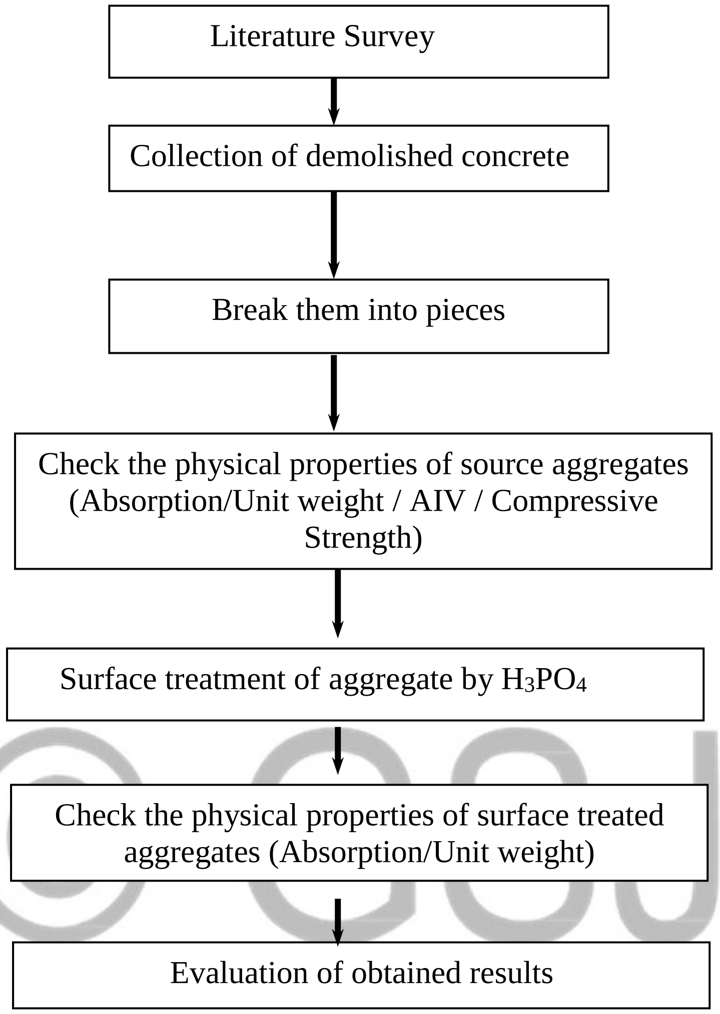
1.4 Flow diagram:

The flow diagram of the study is shown in below:



1.5 Conclusions

Various methods for enhancing the properties of recycled concrete have been developed and studied. The two common methods for improving the properties of recycled concrete aggregate are removing and strengthening the adhered mortar. Every method shows good results in aggregate enhancing and has its own characteristics, so other parameters (like use of concrete, cost, etc.) should be taken into account.

1.6 References:

ISSN 2320-9186

[1] European directive 2008/98/CE. Directive 2008/98/CE of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Offic J Eur Union.

[2] Pepe, M., Filho, R., Koenders, E., Martinelli, E.: Alternative processing procedures for recycled aggregates in structural concrete, *Construction and Building Materials*, **2014**., vol 69, pp. 124–32.

[3] Hansen, TC.: Recycled aggregate and recycled aggregate concrete, second state of the- art report, developments from 1945–1985, *Materials and Structures*, **1986,** vol.19, pp. 201 – 246.

[4] Katz, A.: Properties of concrete made with recycled aggregate from partially hydrated old concrete, *Cement and Concrete Research*, **2003**,vol.33(5), pp.703–11.

[5] Corinaldesi, V.: Mechanical and elastic behaviour of concretes made of recycled concrete coarse aggregates, *Construction and Building Materials*, **2010**, vol24(9), pp.1616–20.

[6] Nassar, R,. Soroushian, P.: Strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement, *Construction and Building Materials*, **2012**., vol 29, pp. 368–77.

[7] Rahal, K.: Mechanical properties of concrete with recycled coarse aggregate, Building Environment, **2007**,vol 42(1), pp.407–15.

[8] Fathifazl, G., Abbas, A., Razaqpur, A., Isgor, O., Fournier, B., Foo, S.: New mixture proportioning method for concrete made with coarse recycled concrete aggregate, *Journal for Materials and Civil Engineering*, **2009**, vol 21(10), pp. 601–11.

[9] Al-Bayati, H., Das, P.K., Tighe, S., Baaj, H.: Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate, *Construction and Building Materials*, **2016**, vol. 112, pp. 284–298.

[10] García-González, J., Rodríguez-Robles, D., Juan-Valdés, A., Morán-del Pozo, J., Guerra-Romero, M.I.: Pre-Saturation Technique of the Recycled Aggregates: Solution to the Water Absorption Drawback in the Recycled Concrete Manufacture, *Materials*, **2014**, vol *7*, pp. 6224-6236, doi:10.3390/ma7096224.

[11] Tam, V., Tam, C.M., Le, K.N.: Removal of cement mortar remains from recycled aggregate using pre-soaking approaches, *Resources, Conservation and Recycling*, **2007**, vol 50, pp. 82–101.

[12] Ismail, S., Ramli, M.: Mechanical strength and drying shrinkage properties of concrete containing treated coarse recycled concrete aggregates, *Construction and Building Materials*, **2014**, vol. 68, pp. 726–39.

ISSN 2320-9186

[13] Guneyisi, E., Gesogˇlu, M., Algın, Z., Yazıcı H.: Effect of surface treatment methods on the properties of self-compacting concrete with recycled aggregates, *Construction and Building Materials*, **2014**, vol. 64, pp. 172–83.

[14] Ismail, S., Ramli, M.: Engineering properties of treated recycled concrete aggregate (RCA) for structural applications, *Construction and Building Materials*, **2013**, vol. 44, pp. 464–76.

[15] Tam, V., Tam, C.M., Wang, J.: Optimization on proportion for recycled aggregate in concrete using two-stage mixing approach, *Construction and Building Materials*, **2007**, vol. 21, pp. 1928–39.

[16] Gao, X.X., Cyr, M., Multon, S., Sellier, A.: A three-step method for the recovery of aggregates from concrete, *Construction and Building Materials*, **2013**, vol. 45, pp. 262–69.

[17] Elhakam, A.A., Mohamed, A.E., Awad, E.: Influence of self-healing, mixing method and adding silica fume on mechanical properties of recycled aggregates concrete, *Construction and Building Materials*, **2012**, vol. 35, pp. 421–27.

[18] Behera,M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R., Maiti, S.: Recycled aggregate from C&D waste & its use in concrete –A breakthrough towards sustainability in construction sector: A review, *Construction and Building Materials*, **2014**, vol. 68, pp. 501–16.

[19] Kong, D., Lei, T., Zheng, J., Maa, C., Jiang, J., Jiang, J.: Effect and mechanism of surface-coating pozzalanics materials around aggregate on properties and ITZ microstructure of recycled aggregate concrete, *Construction and Building Materials*, **2010**, vol. 24, pp. 701–08.

[20] Li, J., Xiao, H., Zhou, Y.: Influence of coating recycled aggregate surface with pozzolanic powder on properties of recycled aggregate concrete, *Construction and Building Materials*, **2009**, vol. 23, pp. 1287–91.

[21] Younis,K., Pilakoutas K.: Strength prediction model and methods for improving recycled aggregate concrete, *Construction and Building Materials*, **2013**, vol. 49, pp. 688–701.

[22] Wang, H., Wang, J., Sun, X., Jin W.: Improving performance of recycled aggregate concrete with superfine pozzolanic powders, *J. Cent. South Univ.*, **2013**, vol. 20, pp. 3715−22.

[23] Li, J., Xiao, H., Gong, J.: Granular Effect of Fly Ash Repairs Damage of Recycled Coarse Aggregate, *J. Shanghai Jiaotong Univ. (Sci.)*, **2008**, vol. 13(2), pp. 177–180.

[24] Spaeth, V., Tegguer, A.Dj.: Improvement of recycled concrete aggregate properties by polymer treatments, *International Journal of Sustainable Built Environment*, **2013**, vol.2, pp. 143–52.

ISSN 2320-9186
[25] Grabiec, A., Klama,J., Zawal, D., Krupa, D.: Modification of recycled concrete aggregate by calcium carbonate biodeposition, *Construction and Building Materials*, **2012**, vol. 34, pp. 145–50.

[26] Silva,R.V., Neves, R., de Brito, J., Dhir, R.K.: Carbonation behaviour of recycled aggregate concrete, *Cement & Concrete Composites*, **2015**, vol. 62, pp. 22–32.

[27] Zhan, B., Poon, C.S., Liu, Q., Kou, S., Shi, C.: Experimental study on CO2 curing for enhancement of recycled aggregate properties, *Construction and Building Materials*, **2014**, vol. 67, pp. 3–7.

[28] Xuan, D., Zhan, B., Poon, C.S.: Assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates, *Cement and Concrete Composites*, **2016**, vol. 65, pp. 67-74.

[29] Kou, S., Zhan, B., Poon, C.S.: Use of a CO2 curing step to improve the properties of concrete prepared with recycled aggregates, *Cement and Concrete Composites*, **2014**, vol. 45, pp. 22-28.

[30] Zhang,J., Shi,C., Li, Y., Pan, X., Poon, C.S., Xie, Z.: Influence of carbonated recycled concrete aggregate on properties of cement mortar, *Construction and Building Materials*, **2015**, vol. 98, pp. 1-7

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Chapter 2
Literature Review: Recycled Aggregate Concrete and its properties

2.1 RECYCLED CONCRETE AGGREGATE

2.1.1 General

In recent years certain countries have considered the reutilization of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities. The literature review presents the current state of knowledge and examples of successful uses of alternative materials in concrete technology, and in particular the use of Recycled Concrete (RC) aggregate as a coarse aggregate fraction in nonstructural and structural concrete. Many researchers have dedicated their work to describe the properties of these kinds of aggregate, the minimum requirements for their utilization in concrete and the properties of concretes made with recycle aggregates. It also presents a review of available literature on physical, mechanical and durability properties of RC aggregates, and mechanical, durability and structural properties of RCA concrete. However, minor attention has been paid to the structural behavior recycled aggregate concrete slabs. This thesis focuses on recycling of concrete waste as an aggregate in structural concrete in flexure and punching shear.

2.1.2 Constituent Materials in Concrete

Modern concrete is a sophisticated composited material which is constantly undergoing improvements and modifications. However, the basic constituents of conventional Ordinary Portland Cement (OPC) concrete such as fine and coarse aggregate, cement and water remain same. There are other materials such as chemical admixtures including superplasticisers, water reducers and air-entrainers that can be used to modify the charecteristics of OPC concrete. There is also an increase in the use of pozzolanic materials like fly ash, metakoline, granulated blast-furnace slag and silica fume. Over the last few decades, the uses of various alternative fine and coarse aggregates in the production of concrete have been investigated, including the use of RC aggregates.

2.1.3 Concrete Waste and Concrete Recycling

Concrete waste, which falls into the Construction and Demolition (C & D) waste category, is generated when creation of new, or modifications to existing urban infrastructure such as transport systems, communication networks and buildings are made. With the increased urbanisation of the worlds growing population there is also an

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increase in C & D waste generation. This prompts a realisation that built-in urban infrastructure along with C & D waste contains a large stock of materials, and that efficient management of concrete, steel, bricks, their waste, is necessary to sustain the future growth and increased demand for construction materials. In developed countries there is an increased societal demand on government agencies and industries to search for alternative materials and reduce waste to achieve ecologically sustainable development, resulted in an increased rate of recycling, and reuse of concrete waste. It seems that there is a common understanding and consensus that depletion of natural resources is a real threat, landfill space is becoming scarce, and the waste disposal causes significant environmental and social impact. There is also a general consensus that recycled C & D waste including RC aggregates can be used for construction purposes. The main source of raw material for recycling of concrete waste comes from demolition of concrete structures. The quality and purity of the raw material affect the quality of recycling products and ultimately commercial acceptance of concrete recycling products. The process of manufacturing concrete recycling products is relatively simple. To produce high quality concrete recycling products that satisfy commercial and technical specifications, it is crucial to segregate concrete waste at source eliminating any low and high density and friable contaminants. Recycling process and plant setup depends on desired grading and quality of the final product. In situations when crushed concrete waste is to be used as fill material, the use of a mobile crusher is usually sufficient. However, when crushed concrete waste is used to produce RC aggregates for road sub-base or as a concrete aggregate, a proper plant with at least two crushers, vibrating screens, magnets and conveyor belts have to be established. Once concrete rubble has been deposited at a recycling plant it is then broken by a pulveriser mounted on a excavator. Pieces of concrete waste broken to a suitable size are then crushed in a primary jaw crusher and then passed via conveyor belts into a cone crusher. The crushed material is passed through a set of vibrating screens and sieved on the way to a stock pile. After each crusher, the rotating magnets remove remains of steel reinforcement where as pickers manually remove other contaminants.

2.1.4 Properties Of Recycled Aggregate

Raw materials for production of the natural aggregates and RC aggregate contribute to some differences and variations of aggregate properties. Recycled concrete aggregate consists of natural aggregate coated with cement paste residue, pieces of natural aggregate, or just cement paste and some impurities. Relative amounts of these components, as well as grading, affect aggregate properties and classify the aggregate as suitable for production of concrete. There is a general consensus that the amount of

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cement paste has a significant influence on the quality, and the physical, mechanical and chemical properties of the aggregates and as such has potential influence on the properties of RC concrete.

2.1.4.1 Physical

The various physical properties of recycled aggregate are presented below.

2.1.4.1.1 Adhered paste and mortar

In recycled aggregates, the adhered mortar and paste are always present. The main factors which influence the quantity of adhered mortar in recycled aggregate crushed are water/cement ratio, original concrete strength and aggregate size. The grinding process has also influence on the amount of adhered mortar and the quality of recycled aggregates. BCSJ (1978) indicated that approximately 20% of cement mortar was attached to 20 to 30mm size aggregate particles, while up to 0.3mm size filler fractions of recycled fine aggregate contain 45 to 65% of old cement mortar. Hasaba (1981) stated that the quantity of adhered mortar in the original aggregate is proportional to the strength of the original concrete. The recycled aggregates which originated from the low strength concrete had less adhered mortar and the high strength concrete had more adhered mortar, when the crushed concrete was grinded with the same type of the machine and the same energy applied. Hansen and Narud (1983) stated that the water/cement ratio of the original concrete influences the amount of adhered mortar to original aggregates and the quantity of adhered mortar increases with the decrease of the size of the aggregate, when the concrete is crushed with the same grinding machine and the same power.

2.1.4.1.2 Shape and surface texture

In particular, the shape of the coarse aggregate is an important characteristic that can affect the mechanical properties of concrete. The shape and surface texture of the coarse aggregate influence the strength of concrete by providing an adequate surface area for bonding with the paste or creating unfavorable high internal stresses. The surface texture of aggregate contributes significantly to the development of a physical bond between aggregate and cement paste. Tasong et al. (1998) identified that the rough surface texture of the aggregate as contributing to a better bonding between aggregate and cement paste in concrete.

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2.1.4.1.3 Bulk density

The bulk density or unit weight of an aggregate gives valuable information regarding the shape and grading of the aggregates. For a given specific gravity the angular aggregates shows a lower bulk density. Bulk density of aggregates is of interest when dealt with light weight aggregates and heavy weight aggregates. In general, the saturated surface density of recycled aggregates is lower than that of natural aggregates, due to the low density of the mortar that is adhered to the original aggregate. It depends on the strength of original concrete and size of original aggregates. Hansen et al. (1983) concluded that the recycled aggregate which obtained from a concrete of higher strength had higher density and also the saturated surface density depends on the kind of crushing machine employed and the energy used. Hansen (1985) concluded that the density changes with the size of the aggregate and the amount of adhered mortar to the aggregate, when the concrete is grinded with the same type of the machine and the same energy applied. The density of recycled aggregate concrete reduces with smaller size of aggregates. The density decreases with the higher amount of adhered mortar to the aggregate. Gonzalez et al. (2008) concluded that recycled aggregate concrete shows less dense than conventional concrete. Furthermore it is concluded that by addition of silica fume to the recycled aggregate concrete and conventional concrete, reduces the density. Tam et al. (2008) concluded that as cement mortar density of around 1.0 to 1.6mg/cum is less than that of natural aggregate particles at around 2.6mg/cum, the lower the density of demolished concrete samples, the higher the cement mortar content will be. The demolished concrete density ranges between 2269kg/cum and 2432kg/cum.

2.1.4.1.4 Specific gravity

Hansen et al. (1983) investigated that the specific gravity decreases from 4.5 to 7.6% when compared with specific gravity of natural aggregate. Topcu et al. (2004) investigated that the specific gravity of Waste Concrete Aggregates (WCA) was lower than normal crushed aggregates. The reason for this was thought to be the fact that there was a certain proportion of mortar over these aggregates. Prasad et al. (2007) noted that the specific gravity of demolished concrete aggregates is lower than that of natural aggregate. The average specific gravity of aggregate usually varies from 2.6 to 2.8.

2.1.4.1.5. Water absorption

Hansen et al. (1983) found that the water absorption is 8.7% for the material that is 4–8mm in size, 3.7% for the material that is 16-32mm in size and the absorption capacity of

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recycled aggregate increased with a higher amount of adhered mortar. Bairagi et al. (1993) concluded that very rapid rates of absorption are observed for recycle aggregate. Nearly 75% of the 24hour absorption capacity was attained in the first 30 minutes of the soaking period. Ravindraraja (2000) demonstrated that the average value of water absorption in recycled aggregate was 6.35%, where as in natural aggregate it was 0.9%. The absorption capacity of recycled aggregates depends on the quality and quantity of adhered mortar. There was dependence between density and water absorption capacity. Recycle aggregates with adhered motor have lower density and higher water absorption capacity. Gomez (2002) showed that the porosity increases considerably when natural aggregate is replaced by recycled coarse aggregate. Topcu et al. (2004) investigated that the water absorption ratio was found to be much higher compared with that of normal crushed aggregates. This was attributable to mortar over these aggregates. Gonzalez et al. (2008) concluded that recycled aggregate concrete shows more water absorption than conventional concrete. Furthermore it is concluded that by addition of silica fume to the recycled aggregate concrete and conventional concrete increases the water absorption. Gao et al. (2008) found that the traditional testing approach for water absorption cannot give accurate results for recycled aggregate, based upon which, errors in concrete mix designs may result. Patches of cement pastes attached to the surface of recycled aggregate may affect water absorption in a manner different to conventional aggregate. Because of this, the standard duration of 24hour of saturation is not suitable for recycled aggregate. In order to affect by the amount of cement paste sticking on the aggregate, it varies from the site to site after crushing from which the recycled aggregate was generated. In order to obtain the water absorption rates and corresponding soaking time, real-time assessment of water absorption is proposed to provide values of water absorption at different time intervals. Further, the proposed method can avoid the removal of cement paste during the soaking and drying process of recycled aggregate sample. This approach is simple and more accurate in measuring the genuine water absorption rate of recycled aggregate. This method has been tested and proven to be a good alternative for measuring water absorption of recycled aggregate. Chakhradhara rao et al. (2011) observed that The volume of voids and water absorption of recycled aggregate concrete are 2.61 and 1.82% higher than those of normal concrete due to the high absorption capacity of old mortar adhered to recycled aggregates.

2.1.4.2 Mechanical

The various mechanical properties of recycled aggregate are as follows.

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2.1.4.2.1. Abrasion

With respect to recycled aggregates the value of Los-Angles abrasion changes depending on the strength of the original concrete, the amount of adhered mortar and the original aggregate quality. Hansen et al. (1983) found that the Los-Angels abrasion loss value is 22.4% for aggregates sized 16-32mm and 41.4% for aggregates sized 4-8mm which were produced from high strength original concrete.

2.1.4.3. Durability properties

The various durability properties of recycled aggregate are as follows.

2.1.4.3.1. Sulphate soundness

The Sulphate soundness guarantees the aggregates resistance to freezing and thawing cycles. The percentage loss of weight of recycled aggregates exposed to sulphates solution depends to a great extent on the composition of the tested aggregates, as well as the type of original concrete and the method of crushing. BCSJ (1978) verified that the loss of weight after five cycles changed from 18.4 to 58.9% with respect to coarse recycled aggregates and by using the fine recycled aggregates values were from to 7.4 to 20.8%. Fergus (1981) found that the loss of sulphate weight to be between 0.9 to 2.0% with respect to coarse recycled aggregates, and 6.8 to 8.88% with regard to fine recycled aggregates. Kasai (1985) concluded that the sulphate soundness test is unsuitable for evaluation of the durability of recycled aggregates.

2.1.4.3.2. Chemical-mineralogical characteristics

Limbachiya et al. (2007) concluded that commercially produced coarse RCA has chemical and mineralogical characteristics suitable for use in new concrete production. And also indicate that for coarse RCA samples obtained by crushing C & D debris from different sites, there was no significant variation in these characteristics, indicating no significant effect, if adequate quality control criteria during RCA production are being adopted. X-ray diffraction analysis results indicated the presence of calcite, port-landite and minor peaks of muscovite/illite in recycled aggregates, although they were directly proportioned to their original composition. Furthermore showed that up to 30% coarse RCA (when used as direct replacement of natural gravel) has no influence on the main three oxides (SiO_2, Al_2O_3 and CaO) of concrete, but there after there is a marginal

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reduction in SiO_2, and increase in Al_2O_3 and CaO contents with increase in RCA content, reflecting the composition of the original material. Similar trends were observed in concrete produced using RCA samples obtained from three different C & D sources.

2.1.5 Recommendations

Some of the recommendations given by the RILEM and Oikonomou (2005) are discussed below. According to RILEM, for the application of the recycled aggregates in the production of concretes, besides fulfilling all the specifications that have been defined in Table 2.1.

Mandatory requirements	Type I	Type II	Type III	Test method
Min. dry particle Density Kg/cum)	1500	2000	2400	ISO 6783 & 7033
Max. Water absorption (%)	20	10	3	ISO 6783 & 7033
Max. content of foreign materials (metals, glass, soft material & Bitumen) (%)	5	1	1	Visual
Max. content of metals (%)	1	1	1	Visual
Max. Content of organic material (%)	1	0.5	0.5	NEN 5933
Max. content of defiler (<0.063mm) (%)	3	2	2	PrEN 933-1
Max. content of sand (<4mm) (%)	5	5	5	PrEN 933-1
Max. content of sulphate (%)	1	1	1	BS 812- Part 118

Table: 2.1 Specifications of RCA as per RILEM

2.1.6 Mix design

Bairagi et al. (1990) identified the most suitable method of mix design for recycled coarse aggregate, amongst the available conventional methods of mix design. An influencing parameter was identified and an empirical relation was suggested to modify the influencing parameter. Mix design parameters thus obtained, enable recycled coarse aggregate concrete to attain the desired and designed target strength without attempting any trail mixes. The suggested modified procedure, however, demands 10% more cement which was considered quiet reasonable and acceptable in view of the inferior quality of recycled aggregate. Of the four methods (IS code method, ACI method, RRL method and surface angularity index method) of mix design ACI method had been found to be more appropriate for the design of recycle aggregate concrete.

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Tests	Limits
Specific gravity, kg/cum, min	2.2
Water absorption, %, m/m, max	3
Foreign ingredients, %, m/m, max	1
Organic ingredients, %, m/m, max	0.5
Sulphate ingredients, %, m/m, max (as SO_3)	1
Amount of sand, %, m/m, max (<4 mm)	5
Amount of filler, %, m/m, max (<0.063 mm)	2
Resistance to abrasion/degradation by the use of L.A. machine, %, max	40
Soft granules, %, max	3
Soundness, loss, %, max	10
Sand equivalent, %, min	80

Table 2.2 Basic tests and limits of RCA (Oikonomou (2005))

2.1.7 Properties of Recycled Aggregate Concrete

Recycled aggregates used in concrete production have less density and more absorption capacity than conventional aggregates due to the adhered mortar. Consequently, in concrete made with recycled aggregates two interfacial transition zones are present: the existing interface between the original aggregate and the adhered mortar, and the new interface between the old and new mortar. The existing interface cannot be improved, and it is very important to achieve an effective new interface.

2.1.7.1 Properties of fresh concrete

The various properties of fresh concrete are discussed below.

2.1.7.1.1 Water demand and workability

In accordance with Hansen et al. (1983) and Ravindrarajah et al. (1985), recycled aggregate concrete made with recycled coarse aggregates and natural sand needs 5% more water than conventional concrete in order to obtain the same workability. If the sand

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was also recycled, 15% more amount of water was necessary to obtain the same workability. Hansen (1986) concluded that the recycled aggregates in concrete production must be used in a condition of near saturation point to decrease the absorption capacity. The recycled aggregate concrete be dosed, mixed, transported, placed, and compacted in the same way as conventional concrete. Malhothra (1978) and Kumar Roy et al. (1988) concluded that the workability of recycled aggregate concrete can be maintained on par with the conventional concrete if the additional water demand of 5 to 8% required by a recycled aggregate concrete is approximately met with. Bairagi et al. (1993) concluded that the workability of recycled aggregate concrete had been affected, but from a practical point of view all mixes have shown the same degree of workability. Loss of workability in the first 10 minutes was progressively greater with increase in replacement ratio. Topcu et al. (1995) concluded that the workability of waste concrete aggregate is low and could be explained the higher water absorption of waste concrete aggregate. Topcu et al. (1997) concluded that the slump values decreases where by waste concrete aggregate increases. The slump values are 75mm for waste concrete aggregate concrete and 100mm for normal aggregate concrete. The most important reason for this is that waste concrete aggregate has cement paste debris over that. The water in the mixture decreases because of the cement paste debris and also the workability of the mixture decreases. Poon et al. (2004) concluded that the moisture states of the aggregates affected the change of slump of the fresh concrete. Oven dried aggregates led to a higher slump and quicker slump loss, while saturated surface dry and air dried aggregates had normal initial slumps and slump losses. The initial slump of concrete was strongly dependent on the initial free water content of the concrete mixes. Topcu et al. (2004) investigated that the recycling waste concrete aggregates in concrete production raises the problem of workability. In particular, concrete with more than 50% waste concrete aggregates experiences more workability problem. Tu et al. (2006) demonstrated that the recycled aggregates are not suitable for use in the production of High Performance Concrete (HPC) due to their relatively high absorption capacity, unstable properties and weaker strength. Such inadequacies can be overcome through carefully examining the characteristics of recycled aggregates and then adopting proper mixing procedure. Recycled aggregates from demolished construction wastes were examined and the Densified Mixure Design Algorithm (DMDA) was applied in the design of HPC. Results showed that HPC specimens containing recycled aggregates can be designed to have a slump more than 180 mm and a slump flow larger than 550 mm. However, HPC specimens with high amount of recycled aggregates and cement added loose their high-flowing and self consolidating charecteristics after 1 hour due to their greater water absorption.

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2.1.7.1.2 W/C Ratio

Tavakoli et al. (1996) demonstrated that concrete made with 100% recycled aggregate with lower W/C ratio than the conventional concrete can have a larger compressive strength. When the W/C ratio is the same the compressive strength of concrete made with 100% recycled aggregate was lower.

2.1.7.1.3 Cement quantity

In accordance with Hansen (1985) and other researches in order to achieve the same compressive strength as in conventional concrete it is necessary to use more cement (5-9%) in concrete made with 100% recycled aggregates. The values depend on the quality of aggregate. When recycled fine aggregates are also used 15-20% more cement could be necessary.

2.1.7.1.4 Density and air content

Hansen et al. (1983) concluded that fresh concrete made with 100% recycled aggregates have higher and more varied natural contents than conventional fresh concrete. Hansen (1985) concluded that the natural air content of recycled aggregate concrete may be slightly higher than that of control concretes made with conventional concrete. But it is certainly possible to produce recycled aggregate concrete in the laboratory with no significant increase in air content compared with control mix. Topcu et al. (1997) concluded that the unit weight of waste concrete aggregate is 2235 kg/cum and the unit weight of normal concrete is 2370 kg/cum. This decline is directly connected with the fact that the unit weight of the waste concrete aggregate concrete is lower than the normal aggregate concrete. The ultrasound velocity is 92- 93 ・ s for waste concrete aggregate concrete and 69-70 ・ s for normal concrete, and it shows that the air voids become wider in the concrete and the strength of concrete decreases.

2.1.7.1.5 New interfacial transition zone

In conventional concrete the unique interfacial transition zone is presented between the mortar paste and the aggregates. Concrete made with recycled aggregate have an additional Interfacial Transition Zone (ITZ) between the old adhered mortar to the original aggregate and the new mortar. These zones have to be considered when the concretes permeability and strength are studied. Otsuki et al. (2003) concluded that the quality of recycled aggregate, in terms of adhesive mortar strength, affects the strength of

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recycled aggregate concrete when the water-binder ratio is low, however, the quality of recycled aggregate concrete does not affect the strength of recycled aggregate concrete when the water-binder ratio is high. In case of a high water-binder ratio concrete, where the old ITZ is stronger than the new ITZ, the strength of recycled aggregate concrete was equal to that of normal aggregate concrete. On the other hand, in case of a lower water-binder ratio, where the old ITZ is weaker than the new ITZ, the strength of the recycled aggregate concrete is lower than that of normal aggregate concrete. Tokyay et al. (2004) observed that ITZ becomes critical for larger size of aggregates and lower w/c ratio mortar matrices. The negative effect of smooth surface texture of the aggregate and the larger difference between aggregate and matrix moduli of elasticity on the properties of ITZ was of paramount importance for the low w/c ratio composites. The effect of reduced bond properties of ITZ relative to its matrix was reflected in the lower critical stress levels for the low w/c ratio composites with larger aggregates. Shui et al. (2004) observed that the high-performance concrete and normal strength concrete recycled aggregates induced different interfacial transition zone microstructures in the recycled aggregate concrete. A relatively dense interfacial zone was present in high-performance recycled aggregate concrete where as a loose and porous product layer filled the normal-strength concrete interfacial zone. The interfacial transition zone microstructure in concrete with recycled aggregates appeared to be an important factor in governing strength development of the recycled aggregate concrete. It is expected that the mechanical properties of recycled aggregate concrete can be improved by modifying the surface properties and the pore structure of the recycled aggregates. Nagataki et al. (2004) evaluated that the complex nature of recycled concrete aggregates are susceptible to damage due to recycling. The laboratory produced recycled concrete aggregates were investigated using fluorescent microscopy and image analysis. Contrary to common opinion, micro-structural studies showed that adhered mortar is not always the primary parameter determining the quality of the recycled coarse aggregate. Sandstone coarse aggregate originally had defects in the form of voids and cracks. Further processing of the recycled coarse aggregate changed the micro-structural profile of the material and enhanced their properties. Akcaoglu et al. (2004) demonstrated that with larger aggregates, low w/c ratio matrices result in more critical ITZs with a more condensed micro crack in a narrower region. This indicates that the adverse effect of the rigid aggregate becomes more pronounced with increased matrix quality and aggregate size. The role of ITZ and matrix on the damage process depends on the w/c ratio of the mixture. In high w/c mixtures, ITZ effect is more pronounced up to the onset of crack propagation, whereas it is important at rapid crack propagation in low w/c mixtures. Katz (2004) summarised that scanning electron microscopy of recycled aggregates derived from the crushing of old concrete showed extensive cracking of the old cement paste that remained adhered to the natural

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aggregate. In addition, contamination of the surface of the crushed concrete by small particles that were loosely connected to the aggregate were observed. Two treatments were evaluated, with the purpose of improving the surface properties of the recycled aggregates: one is impregnation of the recycled aggregate with a 10% by weight silica fume solution; and the other is ultrasonic cleaning of the recycled aggregate to improve loose particles from the surface. The silica fume treatment resulted in an increase of 23 to 33% and 15% in the compressive strength at ages 7 and 28 days, respectively. Ultrasonic treatment yielded a moderate increase of 7%, with no clear difference between early and late ages. It appears that silica fume impregnation improves both the interfacial transition zone between the recycled aggregates and the new cement matrix, and the mechanical properties of the recycled aggregate. As a result, early strength of new concrete increases significantly when the disparity between the properties of recycled aggregate and new cement matrix is relatively small and the filler effect of the silica fume is dominant. At a later age, after the cement matrix has strengthened, these effects are weaker, leading to a lesser influence on the strength. Cracking of the old cement matrix seems to have a strong influence on the properties of the recycled aggregate. Tam et al. (2005) concluded that the two-stage mixing approach gives way for the cement slurry to gel up the recycled aggregate, providing a stronger ITZ by filling up the cracks an pores with in recycled aggregate.

2.1.8 Mechanical Properties of Recycled Aggregate Concrete

The various mechanical properties of recycled aggregate concrete are as follows.

2.1.8.1 Compression

The behavior of various combinations of recycled aggregate and natural aggregate in compression is as follows.

2.1.8.1.1. Behavior of recycled aggregate concrete produced with natural coarse aggregate and recycled fine aggregate

Concrete produced with recycled sand may behave differently from conventional concrete. When the entire natural sand is replaced by recycled sand part of the compressive strength is lost with respect to conventional concrete. Recycled sand reduces the freezing and thawing resistance. According to the researchers it is recommended to avoid the utilization of recycled aggregates smaller than 4 to 5mm.

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2.1.8.1.2. Behavior of recycled aggregate concrete produced with recycled coarse aggregate and recycled fine aggregate

Hansen et al.. (1983) and Soshiroda (1983) obtained the compressive strength trend loss by increasing the recycled sand quantity in concrete. The recycled concrete losses half of its compressive strength when the entire natural sand is replaced with recycled sand. More over when the recycled sand is smaller than 2mm more loss of strength was produced. Furthermore, this recycled sand also had a tendency to diminish frost resistance. It was not recommended to use any recycled aggregate smaller than 2mm.

2.1.8.1.3. Behavior of recycled aggregate concrete produced with recycled coarse aggregate and natural sand

Nixon (1978) concluded that the compressive strength of concrete made with 100% of recycled aggregate was 20% lesser than the conventional concrete. Hansen et al. (1983) concluded that, not only the w/c ratio influences on compressive strength of concrete made with 100% of recycled aggregate, but the compressive strength of the recycled aggregate concrete also depends on the strength of the original concrete. The compressive strength of recycled aggregate concrete is strongly controlled by the combination of w/c ratio of the original concrete, when other factors are essential equal. Therefore dependence exists with respect to the new old w/c ratio. When the w/c ratio of the original concrete is equal or lower than that of the recycled aggregate concrete, the resistance of the recycled concrete can be equal to or greater than the original one. However, when the w/c ratio of the original concrete is high, the original concrete strength will determine the new concrete strength. The coefficient variation of the compressive strength of a recycled aggregate does not differ too much from the established conventional concrete behaviors. However, it must be noted that in practice these results are not easily demonstrated. Since the w/c ratio is difficult to determine. Hansen (1986) concluded that any variation in concrete production or in the properties used produces a variation of strength in the resultant concrete. The employment of different qualities of recycled aggregate in concrete production brings about an increase of the coefficient variation. Bairagi et al. (1993) concluded that the average relative compressive strength varies from 98 to 94% when the replacement ratio is varied from 0.25 to 0.50. For the replacement ratio 1.0 the average relative compressive strength was 86%. Oliveira et al. (1996) studied the effects of three different moisture conditions from the recycled aggregate are compared (dry, saturated and semi-saturated) and concluded a slight decrease in the compressive strength of the concrete made from dry and saturated recycled aggregates. Salem et al. (1998) concluded that the compressive strength of

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concrete made with 100% of recycled aggregate increases by 2% from 7 to 28 days with respect to the 16% increasing conventional concrete. This could be due to either the absorption capacity of the recycled aggregate or the bad adherence of the aggregate with the cement paste. Giaccio et al. (1998) demonstrated that the type of coarse aggregate increases as strength level increases, as matrix strength is close to rock strength the probability of crack development through aggregates increases, and the mechanisms of cracking are modified compared with conventional concrete. At the same time, there is a strong relationship between interface strength and concrete failure behavior. The strength of the composite differs from the strength of the component phases due to limitations in bond strength. Adhesion and mechanical interlocking between matrix and aggregates are the main factors responsible for adherence development. Limbachiya et al. (2000) showed that 30% coarse recycled concrete aggregate concrete had no effect on the ceiling strength of concrete, but thereafter this reduces with increase in recycled concrete aggregate content. A method had been established to take account of the effects of recycled concrete aggregate on compressive strength, requiring a simple adjustment to the water/cement ratio. Otsuki et al. (2003) concluded that the improvements in strength of recycled aggregate concrete can be achieved by using the double mixing method in the case of higher water binder ratio concrete. Katz (2003) concluded that the properties of the recycled aggregates crushed at different ages were quiet similar. Concrete made with 100% recycled aggregates was weaker than concrete made with natural aggregates at the same w/c ratio. When the new concrete was made from the same type of OPC and the same w/c ratio as the old concrete, the strength reduction was up to 25%, regardless of the crushing age of the old concrete. With white cement, the reduction was 30 to 40%, depending on the crushing age of the old concrete (the white cement provides with 20% higher compressive strength than the OPC concrete at the same w/c ratio prepared with natural aggregate). The properties of recycled White Pozzalona Cement (WPC) concrete made with recycled aggregate at age 3 days significantly better than those of concretes made with aggregate crushed at age 1 or 28 days. Opposing trends were seen recycled OPC concrete in which the new cement matrix was weaker than that of the WPC concrete at the same w/c ratio. Two opposite mechanisms seem to affect the properties of the new concrete one is the physical properties of the old concrete and the other is the presence of un- hydrated cement in the recycled aggregate. These effects are prominent when the new cement matrix is significantly stronger than that the one in the old concrete. In such concrete, the combination of strength and cementing capacity of the recycled aggregates crushed at 3 days provides better strength over crushing ages of 1 or 28 days. In a weaker new cement matrix, this effect is reversed and the new concrete made from recycled aggregates crushed at 3 days was slightly weaker than concrete made from aggregates crushed at 1 or 28 days. Poon et al. (2004) concluded that for the concrete mixtures

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prepared with the incorporation of recycled aggregates, the air dried (AD) aggregate concrete exhibited the highest compressive strength. The saturated surface dry (SSD) recycled aggregates seemed to impose the largest negative effect on the concrete strength, with might be attributed to “bleeding” of excess water in the pre-wetted aggregates in the fresh concrete. The aggregates in the AD (as received) state and contain not-more than 50% recycled aggregates should be optimum for normal strength recycled aggregate concrete production. Topcu et al. (2004) investigated that the compressive strength decreased in both control concrete and concrete with WCAs in parallel to w/c ratio. However, compressive strength decreased in proportion to low w/c ratio in concrete with WCAs. Lin et al. (2004) investigated the procedure for assessing the optimal mixture proportioning of concrete made with recycled concrete aggregates based on the orthogonal array, ANOVA, and significance test with F statistic. The proposed procedure provides a better way for understanding the real engineering behavior of recycled concrete. Shui et al. (2004) concluded that the concrete prepared with the recycled aggregate derived from high-performance concrete developed higher compressive strength than the concrete prepared with recycled normal-strength concrete aggregates at all ages. In particular, the strength of the concrete with HPC recycled aggregates reached the level of the concrete prepared with the crushed natural granite aggregates after 90 days of curing. The difference in the strength development between the concretes with high-performance concrete and normal-strength concrete recycled aggregates was due to the differences in both the strength of the coarse aggregates and the microstructural properties of the interfacial transition zones. Tam et al. (2005) concluded that the two-stage mixing approach can provide an effective method for enhancing the compressive strength and other mechanical performance of RAC and thus, the approach opens up a wider scope of RAC applications. Kheder et al. (2005) concluded that the compressive strength of RAC depends largely on the w/c ratio of the mix. It was possible to reach a compressive strength of 53.5 MPa by the use of binding mortar with strength of 52.4 MPa. The corresponding NAC strength was 55.2 MPa. Xiao et al. (2005) concluded that the compressive strengths including the prism and the cube compressive strengths of RAC generally decreases with increasing RAC contents. But the ratio of the prism compressive strength and cube compressive strength is higher than that of normal concrete. The failure mode of RAC is a shear mode under the experimental conditions. The failure process of RAC is relatively short. The inclination angle between the failure plane and the the vertical load plumb is about 63 to 79 degrees. Etxeberria et al. (2007) concluded that the concrete made with 100% of recycled coarse aggregate has 20 to 25% less compressive strength than conventional concrete at 28 days, with the same effective w/c ratio and cement quantity. Concrete made with 100% of coarse recycled aggregates requires high amount of cement to achieve a high compressive strength and consequently

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is not an economic proposition as it is not cost effective. These recycled aggregates should be used in concrete with low- medium compressive strength (20-45MPa). More over the adhered mortar in recycled aggregates is lower in strength than conventional aggregates and the new paste. Consequently the weakest point in concrete made with coarse recycled aggregates employing a cement paste of medium-high strength (45-60MPa) can be determined by the strength of the recycled aggregates or their adhered mortar. Medium compressive strength (30 to 45MPa) concrete made with 25% of recycled coarse aggregate achieves the same mechanical properties as that of conventional concrete employing the same quantity of cement and the equal effective w/c ratio. Medium compressive strength concrete made with 50% or 100% of recycled coarse aggregates needs 4 to 10% lower effective w/c ratio and 5 to 10% more cement than conventional concrete to achieve the same compressive strength at 28 days. Rahal (2007) concluded that the 28 days target compressive strength for all five mixes of RCA (20, 25, 30, 40 and 50MPa) were achieved except for the 40 and 50 MPa where the observed strength was slightly lower than the target strength. On the average, the 56 day cube strength was 5% and 3% higher than the 28 day strength for RAC and NAC, respectively. RAC and NAC showed similar trends in compressive strength development, with relatively faster strength gain in NAC up to an age of 7 days. The 28 day cube strength in RAC showed a scatter somewhat similar to that in NAC. The average coefficient of variation is 2.73% for RAC and 2.60% for NAC. This relatively small variation could be due to the limited number of sources of recycled aggregates. Eguchi et al. (2007) concluded that as the replacement ratio of recycled coarse aggregate increases the compressive strength decreases. However by estimating the decrease in quality by relative quality values and adjusting the replacement ratio, the quality required for the concrete can be ensured. Shi Cong kou et al. (2007) concluded that the compressive strength decreased as the recycled aggregate content increased. However the reduction could be adequately compensated by the use of a lower W/B ratio. At the same recycled aggregate replacement level and W/B ratio, the use of fly ash as a partial replacement of cement decreased the compressive strength Gonzalez et al. (2007) concluded that it was possible to produce a recycled aggregate concrete (with 50% of recycled concrete aggregates) with almost the same compressive strength by changing quantity of cement 6.2% higher than the one of conventional concrete. Ann et al. (2008) concluded that the compressive strength of concrete containing recycled aggregate at 7, 28, 90 and 180 days was lower than that of the control concrete specimens, but was recovered by replacing for cement in binder with 30% pulverized fuel ash (PFA) and 65% ground granulated blast furnace slag (GGBS), which were, however, less effective in increasing the tensile strength at 28 days.

Tam et al. (2008) demonstrated that there are correlations among the characteristics of the Recycled Demolished Concrete (DC) samples, and their Recycled Aggregate (RA) and

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Recycled Aggregate Concrete (RAC). It is shown that the inferior quality of DC can lower the quality of their RA and RAC. It is important to measure the characteristics of DC to provide a pre-requisite consideration for their RA and RAC applications. This can save time and cost for the production of inferior quality RA and ensure that high quality RA is produced for higher grade concrete applications. RAC design requirements can also be developed at the initial concrete demolition stage. Gonzalez et al. (2008) concluded that it was possible to produce RC (with 50% of RC aggregates and a quantity of cements 6.2% higher than the one in CC) with almost same strength as CC and with the same consistency. The compressive strength of recycled concrete with silica fume was also similar to that of conventional concrete with this admixture. However, in all cases after 28 days (following the pozzolanic reaction) the RCS displayed greater compressive strength than the CC. In other words, the addition of 8% silica fume to mixes containing recycled aggregates was found to be beneficial in terms of compressive strength. Recycled concrete (RC) and control concrete (CC), recycled concrete with silica fume (RCS) and control concrete with silica fume (CCS) showed similar trends in compressive strength development. Chakhradhara rao et al. (2011) observed that the concrete cured in air after 7 days of wet curing shows better strength than concrete cured completely under water for 28 days for all coarse aggregate replacement ratios.

2.1.8.2 Behavior of recycled aggregate concrete in tension

BCSJ (1978) and Ravindrarajah et al. (1985) demonstrated that there are no great differences in the tensile strength of recycled course and natural sand concrete with respect to conventional concrete. However if recycled sand replaces the natural sand used in the concrete employing recycled coarse aggregates then the tensile strength diminishes 20% with respect to conventional concrete. Bairagi et al. (1993) concluded that the relative split tensile strength varies from 94 to 90% when the replacement ratio is varied from 0.25 to 0.50. For the replacement ratio 1.0 the average split tensile strength was 60% less. Otsuki et al. (2003) concluded that the improvements in strength of recycled aggregate concrete can be achieved by using the double mixing method in the case of higher water binder ratio concrete. Akcaoglu et al. (2004) demonstrated that the interfacial bond was observed to be the determining factor for the tensile strength and played little role on the compressive strength. The tensile strength decreases as the aggregate size increases. The rate of tensile strength reduction with increasing single aggregate size becomes higher in High Strength Concrete. Kheder et al. (2005) concluded that the splitting tensile strength of NAC was higher than that of mortar, while RAC was lower than that of mortar for mixes of high strength. Shi Cong kou et al. (2007) concluded that the splitting tensile strength decreased as the recycled aggregate content increased.

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However the reduction could be adequately compensated by the use of a lower W/B ratio. At the same recycled aggregate replacement level and W/B ratio, the use of fly ash as a partial replacement of cement decreased the splitting tensile strength. Gonzalez et al. (2007) concluded that it was possible to produce a recycled aggregate concrete (with 50% of recycled concrete aggregates) with almost the same split tensile strength by changing quantity of cement 6.2% higher than the one of conventional concrete.

2.1.8.3. Behavior of recycled aggregate concrete in flexure

Ravindrarajah et al. (1985) demonstrated that there was no great difference between the flexural strength of concrete made with recycled coarse aggregate and natural sand with conventional concrete. Bairagi et al. (1993) concluded that the relative modulus of rupture varies from 94 to 87% when the replacement ratio is varied from 0.25 to 0.50. For the replacement ratio 1.0 the average split tensile strength was 74%. Oliveira et al. (1996) studied the effects of three different moisture conditions from the recycled aggregate are compared (dry, saturated and semi-saturated) and concluded that the decrease is especially noticeable in flexural strength in the concrete with the saturated recycled aggregates. Kheder et al. (2005) concluded that the flexural strength of both NAC and RAC were lower than that of mortar by about 5 to 28% and 20 to 39%, respectively. The difference decreased with the increase in compressive strength of the mix. Casuccio et al. (2008) resulted that the increase in bond strength and reduction in stiffness that take place when natural coarse aggregate is replaced by recycled aggregate, increases the elastic compatibility between concrete phases (mortar and coarse aggregates) modifying the fracture process. This has a special interest in normal strength concrete. Compared with concrete including natural crushed stone as coarse aggregate, RAC has a lower stiffness, shows smaller reduction in tensile or compressive strengths and also show clear decrease in the energy of fracture and in the size of the fracture zone. A reduction in branching and meandering of cracks on the fracture surfaces was also observed.

2.1.8.4 Stress strain behavior of recycled aggregate concrete

Bairagi et al. (1993) concluded that variation in replacement ratio affects the stress strain relationship of a concrete mix. Its curvature was greater as the replacement ratio increases, thus giving reduced values of modulus of elasticity. Topcu et al. (1995) proposed that with the increase of waste concrete aggregate amount in mixture the values of toughness, plastic energy capacity and elastic energy capacity decreases. Akcaoglu et al. (2004) demonstrated that in High Strength Concrete (HSC) the stress levels

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corresponding to the onset of crack propagation decreases with increasing aggregate size while it was nearly constant in Low Strength Concrete (LSC) containing the same size aggregates. The critical stress at which rapid and continuous crack propagation starts is around the ultimate and showed no significant size in LSC whereas it is lower in HSC and decrease with increasing aggregate size. Xiao et al. (2005) concluded that the RCA replacement percentage has a considerable influence on the stress-strain curves of RAC. For all cases 0 to 100%, the stress-strain curves show a similar behavior. The stress-strain curves of RAC indicate an increase in the peak strain and a significant decrease in the ductility as characterized by their descending portion. The peak strain of RAC is higher than that of normal concrete. It increases with the increase of RCA contents. For a RCA replacement percentage equals to 100%, the peak strain was increased by 20%. Bhikshma et al. (2010) concluded that the Saenz (1964) mathematical model is successfully evaluated and validated for all recycled aggregate concrete mixes. Stress strain values for various grades and percentages of recycled coarse aggregates of developed exclusively for recycled aggregates concrete mixtures, and they are validated for all concrete mixtures.

2.1.8.5 Young's modulus

The old mortar which is adhered to the recycled aggregates has a low modulus of elasticity, consequently concrete made with recycled aggregates will always have a lower modulus of elasticity than that of conventional concrete. Hansen et al. (1985) reported that both dynamic and static modulus of elasticity reduce between 14 and 28% for recycled aggregate concrete. The modulus of elasticity of a recycled aggregate concrete that consisted of a low quality crushed mortar to be 45% lower than the modulus of elasticity of a corresponding control concrete made with conventional aggregates. Bairagi et al. (1993) concluded that the relative modulus of elasticity varies from 93 to 85% when the replacement ratio is varied from 0.25 to 0.50. For the replacement ratio 1.0 the average split tensile strength was 71%. Topcu et al. (1995) reported that the modulus of elasticity of recycled aggregate concrete is 80% less than normal concrete. Xiao et al. (2005) concluded that the elastic modulus of RCA is lower than that of the normal concrete. It decreases as the RCA content increases. For a RCA replacement percentage equal to 100%, the elastic modulus is reduced by 45%. Kheder et al. (2005) concluded that modulus of elasticity of NAC and RAC exceeded that of corresponding mortar by about 40 and 10%, respectively. The modulus of elasticity of RAC is about 20 to 25% lower than NAC. Rahal (2007) concluded that for concrete with cylindrical strengths between 25 and 30 MPa , the modulus of elasticity of RAC was only 3% lower than that of NAC. The ACI equation over estimated the secant stiffness. The strains at peak

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compressive stress in RAC were 5.5% larger than that in NAC. This difference is not likely to have any significant implications on structural designs. Eguchi et al. (2007) concluded that as the replacement ratio of recycled coarse aggregate increases the elastic modulus decreases. However by estimating the decrease in quality by relative quality values and adjusting the replacement ratio, the quality required for the concrete can be ensured. Shi Cong kou et al. (2007) concluded that the static modulus of elasticity decreased as the recycled aggregate content increased. However the reduction could be adequately compensated by the use of a lower W/B ratio. At the same recycled aggregate replacement level and W/B ratio, the use of fly ash as a partial replacement of cement decreased the static modulus of elasticity. Poon et al. (2007) concluded that the use of recycled aggregate decreased the elastic modulus; the addition of fly ash could be used to offset this detrimental effect. ACI equation slightly overestimates the elastic modulus of recycled aggregate concrete. Gonzalez et al. (2008) concluded that a reduction in the static elastic modulus of elasticity was observed in all the recycled aggregate concrete. The addition of silica fume did not improve the static elastic modulus of elasticity.

2.1.11 Durability Properties

According to Allexander et al. (1999) ranges of index values for concrete durability are tabulated in Table 2.3.

Durability Class	Oxygen Permeability Index (OPI) (log scale)	Sorptivity (mm/sqrt (h))	Chloride conductivity mS/cm)
Excellent	>10.0	<6.0	<0.75
Good	9.5 – 10.0	6.0-10.0	0.75 -1.50
Poor	9.0 – 9.5	10.0 – 15.0	1.50 – 2.50
Very poor	<9.5	>15.0	>2.50

Table 2.3 Durability index

2.1.11.1 Permeability and water absorption

Limbachiya et al. (2000) concluded that up to 30% coarse RCA had no influence on the initial surface absorption (ISAT) measured at 10 minutes (ISAT-10) and thereafter ISAT-10 increased with RCA content. This is due to the increase proportion of cement paste in RCA, as the quantity of attached cement paste in the concrete with 100% coarse RCA increased by three times than that of concrete with 30% coarse RCA. And also concluded that up to 30% coarse RCA had no detrimental effect on air permeability, regardless of

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concrete strength. However, intrinsic air permeability found to increase with RCA content beyond this level. Buyle-Bodin et al. (2002) examined that when both fine and coarse RA are used in the concrete, the permeability increases 6.5 times compared to coarse RA concrete and 13 times compares to that of NAC. Olorunsogo et al. (2002) showed that for a given percentage of RA content, OPI of the concrete samples increases, the longer the duration of curing. Between the curing periods of 3 and 56 days and for the concrete mix containing 0% RA, OPI increased by 33.6%. Similar increases of OPI for the concrete mixes incorporating 50% and 100% RA were 37.6% and 38.2% respectively. Comparing the recommended values of OPI for concrete durability classified by Alexander et al. (1999), the 100% NA concrete attained the class status of 'good' at the curing age of 28 days with an OPI of 9.6, whilst the 50% RA concrete attained similar class status at 56 days with an OPI of 9.69. However 100% RA concrete only achieved a class status of 'poor' with the OPI value 9.22 at the curing age of 56 days. It is, however, possible that this value increase the longer the curing duration. This trend of reduction in OPI with increase in replacement levels of RA in a concrete mix was due to cracks and fissures in the attachment mortar over RA in turn create paths for ease of passage of fluids through the resulting concrete mix in which they are incorporated. Zaharieva et al. (2003) showed that the recycled aggregate (both coarse and fine aggregates) concrete is significantly more permeable than natural aggregate concrete. A possible use of admixtures such as fly ash or silica fume could decrease significantly porosity and permeability of recycled aggregate (both coarse and fine aggregates) concrete. Shui et al. (2004) investigated that the porous interfacial transition zone microstructure in the normal-strength concrete can be attributed to the higher porosity and absorption capacity of recycled aggregate. The interfacial transition zone formation was related to moisture movement and chemical reactions in the recycled aggregate concrete.

2.1.11.2 Freezing and thawing resistance

Oliveira et al. (1996) studied the effects of three different moisture conditions from the recycled aggregate are compared(dry, saturated and semi-saturated) and concluded that the bad resistance to freeze-thaw of concretes with saturated and dry recycled aggregates and the good results of those made with semi-saturated aggregates. Salem et al. (1998) concluded that the air entrained method is the best way to improve the frost resistance of recycled aggregate concrete; however this method decreases some of the concrete physical properties. Limbachiya et al. (2000) concluded that the concrete produced using up to 100% coarse RCA had durability factor in excess of 95%, showing good freeze/thaw durability potential. Zaharieva et al. (2004) concluded that the frost resistance of saturated recycled aggregate concrete (RAC) is not satisfying, and their use in

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structures exposed to severe climate is not recommended. The main reason seems to be the high total w/c ratio, including higher porosity and lower mechanical characteristics of RAC, as well as the frost resistance of RA themselves. First, they might contain unsound particles, which would be deteriorated by the repeated action of freezing-thawing cycles, and, second, RA could contribute to the frost damage by expelling water in to the surrounding cement paste during the freezing periods. Gokce et al. (2004) demonstrated that non-air-entrained concrete is a serious handicap to achieve a good freezing and thawing resistance when it is used as recycled coarse aggregate in air-entrained concrete. Improper air void system of each independent aggregate particle converts the total voids system to a partial non-airentrained system causing a poor freezing and thawing resistance. However, if an airentrained concrete incorporates also air-entrained recycled course aggregate, this concrete has an entirely air-entrained voids system an excellent performance under freezing and thawing exposure. Although the beneficial effect of the further processing to reduce adhered mortar content was observed in the concrete made with non-air-entrained recycled coarse aggregate, this limited contribution was not enough to attain desired freezing and thawing resistance. On the other hand, reducing the adhered mortar content of a sound recycled concrete aggregate did not create a clear contribution to freezing and thawing resistance of the concrete. The presence of a small amount of non-air-entrained recycled coarse aggregate in the aggregate population would be enough to drastically reduce freezing and thawing resistance of the concrete. To ensure high freezing and thawing durability, only pure air-entrained recycled coarse aggregate with enough quality should be used in the mixture. Even though the matrix performance of the concrete incorporating non-air-entrained recycled coarse aggregate was considerably improved with a low w/b ratio of 0.30, the freezing and thawing resistance for a long term exposure could not be achieved. Only the concrete containing metakaolin performed relatively well and satisfied the durability limits resisting over 300cycles. Microscopic level investigation of the damage mechanism for the concretes incorporating non-air-entrained recycled coarse aggregate showed that deteriorated adhered mortar with heavy cracks first caused disintegration of the recycled coarse aggregate itself, than the damaged particles behaved as local defects to distress the new mortar. After development of the crack network the concrete failed with heavy damage. If adhered mortar was frost resistance (air-entrained), recycled aggregate concrete did not show a serious sign of cracking. The severity of cracking was even lower than that of natural aggregate concrete. This was due to the pre-exposure defect potential of the sand stone coarse aggregate. The recycling process reduced the size of the original coarse aggregate particles under a critical value. The porous particles were mostly eliminated during crushing as well. Thus, sand stone coarse aggregate particles reduced in size and amount could not propagate

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micro cracking with in sound recycled coarse aggregate and into the other constituents of the recycled aggregate concrete subjected to freezing and thawing action.

2.1.11.3 Chloride diffusion/Penetration

Limbachiya et al. (2000) concluded that the use of 100% coarse RCA has no negative influence on the chloride diffusion of resulting concrete. Olorunsogo et al.. (2002) showed that chloride conductivity increased with increases in the replacement levels of RA for a given curing duration of concrete mixes. At a curing age of 3, 7, 28 and 56 days, the concrete mix that containing 100% RA showed 41.4, 53.6, 73.2 and 86.5% increase in the value of chloride conductivity over the mix that contained 0% RA, respectively. Considering the effect of curing age on the chloride conductivity of RA concrete, showed that the longer the duration of curing, the lower the conductivity of concrete mix at a particular replacement level of RA. For 0, 50 and 100% RA concrete, the mix that was cured for 56 days showed 69.0, 62.7 and 59.2% increase in chloride conductivity over the mix that was cured for 3 days, respectively. Comparing the recommended values of chloride conductivity for concrete durability classified by Alexander et al. (1999), the 100% NA concrete attained the class status of ‘good’ at the curing age of 56 days with a value of 1.48 mS/cm. 50% RA and 100% RA concrete mixes fall under the ‘poor’. Otsuki et al. (2003) concluded that the chloride penetration increase with an increase in the water binder ratio. Furthermore, for the same water binder ratio the chloride penetration of recycled aggregate concrete are slightly higher than those of normal aggregate concrete. This is due to the presence of old ITZ and adhesive mortar in recycled aggregate, which makes recycled aggregate concrete more permeable than normal aggregate concrete. Decrease in chloride penetration of recycled aggregate concrete can be achieved by using the double mixing method in case of high water binder ratio concrete. Shi Cong kou et al. (2007) concluded that the resistance to chloride ion penetration decreased as the recycled aggregate content increased. However, the resistance was improved by incorporation fly ash in the concrete mixtures. A decrease in the W/B ratio improved the resistance to chloride ion penetration. Further, it was found that the resistance increased as the curing age increased from 28 to 90 days. Poon et al. (2007) concluded that Chloride ion penetration could be significantly minimized with a proper mix design. Concrete, which had a low w/c ratio and the use of fly ash as an addition of cement, had much better resistance to chloride ion penetration compared to that with high w/c ratio and without fly ash addition. Ann et al. (2008) concluded that the rapid chloride ion test indicated that the concrete containing recycled aggregate forms a more open pore structure, compared to control concrete specimens. The use of 30% pulverized fuel ash and 65% ground granulated blast furnace slag in binder resulted in a decrease in the charged passed

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through concrete specimens, which implies the enhancement resistance to chloride ions permeability in to a concrete body.

2.1.11.4 Carbonation

Rasheed Uzafar et al. (1984) concluded that concrete made with already carbonated recycled aggregate suffers 65% more of carbonation than conventional concrete. Barra et al. (1998) demonstrated that the carbonation risk of recycled aggregate concrete using a higher amount of cement than 400 kg/cum of concrete mix is larger than in conventional concretes. The carbonation depth in recycled aggregate concrete and conventional concrete is similar when the amount of cement employed in the mix is between 300 kg/cum and 400 kg/cum. This occurs when the cement is added; the aggregates are saturated or very humid. In poor concrete, using less than 300 kg/cum of cement, the carbonation depth is similar in both concretes. Sagoe-Crentsil et al. (2001) reported that the variation of depth of carbonation with time under accelerated exposure conditions is a parabolic rate law for coarse RCA concrete with OPC cement as with the reference mix. The coarse RCA concrete with slag cement shows a slight deviation from this trend, suggesting the possibility of a different mechanism of carbonation. Buyle-Bodin et al. (2002) concluded that the process of CO2 diffusion in concrete with fine and coarse recycled aggregate complies parabolic rate law established with classic concrete. However, concrete with fine and coarse recycled aggregate was carbonated faster than natural aggregate concrete. Extended curing of concrete made with fine and coarse recycled aggregate decreases the carbonation rate. Zaharieva et al. (2003) showed that the replacement of natural aggregates by recycled aggregates affects the quality of the concrete cover. The carbonation of recycled aggregate (both coarse and fine aggregates) concrete (RAC) is faster. This effect limits the use of recycled aggregate in the production of reinforced concrete elements. Nevertheless, based on the criteria proposed in other studies, RAC can be characterized as being of moderate quality rather than poor quality. Mixed aggregate concrete is intermediate between RAC and NAC. It can be concluded that the main problems of durability are caused by the use of recycled sand. Therefore, the use of the fine recycled aggregate needs to be restricted. Another way of increasing the durability of RAC is to use extended curing using a moist environment. Otsuki et al. (2003) concluded that the carbonation depth increase with an increase in the water binder ratio. Furthermore, for the same water binder ratio the carbonation depth of recycled aggregate concrete are slightly higher than those of normal aggregate concrete. This is due to the presence of old ITZ and adhesive mortar in recycled aggregate, which makes recycled aggregate concrete more permeable than normal aggregate concrete. Decrease in carbonation depth of recycled aggregate concrete can be achieved by using the double

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mixing method in case of high water binder ratio concrete. Levy et al. (2004) concluded that the carbonation depth decreased when the replacement was 20 or 50% of coarse recycled masonry aggregate (CRMA) and coarse recycled concrete aggregates (CRCA). For CRMA concrete family, this better behavior also occurred when the replacement ratio was 100%. This behavior shows that carbonation depth depends strongly on the chemical composition of the concrete and not only on the physical aspects.

2.1.11.5 Water Sorptivity

Absorption is regarded as the process whereby fluid is drawn into a porus, unsaturated material under the action of capillary forces. The capillary suction is dependent on the pore geometry and the saturation level of the material. The water absorption that is caused by wetting and drying of concrete is an important fluid transport mechanism near the surface, but becomes less significant with depth. The rate of movement of a wetting front through a porous material under the action of capillary force is defined as Sorptivity. Olorunsogo et al. (2002) showed that water sorptivity increased with increases in the replacement levels of RA for a constant age of curing. At a curing age of 3, 7, 28 and 56 days, the concrete mix that containing 100% RA concrete showed 47.3, 43.6, 38.5 and 28.8% increases in the value of water sorptivity over the mix that contained 0% RA, respectively. It was shown that these percentage increments decreased with duration of curing, for a considerable curing length of time there was no difference in water sorptivity values.

2.1.11.6 Reinforcement corrosion

RasheedUzafar et al. (1984) concluded that rust occurs in the steel reinforcement with 2-3mm of clean cover at 2 months. The rust risk in reinforced recycled aggregate concrete is higher than conventional concrete. However this risk is possible to decrease with lower w/c ratio in recycled aggregate concrete the conventional concrete. Limbachiya et al. (2000) concluded that little difference in the performance of the RCA and NA concrete mixes, suggesting equal corrosion activity. However, the corrosion currents of the steel in 100% coarse RCA concrete were slightly higher and the corrosion initiation time was shorter than concrete containing NA and up to 50% coarse RCA. Ann et al. (2008) concluded that the chloride threshold level for steel corrosion was not affected by pulverized fuel ash (PFA) or ground granulated blast furnace slag (GGBS) as partial replacement for cement in binder, but the OPC concrete with only recycled aggregate indicated the lowest level of chloride threshold level. After the onset of corrosion, the

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corrosion rate was significantly reduced by PFA and GGBS, due to the restriction of cathodic reaction, which needs a sufficient supply of oxygen and water.

2.1.11.7 Creep, elastic shrinkage and drying shrinkage

Mesbah et al. (1999) concluded that for the recycled aggregate mortars the drying shrinkage reduces 15% when the metallic fibres are added and tiny changes when the polypropylene fibres are added. Sagoe-Crentsil et al. (2001) reported that both natural and recycled aggregate concretes display similar trends with regard to the rate of shrinkage. The shrinkage strains associated with recycled concrete made with slag cement are over 35% higher and with Portland cement are over 15% higher than the reference mixture. Shi Cong kou et al. (2007) concluded that the drying shrinkage of concrete increased with an increase in the recycled aggregate content. However, the use of fly ash as a partial replacement of cement was able to reduce the drying shrinkage of the recycled aggregate concrete. Further, a decrease in the W/B ratio also led to a reduction in the drying shrinkage. The creep of the concrete increased with an increasing recycled aggregate content. The use of fly ash as a partial replacement of cement was able to reduce the creep of concrete as a result of the greater long term strength development due to the pozzolanic reaction of fly ash. Poon et al. (2007) concluded that the use of low w/c ratio or fly ash as a addition of cement is a good way to reduce the potential high drying shrinkage of concrete prepared with recycled aggregate. Drying shrinkage of recycled aggregate concrete tended to decrease with an increase in compressive strength. Reducing w/c ratio from 0.55 to 0.40 was a more effective way to mitigate the drying shrinkage of concrete compared to adding 25% fly ash in the concrete mix. Eguchi et al. (2007) concluded that as the replacement ratio of recycled coarse aggregate increases the drying shrinkage strain increases. However by estimating the decrease in quality by relative quality values and adjusting the replacement ratio, the quality required for the concrete can be ensured.

2.1.12 Economic Comparison Concrete Recycling

Eguchi et al (2007) proposed new production method for recycled aggregate concrete with different replacement ratios called as “On-site mixing method”. In this method, all the materials except the recycled coarse aggregate (base concrete) were first mixed at an available batching plant, and the mixture was transported by loading to a truck agitator. Next, the recycled coarse aggregate was measured using temporary weighing and loading equipment installed at the construction site, and was loaded to the truck agitator. The truck agitator drum was then rotated at a high speed and a recycled coarse aggregate was mixed with the base concrete. The effectiveness of a production method for the recycled

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concrete is confirmed. When recycled concrete is produced by this method, the cost and the environmental loads could decrease in comparison to construction without recycling, at least in terms of large-scale construction, or construction with recycling to crusher run only. Tam (2008) recommended that there should have standard specifications to encourage the implementation of recycled materials for non structural and structural application. One of the main burdens on the use of recycled materials is its low quality. Although there are literatures that to support high quality of recycled materials can be produced, the industry is still hesitated to use the recycled materials for new material production. It is encouraged that the government should widely initiate the use of recycled materials for their projects, which can then encourage its use to the industry. It should be highlighted that improving technology for producing recycled materials can significantly improve their quality. Lack of in house training on concrete recycling is another major issue affecting the use of recycled materials in the industry. It is encouraged that training programs should be produced to all employees to enhance their environmental awareness, thus to improve the environment. Tam (2008) concluded that the huge generation of construction waste has reached a state that a warning signal is flicking as reflected from the running out of landfill areas. One of the best ways to manage this acute environmental problem is by recycling construction waste. As concrete waste forms the major source of construction solid waste, recycling concrete waste is the best option to mitigate quantities of construction waste. And also studied the cost and benefit on the current practice in dumping the construction waste to landfills and producing new natural materials for new concrete production, and the proposed concrete recycling method to recycle the construction waste as aggregate for new concrete production. With the advent of the cost on the current practice, it is found that the concrete recycling method can result in a huge sum of savings. The benefits gained from the concrete recycling method can balance the cost expended for the current practice. Therefore, recycling concrete waste for new production is a cost-effective method that also helps protecting the environment and achieves construction sustainability.

2.1.13 Structural Properties

The structural properties of recycled aggregate concrete are as follows.

2.1.13.1 Flexural behaviour of recycled aggregate concrete

Mukai et al. (1988) concluded that the failure in low reinforced concrete beam specimens made with recycled aggregate or conventional aggregate occurs when reinforcement yields. However in high reinforced beam specimens the failure occurs by compression of

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top part. On subjecting both the reinforced recycled aggregate concrete and conventional concrete beam specimens to the same load conditions it was discovered that cracking first appeared in the reinforced RAC beam specimens, however the ultimate load is similar in both beams with respect to low reinforced concrete beam specimens made with recycled aggregates the displacement is larger than in conventional concrete. However there is no difference when the specimens are strongly reinforced.

2.1.13.2 Shear behavior of recycled aggregate concrete

Mukai et al. (1988) concluded that the shear strength of a low reinforced concrete beam specimen made with recycled aggregate is 10% lower than that of a conventional concrete beam. However with reinforcement, the recycled aggregate concrete beam specimens achieve the same and sometimes even larger strength than conventional ones. Recycled aggregate concrete beam specimens with low transversal reinforcement have less ductility than conventional concrete specimens. However this can change when the beam specimens are strongly reinforced. Yagishita et al. (1993) concluded that in concrete beam specimens made with recycled aggregate the first diagonal crack occurs before than that of conventional concrete. However, the ultimate shear load is similar in both recycled aggregate concrete and conventional concrete beam specimens. The cracks widths are larger in recycled aggregate concrete beam specimens. The bond between reinforcement and concrete is lower in recycled aggregate concretes than in conventional concrete. The splitting crack is more relevant in recycled aggregate concretes than conventional ones, however this phenomena is less significant with the presence of transversal reinforcement. Gonzalez-Fonteboa et al. (2007) concluded that little differences were observed in the structural behavior of concrete beams in terms of both deflections and ultimate load. Differences were only evident during the analysis of cracking. Premature cracking and notable splitting cracks along the tension reinforcement were observed in recycled concrete beams. Both may be controlled by introducing stricter limits on the minimum stirrups spacing.

2.1.13.3 Compression behavior of recycled aggregate concrete

Yang et al. (2006) concluded that the typical failure modes of RACFST columns are similar to those of the normal CFST columns. They were all overall buckling failure. The ultimate capacities of such composite columns decreased with the increase in load eccentricity ratio. The recycled aggregate concrete in-fill columns have slightly lower but comparable ultimate capacities compared with the specimens filled with normal concrete. It was found that, in general, the ultimate capacities of the members with normal concrete

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were 1.7 to 9.1% higher than those of circular columns with recycled aggregate concrete containing 25% recycled coarse aggregate and 50% recycled coarse aggregate, and for square specimens, the ranges are 1.4 to 13.5%. The lowering in capacities of RACFST columns can be attributed to the lower strength of recycled aggregate concrete as compared to the normal concrete. Generally, ACI, AIJ, AISC-LRFD, BS and DBJ methods are conservative for predicting the strengths of circular and square composite columns filled with recycled aggregate concrete. However, EC method gives a member capacity about 5 and 12% higher than the experimental result for circular and square RACFST columns respectively, and gives an unsafe prediction.

2.1.13.4 Bond behavior of recycled aggregate concrete with steel rebar’s

Xiao et al. (2007) concluded that the shape of the load versus slip curve between recycled aggregate concrete and steel rebars is similar to the one for normal concrete and steel rebars, which includes micro slip, internal cracking, pull out, decending and residual stages. Under the conditions of the equivalent mix proportion and compared with that of normal concrete, the bond strength between the recycled aggregate concrete and the plain rebar decreases by 12% and 6% for an RCA replacement percentage of 50% and 100%, respectively. While the bond strength between the recycled aggregate concrete and the deformed rebar is similar, irrespective of the RCA replacement percentage. For the case of the same compressive strength, the bond strength between the recycled aggregate concrete with 100% replacement of RCA and steel rebars is higher than the one between the normal concrete and steel rebars. For the recycled aggregate concrete, the bond strength between deformed steel rebars and concrete is approximately 100% higher than the one between plain steel rebars and concrete, and the coefficient of variation for the bond strength of the plain steel rebar is much higher than the one for the deformed steel rebars. The anchorage length of steel rebars embedded in the recycled aggregate concrete with 100% replacement can be chosen as the same for normal concrete under the condition of the same compressive strength of concrete. Eguchi et al. (2007) studied that when the lateral reinforcement ratio is high, the maximum bond stress tends to decrease slightly as the replacement ratio of recycled aggregate increases. The bond failure strength of recycled concrete can be evaluated as being safe according to the AIJ formula in the standard specification, regardless of its replacement ratio.

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2.1.13.5 Seismic performance of recycled aggregate concrete

Xiao et al. (2006) concluded that the presence of RCAs reduces the yield, maximum and ultimate loads of frames made with RAC: however, this reduction is less than that of the mechanical properties of the RAC material. The characteristic displacements among the test specimens prove that there are no obvious differences between frames with recycled concrete and conventional concrete, particularly form the ductility coefficients and lateral rotations points of view. From the hysteresis loops, the energy dissipation and the rigidity degradation points of view, the seismic performance of frames with recycled aggregate concrete is comparable to that with conventional concrete. It is also concluded that the frames with properly mix-designed recycled aggregate concrete are good enough to resist an earth quake according to GB code, and it is feasible to apply the recycled aggregate concrete structure in civil engineering.

2.1.13.6 Glass fiber reinforced recycled aggregate concrete

Prasad et al. (2007) concluded that recycled aggregate concretes are not inferior to normal concrete. Addition of glass fibers has definitively increased the compressive strength, though marginally in the range of 2 to 3%. The addition of glass fibers in the recycled aggregate concrete has increased the split tensile strength by 13.03 and 10.57% in M20 and M40 grade concretes and also the flexural strength has increased by 10.62 and 7.94% in M20 and M40 grade of concretes. There is an improvement in Youngs modulus value with glass fibers addition in both normal and recycled aggregate concrete. The increased strains at constant stress in glass fibrous concretes, indicates improved ductility and energy absorption capacity. Ghorpade Vaishali G et al. (2012) concluded that the compressive, tensile, flexural and shear strengths of fibre reinforced high performance recycled aggregate concrete mixes increased with the increase of fiber content up to 1% and decreased beyond 1% fiber volume fraction. Balling of fibers at 1.25% volume fraction is mainly responsible for reduction in strengths. Maximum compressive, tensile, flexural and shear strengths are achieved at 1% fiber volume for steel, glass and poly propylene fibers. The percentage increase in strengths due to addition of fibers, is observed more in mixes prepared with recycled aggregates than those prepared with natural aggregates. The chloride ion permeability of mixes prepared with recycled aggregates is higher when compared to corresponding mixes prepared with natural aggregates.

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2.1.15 Conclusions

From the mid seventies onwards the properties of recycled aggregates and their applications have been studied throughout the world. The conclusions obtained from the research and investigations carried out are as follows;

1. The recycled aggregates obtained from crushed concrete consist of adhered mortar and original aggregates. The quantity of adhered mortar in recycled aggregates is higher in small size aggregates. Due to the adhered mortar in original aggregates mechanical and physical properties of recycled aggregates are worse than those of raw aggregates. Recycled aggregates properties: density, absorption, porosity, Los Angeles abrasion, freezing and thawing resistance are inferior in quality those of raw aggregates.

2. According to RILEM recommendations, the recycled aggregates obtained from crushed concrete, should be defined as type II. Type II is a material that originated primarily from concrete rubble. The recycled aggregate must have a lower than 10% water absorption capacity and a minimal dry particle density of 2000 kg/m3. Recycled aggregate concrete is allowed to achieve 50/60 MPa. It does not require an additional test to be used in exposure class 1. In order to use in other exposure classes ASR expansion and bulk freeze-thaw test are required.

3. The water absorption capacity of recycled aggregates has to be taken into account when using recycled aggregate in concrete production. The recycled coarse aggregates used in concrete manufacture should be kept in humid conditions. This will ensure not only concrete’s workability but also the effective w/c ratio. If the recycled aggregates are used in this condition the new interface transition zone can be effective, producing better properties, and prevention to freezing and thawing. The new interfacial transition zone also depends on the concrete production process. Although it is not possible to improve the old interface transition zone it is possible to achieve an effective new transition zone which produces a low w/c ratio cement paste on the interface.

4. In concrete made with 100% of recycled coarse aggregates the effective w/c ration must be lower than that of conventional concrete in order to obtain the same compression strength. Therefore, in recycled aggregates concretes (using more than 50% of recycled coarse aggregates) more cement than conventional concretes is necessary to achieve the same workability and compression strength.

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5. The compression strength of recycled aggregate concrete depends on the strength of the original concrete. The adhered mortar of recycled aggregates can be the weakest point in the concrete.

6. There is not a significant change in the properties of concrete made with 20-30% of recycled coarse aggregates with respect to that of conventional concrete.

7. Concretes made with 50 and 100% of recycled aggregates strength have a lower increase in compression strength from 7 to 28 days than those of conventional concrete employing only raw aggregates.

8. The variation coefficient of recycled aggregate concrete is higher than conventional concrete.

9. The tension strength of concrete made with recycled aggregates and natural sand is similar to conventional concrete. However, if recycled aggregates are saturated at concrete production, the tension strength of recycled aggregate concrete decreases.

10. The modulus elasticity of recycled aggregate concrete is always lower than conventional concrete.

11. Concrete made with recycled aggregates needs to have a lower effective w/c ratio to achieve lower permeability.

12. The freezing and thawing resistance is lower in recycled aggregates concrete than in conventional concrete. However it can be improved if the recycled aggregates are humid and the air-entrained is used at concrete production.

13. A lower w/c ratio can improve rust risk in recycled aggregate concrete, decreasing its permeability.

14. The rubble processed at recycling plants may originate from structures which were attacked by ASR or which were potentially reactive, but did not react due to a lack of favorable conditions (such as humidity). Preventive measures such as the use of low alkali Portland or blast furnace slag cement, may increase the durability of the recycled concrete as far as ASR is concerned.

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15. The first cracking load is lower in recycled aggregate concrete specimens than that of conventional concrete.

16. According to flexure and shear behavior, the ultimate load is similar in reinforced recycled aggregate concrete specimens and conventional concretes.

17. The bond resistance in recycled aggregate concrete is lower than that of conventional concrete.

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Chapter 3

Experimental Method

3.1 Introduction

This Chapter contains the details of the experimental setup. At first recycled brick aggregate was collected from demolished concrete and then their physical properties was investigated for further comparison. After that physical and mechanical treatment was applied to the aggregate for the improvement of their quality.

3.2 Materials

Since the quality of brick recycled aggregate is to be improved, so the brick recycled aggregate was the main ingredients of the study. In addition to that **H_3PO_4** was taken for physical treatment of the recycled aggregate and motorized shaking machine was used for shaking of the aggregate for mechanical treatment.

3.3 Mix proportion of H_3PO_4 solution

To treat the surface of recycled aggregate, in order to remove the bonded mortar, hence to improve the quality of the aggregate, **H_3PO_4** was used in this study. Detail mix proportion of the acid and aggregate is shown in table below. For surface treatment recycled aggregate was submerged under **H_3PO_4** for 24 hours. After separate the recycled aggregate from **H_3PO_4**, for remove the influence of acid on the surface of aggregate, the aggregate were kept under distilled water for another 24 hours. After that, the aggregate were prepared for other tests.

Serial	Name of acid	Quantity of acid (gm)	Quantity of water (gm)	Quantity of recycling aggregate (gm)
1	H_3PO_4	2000	20000	16000

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3.4 Application of mechanical treatment

For further improvement of quality of recycled aggregate, surface treated recycled aggregate was driven through mechanical treatment process. For mechanical treatment, shaking machine was used. After keeping the aggregate in shaking machine, the machine was shacked for 3 minutes. Due to the shaking of the machine, the weak mortar after physical treatments were removed and the removed mortar were collected by a pan below the machine.

3.5 Exposure condition

Since temperature and humidity has significant influence on the tests of concrete and aggregate, so all the tests (absorption, unit weight) in this study were preformed in normal temperature.

3.6 Test methods

To evaluate the applicability of H_3PO_4 for surface treatment and shaking machine for mechanical treatment, in order to improve the quality, recycled aggregate absorption, unit weight and visual inspection was performed**.**

3.6.1 Visual inspection

Visual inspection is the primary tool to judge the quality improvement of recycled aggregate. To ensure the impact of various treatment methods, after every treatment, visual inspection of recycled aggregate was performed (before and after the test).

3.6.2 Absorption

Absorption of recycled aggregate was performed at different level of the study namely the source aggregate, absorption of recycled aggregate after surface treatment and absorption after mechanical treatment. To determine the absorption of recycled aggregate at different level the following steps were followed as described in the figure below.

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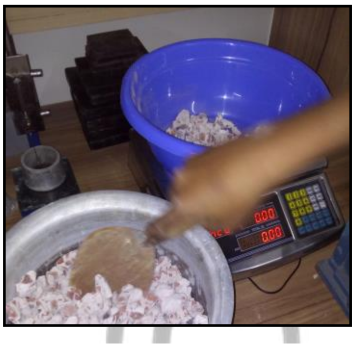
RA was submerge under water to prepare in SSD condition.

Aggregate are squeezed to bring them into SSD condition



Weight being taken to measure the absorption.

Aggregate were kept into oven for dried the water

Fig. 3.1: Procedure to determine absorption of recycled aggregate.

3.6.3 Unit weight

Unit weight is one of the most important indicators to check the quality of recycled aggregate. In order to evaluate the quality of recycled aggregate at different stag treatment, unit weight of recycled aggregate was measured at three different stag. They are the unit weight of source aggregate, unit weight of recycled aggregate after surface treatment and unit weight of recycled aggregate after mechanical treatment.

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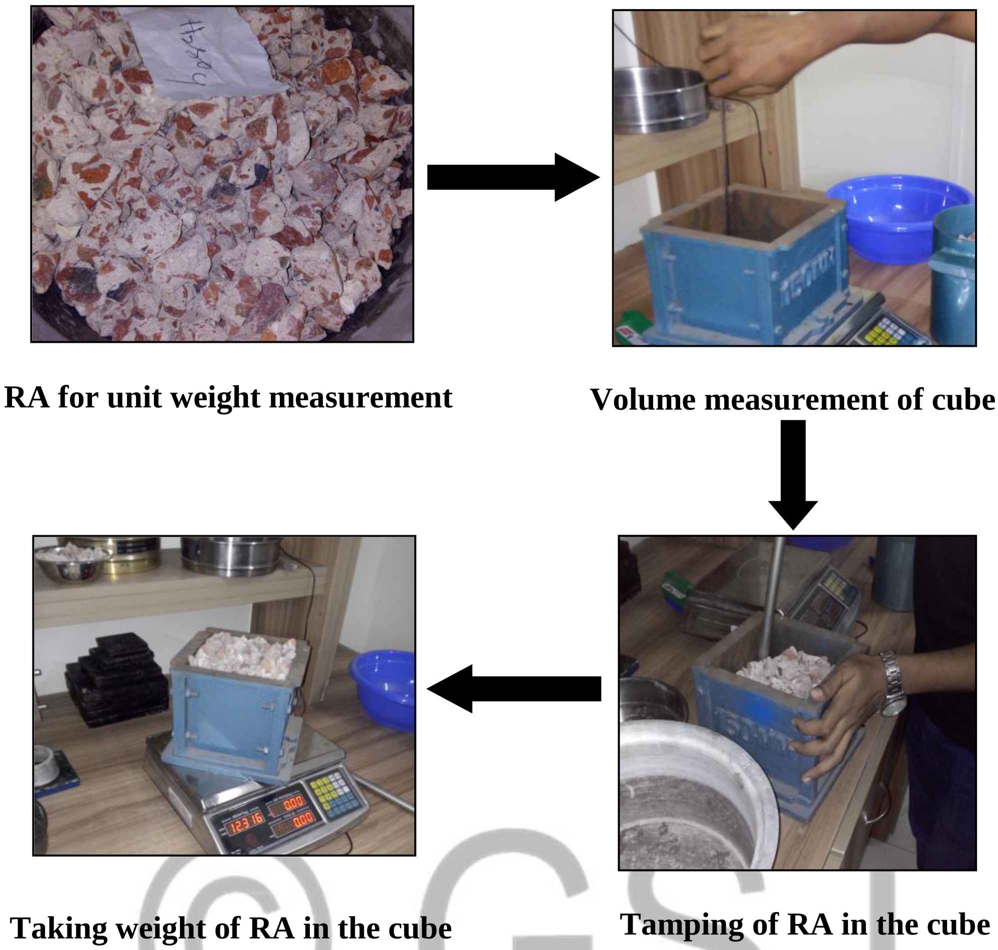

Fig. 3.2: Procedure to determine unit weight of recycled aggregate.

Fig. 3.3: Procedure of Determine Cleaning of Recycled Aggregate by H_3PO_4 Acid

Fig. 3.4: Procedure of Determine Unit Weight of Recycled Aggregate

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3.6.4 Aggregate Impact Value (AIV)

The Aggregate Impact Value is one of the most important indicators to check the quality of recycled aggregate. The Aggregate Impact Value (AIV) gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from its resistance to a slowly applied compressive load. With aggregates of Aggregate Impact Value higher than 30 the result may be anomalous. Also, aggregate sizes larger than14.0 mm are not appropriate to the aggregate impact test. The standard aggregate impact test shall be made on aggregates passing a 14.0 mm test sieve and retained on a 10.0 mm test sieve. In general, the smaller sizes of aggregates will give a lower impact values obtained with different sizes may vary from one aggregate to another. Aggregate Impact Values, (AIV"s) below 10 are regarded as strong and AIV"s above 35 would normally be regarded as too weak.

In order to compare the quality improvement of recycled aggregate before and after surface treatment AIV test was performed in this study as shown in **Fig. 3.3**.

Fig. 3.3: AIV measurement of recycled aggregate before and after surface treatment.

3.6.5 Compressive Strength of Concrete

To judge the degree of improvement of recycled aggregate, concrete was casted by using recycled aggregate and then compressive strength of RAC was investigated in this study as shown in **Fig. 3.4**.

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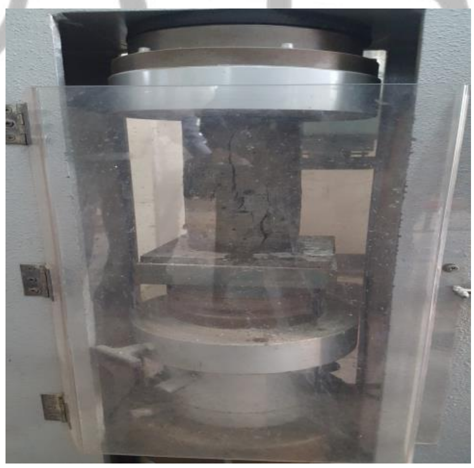
Fig. 3.4: Making cylindrical specimen by using recycled aggregate.



Test performed of concrete cylinder

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Chapter 4

Results and Discussions

To improve the quality of recycled aggregate, physical treatment was applied to the aggregate. After the treatment, visual inspection was conducted for observe the qualitative change in recycled aggregate. Along with visual inspection, absorption, unit weight, AIV of recycled aggregate and compressive strength of recycled aggregate concrete were investigated. The results obtained from various tests are summarized and discussed below.

4.1 Visual inspection of recycled aggregate

After each treatment process, recycled aggregate were visually inspected and compare with source recycled aggregate. Form the comparison it was observed that, after each treatment process the removal of bonded mortar was followed an increasing trend. From this trend it is evident that the quality of source recycled aggregate was improving step by step with the treatment process.

4.2 Absorption

In this study, absorption was considered the main parameter to judge the quality of recycled aggregate. So for that, absorption of recycled aggregate was tested at different stages of study. From the test result as shown in Fig. 4.1, it is observed that the absorption of source recycled aggregate decreae after physical treatment by 12.17% (From 14 % to 12.3%). It is also observed that, the absorption of source aggregate decrease 21% (From 14% to 11%) after both physical and mechanical treatment and it decrease 10.56% (from 12.3% to 11%) when the absorption of recycled aggregate after physical treatment and the absorption of recycled aggegate after mechanical treatment is considered.

From the obtained results, it is clarrified that the removal of bonded mortar taking place significantly after each level of treatment, hence the improvement of quality of source recycled aggregate also taking place. However, several other treatment methods (i.e. In case of physical treatment the aggregate can be submerged under H_2SO_4 for 36 hours, 48 hours or even more to chack further improvement. In case of mechanical tretament the aggregate can be shaked for 5 minutes, 10 minutes or more to check further improvement) need to explore for better removal of bonded mortar.

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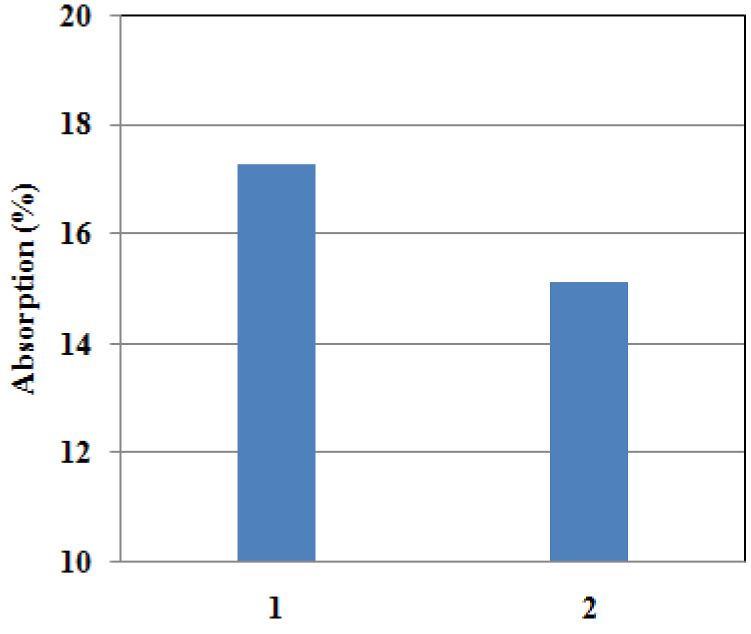
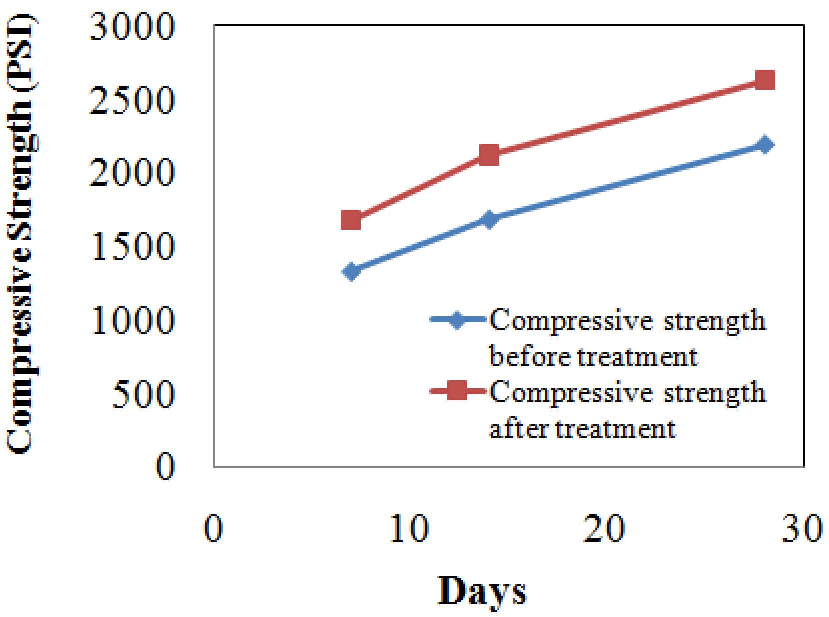


4.3 Unit weight

In this study, unit weight was considered another main parameter to judge the quality of recycled aggregate. So for that, unit weight of recycled aggregate was tested at different stages of study. From the test result as shown in Fig. 4.2, it is observed that the unit weight of source recycled aggregate increases after physical treatment by 9.75% (From 28.84 kg/cft to 12.3 kg/cft). It is also observed that, the unit weight of source aggregate increases 22.55% (From 28.84 kg/cft to 34 kg/cft) after both physical and mechanical treatment and it increases 9.45% (from 31.06 kg/cft to 34 kg/cft) when the unit weight of recycled aggregate after physical treatment and the unit weight of recycled aggegate after mechanical treatment is considered.

4.4 Compressive Strength



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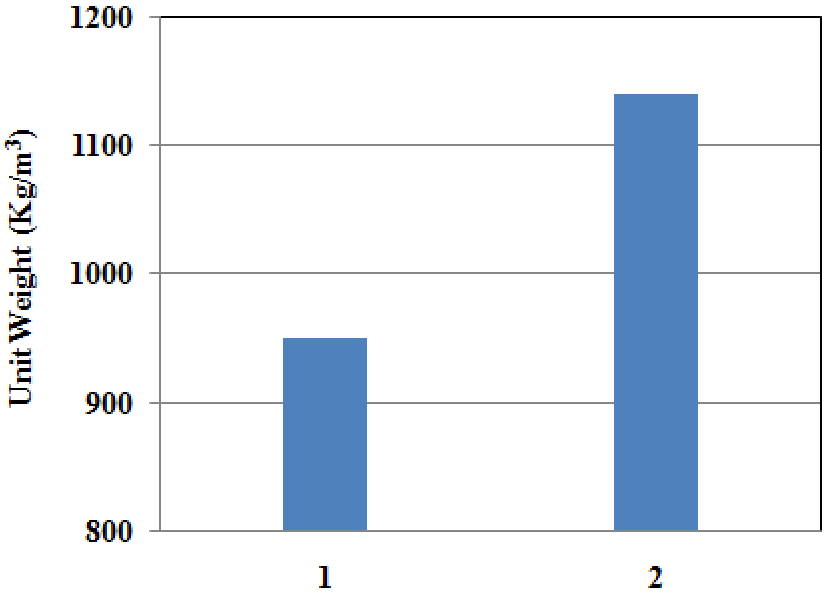
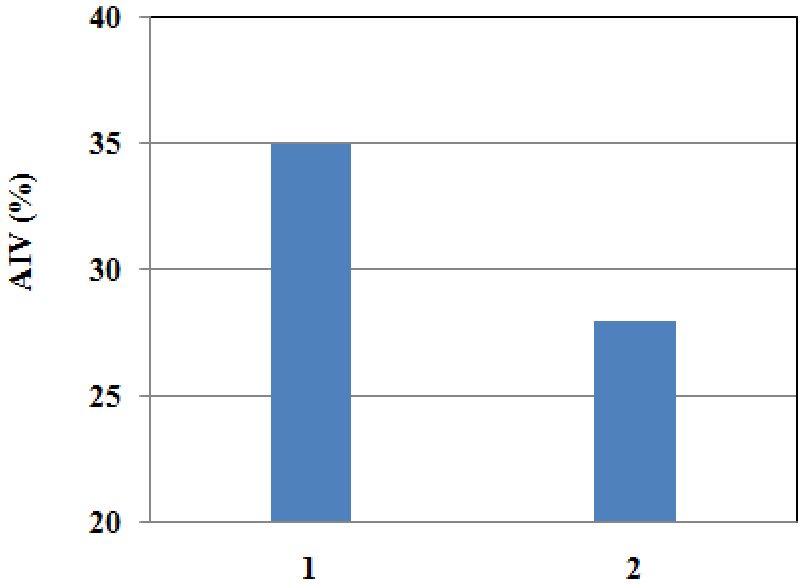
From the obtained results, it is summerized that the removal of bonded mortar taking place significantly after each level of treatment, hence the improvement of quality of source recycled aggregate also taking place. However, several other treatment methods need to explore for better removal of bonded mortar as explained in section 4.2.



4.4 Selection of appropriate method

From the tests results an appropriate methods for treatment of recycled aggregate was not founded. To obtain that, individual mechanical treatment need to be done and compare the results with physically treated recycled aggregate.



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Chapter 5

Conclusions and Future Rrecommendations

In order to develop quality improvement methods and techniques for recycled aggregate various tests have been performed in this study. From the test results and discussions the following conclusions are drawn.

1. Absorption, Unit weight, Specific gravity and Aggregate Impact Value (AIV) are very important parameters to judge the quality improvement of recycled aggregate.

2. From the study it is clarified that with the progress of treatment methods, absorption of source aggregate follows a decreasing trends. Absorption of source recycled aggregate decreae after physical treatment by 12.17% (From 14 % to 12.3%). In addition, absorption of source aggregate decrease 21% (From 14% to 11%) after both physical treatment and it decrease 10.56% (from 12.3% to 11%) when the absorption of recycled aggregate after physical treatment is considered.

3. From the conducted test results it is also clarrified that with the progress of treatment methods, unit weight of recycled aggregate follows a increasing trends. Unit weight of source recycled aggregate increases after physical treatment by 9.75% (From 28.84 kg/cft to 12.3 kg/cft). It is also observed that, the unit weight of source aggregate increases 22.55% (From 28.84 kg/cft to 34 kg/cft) after physical treatment and it increases 9.45% (from 31.06 kg/cft to 34 kg/cft) when the unit weight of recycled aggregate after physical treatment is considered.

4. Combine treatment methods shows better quality improvement. However, combine treatment is not always a preferable choice when economic view point is needed to be consider.

5. Selection of appropiate methods for treating recycled aggregate will depend on the purpose of use of treated aggregate.

6. Removal of bonded mortar taking place significantly after each level of treatment, hence the absorption of recycled aggregate decreases. However, several other treatment methods (i.e. In case of physical treatment the aggregate can be submerged under H_3PO_4 for 36 hours, 48 hours or even more to chack further improvement.

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7. From the obtained results, it is summerized that the removal of bonded mortar taking place significantly after each level of treatment, hence the unit weight of recycled aggregate increasing. However, several other treatment methods need to explore for better removal of bonded mortar.

8. Other acid should try for removal of bonded mortar. To make the treatment process economically feasible, weak or organic acid should be tried.

9. Instead of shaking, several other mechanical treatment should be checked to improve the quality of recycled aggregate.

10. To validate the results obtained from treatment methods, mechanical properties of concrete made with the treated recycled aggregate need to be checked.

11. Social awarness and policy from Goverment level needed to be impose for increase the use of recycled aggregate.

12. Recycle is not an option but a way to survive and ensure sustainability.