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Assessment of Recycled Concrete Aggregate Usage in Concrete

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Abstract: **Recycling concrete is a significant step towards eco-friendly con-struction practices. The use of recycled concrete aggregates in new structures provides a sustainable development. Initially, recycling of demolition waste was first carried out after the Second World War in Germany and henceforth, there have been reduction in the quan-tity of construction and demolition waste; and at the same time, it lessened the depletion of natural resources by providing an alter-native. There have been recorded cases of application of recycled aggregate(RA) in a large number of construction projects of many European, American, Russian and Asian countries. The test results of ductility and the stiffness of beams with RA are equal or higher than those with natural aggregate. However, concrete made with recycled concrete aggregates exhibits different engineering proper-ties. This difference is mainly due to the attached mortar paste on recycled concrete particles. Recycled aggregates have been found to have high water absorption capacity, which affects various prop-erties mainly mechanical performance of the resulting concrete mix. Based on previous research, this paper presents a comprehensive overview of the recycled concrete material characteristics and the effect of using recycled concrete material on the mechanical proper-ties, the durability properties and structural performance of concrete so as to help relevant units and staffs in the practical work.**

I. INTRODUCTION

Population growth and rapid urbanization rate in devel-oping countries has increased the construction of new living, working, sanitary and transportation infrastructures. Concrete is one of the most used construction material be-cause it has a longer life, low maintenance cost and excellent performance. However, its production gives rise to the con-sumption of natural resources. According to the Freedonia Group study, the global demand for construction aggregates is expected to advance 51.7 billion metric tons in 2019, and China alone accounted for more than 50% of worldwide de-mand for all new aggregates during the period 2010-2015 (1). Meanwhile, there is a high rate of construction and demolition (C&D) waste produced yearly due to the demolition of old structures, natural disasters like earthquakes, avalanches, and tornadoes; human causes like war, bombing and structural failures. In China, C&D activities generated over two billion tons of C&D waste in 2011 (2). The disposal into landfills of these C&D waste is an increasing concern throughout the world. The inappropriate disposal of C&D waste is an issue faced by many municipalities. It is responsible together with other factors for damages to landscapes and other damages to human safety and living beings. For instance, at the end 2015, a landslide happened at the Hongao construction waste dump, Shenzhen in China. It destroyed buildings and killed workers living in the nearby (3). In excess of the disasters accompanied with improper disposal of demolition waste, there is also high negative impact on our environment's sustainability. Owing to its significant impact on the natural environment, there is a high requirement of environmental sustainability practices in our modern construction works and hence a proper man-agement of C&D is critical. The old concrete waste can be crushed, processed and reused as recycled concrete aggregates (RCAs) in new concrete structures. This recycling contributes to a greater sustainability in the construction industry be-cause it provides a solution to the problem of C&D waste management and prevents the depletion of natural aggregates (NA) by providing alternative aggregates. Many countries are giving infrastructural laws relaxation for increasing the use of recycled aggregate.However, due to the lack of proper code and standard, many aspects need attention and handling during the design and the application of recycled concrete structures. In this review paper, the challenges of using RCA such as the attached old mortar paste, its high porosity, its high permeability and its high water absorption; and the effect of RCA on rheological properties of the fresh concrete mix, on the mechanical properties and long-term service of RCA concrete are presented.

1. Habitual Sources of RCA

Previous researches have showed that the concrete containing RCA obtained from high strength parent concrete exhibited better mechanical properties than that containing RCA made low strength concrete. For this reason, the source of RCA is very important and fair idea about the extraction site should be considered. The sites for extraction of RCA can be sites of razed buildings, bridges, sidewalks and roads after a period of time into their service life for purpose of replacement or

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Significance Statement

Aggregates occupy a considerable part of a concrete. Their properties notably influence the engineering behavior of the concrete. The use of RCAs is economically and environmentally beneficial, though it is hard to give a clear idea of RCAs properties. The variability and uncertainty of RCAs make their application in engineering project challenging.

landscape changes. Other sources of waste include natural disasters like earthquakes, avalanches, and tornadoes; human causes like war and bombing; and structural failures.

2. Production and Quality of RCA

The commonly recycling concrete process includes the demoli-tion of the old structure into pieces small enough to be handled. Follows the removal of undesired items present in the original concrete. Finally, demolished concrete pieces undergo a series of screening, removal of contaminants, and crushing that result in RCAs sized to meet particular grading requirements. Figure 1 shows a typical recycling process. The amount of adhered mortar paste (AMP) attached to the RCAs greatly influences their quality. The quantity of AMP on the recycled aggregates particles depends on var-ious factors such as the condition of the original concrete and crushing process. Findings have shown that when the steps of crushing procedures increase, the amount of AMP on RCAs decreases (4, 5). The attached mortar is responsible for higher water absorption capacity, lower density, higher porosity and possible content of harmful substances of RCA compared with NA. Hence, it is crucial to control the amount of residual mortar present in RCAs. Faced with this situa-tion, numerous researchers have attempted to develop efficient methods to enhance the quality of RCA. Akbarnezhad et al. (6) introduced a microwave-assisted technique to improve the quality of RCA by removing a part of the attached residual mortar paste. This method makes use the difference in the electromagnetic properties of the adhered mortar and natural aggregates. Pepe et al.(7) used a rotating mill drum to process RCA. Aggregates collide each other while removing pieces of adhered mortar. The results showed that the autogenous cleaning method could reduce the water absorption capacity of RCAs up to 50%. Al-Bayati et al. (8) used different tech-niques to enhance the physical and morphological properties of RCAs. They reported that heat treatment combined with short mechanical treatment exhibit the best performance. Be-sides, there has been much research about the RCA?s surface treatment methods with acid. Acid can dissolve cement hy-dration products. Researchers used acid to remove AMP from RCA particles. Research results proved that the utilization of this technique reduces the water absorption of RCAs and improve mechanical properties without of RCA concrete with-out adverse effect on the alkalinity of RCA concrete. The microstructure analysis of the treated RCAs has demonstrated that their ITZs are less porous, denser and have connected microstructure. Also, there is a linear relationship between the amount of mortar loss with the increase of the molarity of acid. (9–11).

3. Problems of Adhered Mortar Paste(AMP)

From previous discussion, AMP is undoubtedly the main reason for the lower quality of RCAs compared to NAs. More attention should be paid to monitor the effects of the AMP on the RCAs? properties and consider them in the concrete mix proportion design. Some scholars reported that the porous nature of the old mortar is responsible for the increased water absorption capacity, high permeability and decreased density and specific gravity of RCAs. The high water demand of the crushed aggregates affects the workability of the fresh

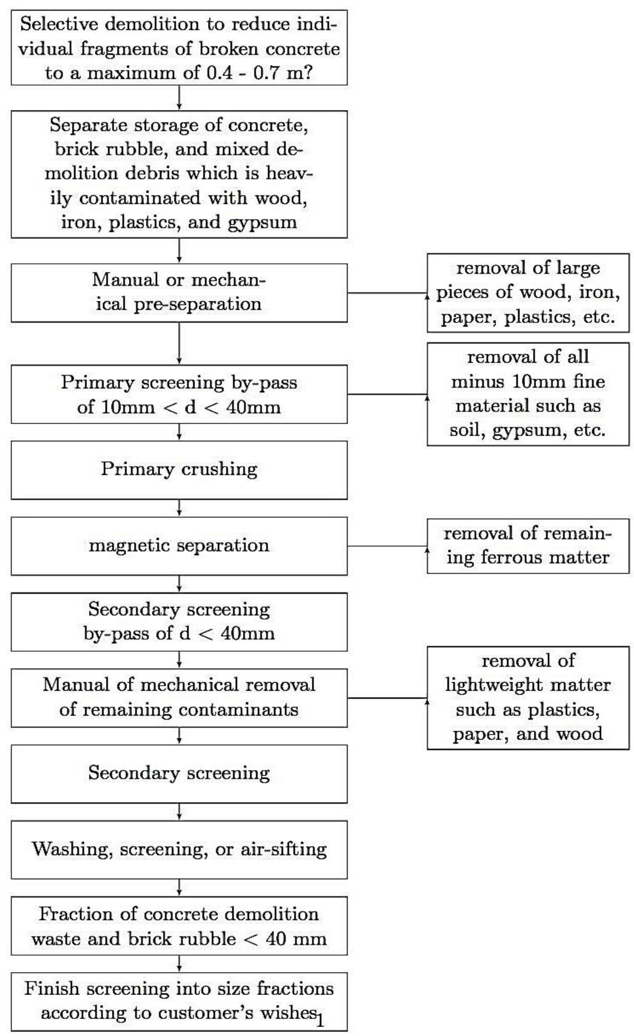

Fig. 1. Typical recycling concrete process

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concrete, thereby that affects the mechanical properties of the concrete in the hardened state (11, 12). The presence of the old mortar makes the RCA a multiple phase's material. Concrete made with natural and recycled aggregate contain more than two phases. The ITZs between? Old? and? New? elements. Close inspection revealed in figure 2 & figure 3 that the interfacial transition zone (ITZ) between the AMP and the original aggregate has a lot of voids and micro-cracks which lead to a high tendency of cracking and reduction in the bond between the new mortar and the old mortar. Consequently, RCAs concrete has lower strength and lower elasticity modulus compared to conventional concrete (13, 14). Moreover, as a consequence of the exposure of the old concrete to aggressive attacks during the previous exploitation, the AMP may contain harmful chemical substances. It is crucial to know if the original concrete contained potentially reactive compounds to avoid damaging reaction and durability problem. Based on its weakness plenty research have been done to improve the quality of the AMP. Results showed the advantageous effect of using mineral admixtures like fly ash, silica fume, and slag in the RAC concrete mix. Mineral admixtures use their strong filling effect and their pozzolanic properties to heal pores and cracks of the AMP. Mineral admixtures particles are much fine and can occupy the small voids in the outer layer of RCAs. Pozzolanic reactions of mineral admixtures with $Ca(OH)2$ produce a secondary C-S-H gel which strengthens the weak bond of RCAs and other concrete?s compounds (15–17)

4. Challenge of Mix Design for RAC

As a direct consequence of the AMP, water absorption is one of the most marked differences between RCAs and NAs. Almost all-available research in this area reported that RCAs manifest higher water absorption compared to NAs. Many researchers

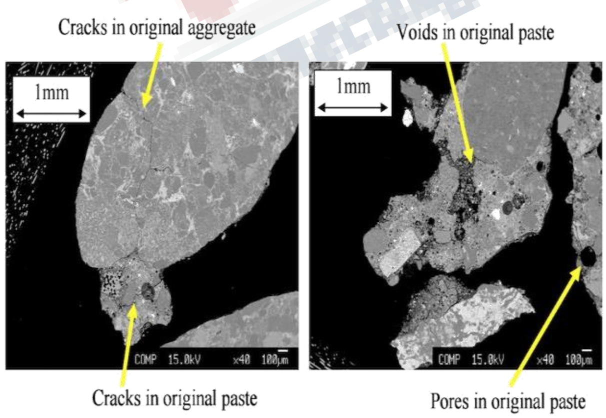

Fig. 2. Grains of recycled fine aggregate crushed by a jaw crusher (21)

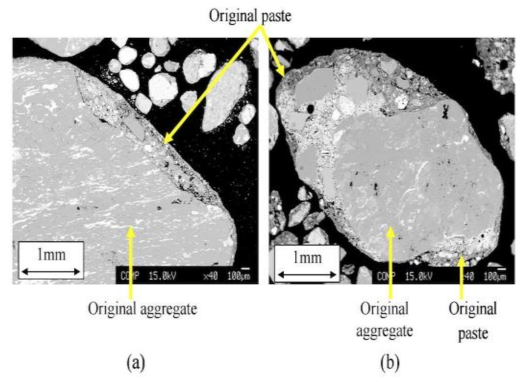

Fig. 3. Grains of recycled fine aggregate with brittle parts removed

concluded that the porous nature of this residual paste is the main reason behind this behavior (18). The quantity of water available in the concrete mix is influenced by the ability of RCAs to absorb water. Joseph et al. (19) reported that the water absorption capacity can reach 10% where as natural aggregate water absorption values less that 1%. The high water absorption capacity of RCAs should be taken into account as it can lead to shortage of water in the concrete mix, affecting the rheological properties of the freshly mixed concrete and the mechanical properties and the durability of hardened concrete. The absorption rate is different for various RCA based on its source of extraction and hence, no standard form of instructions exists for the determination of required water quantity during mix design. However, soaking RCAs for a short time before the concrete mixing can help to overcome this issue (20). But this method is not practical for concrete mass production or fine RCA's as kinetics of water absorption by RCAs is fast in the early stages when aggregates get in contact with water.

5. Imminent Qualities of RAC

The qualities of RAC are antigenic determinants for it's per-formance and durability and hence international laboratory specification codes often use a combination of performance & prescriptive determining factors, such as workability, com-pressive strength, Split tensile strength, flexural strength and water- cement material ratio to describe concrete durability and performance. From above discussion, it is obvious that concrete made with RCAs will behave differently compared to conventional concrete due to some imminent qualities. There-fore, water Absorption, workability, compressive strength, flexural Strength and tensile split are described as Imminent qualities of RAC.

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A. Reduced Workability. The workability of the fresh recycled concrete is affected by the high demand in water of RCAs.
The reduction in workability affects the overall performance of concrete. The elasticity and strength characteristics values of RCAs concrete were found to lower compared to conventional concrete. The concrete?s resistance to different deterioration mechanism may be compromised by the high permeability of RCAs and possible content of harmful substances. Therefore, it is absolutely important to thoroughly understand the influence of RCAs on the concrete structure during the design of the RCAs concrete mix proportion.

B. Increased Rate of Water Absorption. RCAs have a rela-tively high water absorption capacity. RCAs absorb a portion of water in the concrete mix, which lead to a shortage of water. The workability of the fresh concrete decreases proportionally with the increase of RCAs. Parekh et al. (22) observed that when the substitution ratio of NAs by RCAs is considerable (50% or more), the RCAs concrete had poor cohesiveness com-pared to the concrete made with only virgin aggregate. As a consequence of this lack of cohesiveness, the integrity and homogeneity of the fresh concrete during casting were affected, which in turn affected the durability and mechanical prop-erties of the hardened concrete. A pre-saturation technique, which consists in immersing RCAs in water before being used in the concrete mix, was adopted by Julia Garcia-Gonzalez et al. (20). The Results obtained proved that by immersing if RCAs in water, the consistency of the fresh concrete with RCAs can be improved. Nonetheless, this technique leads to a loss in compressive strength because it needs more water in the mix and it is unfeasible with recycled fine aggregate (23). Mirjana Malesev et al. (24) added extra water in concrete mix to get the desired workability of concrete with RCAs. The additional water was determined on the basis of the water absorption capacity of the RCAs. The workability was found to be approximately the same after 30 min. Sandrine et al. (25) used a different approach to optimize the workability. Super-plasticizers were used to improve the workability of con-crete mix with a partial or total substitution of NAs by RCAs. They observed that the compressive strength was enhanced as a result of better rheological properties.

C. Poor Mechanical Performance. The mechanical properties of concrete prepared with RCA have been extensively studied in recent years. Normally, the use of RCA as a replacement of NA affects negatively the mechanical performance of the concrete. Many researchers reported that RCA with full re-placement of NA with RCA reduces the compressive strength in comparison with the conventional concrete. A similar trend was observed in the case of tensile strength, flexural strength, elasticity of modulus, etc. The following discussion will focus on the compressive and flexural strength of RCA concrete.

C.1. Compressive Strength. The compressive strength can be con-sidered as the most important engineering property of a con-crete. Therefore, many scholars have turned their focus on the compressive strength of concrete made with RCAs. In general, research findings showed that the use of RCAs in concrete leads to severe reduction in compressive strength. The extent of this loss depends on different factors, for instance, the re-placement ratio of NAs by RCAs, concrete mix proportion (water to cement ratio), sources and quality of RCAs, the use of chemical or mineral admixtures. Amnon Katz (26) observed a reduction of around 25% in compressive strength for a full
substitution of NAs by RCAs. However, some researchers succeed to produce recycled concrete with higher compressive strength than conventional concrete. Mirjana Malesev et al. (27) stated that the influence of RCAs on the compressive strength primarily depends on the strength of the original concrete. If RCAs are obtained from concrete with higher compressive strength than the targeted compressive strength, it is possible to produce concrete with higher compressive strength than concrete produced with only NAs. Moreover, based on the results of their experimental investigation, several researchers concluded that NAs can be substituted by RCAs up to 30% without major consequences on the compressive strength.

C.2. Flexural Strength. Chen Z et. al (28) proved by experimen-tal research that the increment of recycled coarse aggregate replacement rate leads to decrement of beam rigidity which re-sults in increased beam deflection. This scenario renders RAC less fit for high tensile stress compared to ordinary concrete. Meanwhile, RA extracted from good quality concrete without impurities possesses higher strength than normal aggregates as investigated by K. Usha Nandhini et.al. (29).

D. Inadequate Level of Durability. Concrete structures are de-signed to not only ensure safety and serviceability function; they also need to keep sufficient ability to resist deterioration under a long-term service. Carbonation penetrations, chloride conductivity, alkali silica reaction, freeze thawing resistance and sulfate attack resistances are some of the concrete dura-bility indicators? parameters. The durability of a concrete is greatly influenced by its pore structure and its transport properties. We are aware that concrete with RCA have high porosity and high permeability,

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which make it more vulnerable to the aggressive attack from the environment to which it is exposed to. Research efforts showed that the use of mineral admixtures such as fly ash, silica fume and slag as replace-ment for cement or a supplement to it can ameliorate concrete durability due to densification of pore structure and reduction of permeability.

D.1. Corrosion. The Chloride penetration is together with the carbonation, the principal reasons of the reinforcement de-passivation and thereby of the reinforcement corrosion. In numerous studies, the effect of RCAs on the Chloride penetra-tion and carbonation resistance has been investigated. Results showed that with the increase of RCAs amount, the chloride penetration increase accordingly. Similarly, the increase of RCAs content resulted in lower carbonation resistance.

D.2. Sulfate Attack. RAC naturally is more permeable and has a lower density than conventional concrete and therefore, sulfates attack on RAC could be more aggressive than on conventional concrete. It is necessary to know the characteristics of RAC exposed to sulfates, so that necessary precautions can be taken to minimize the deterioration to insignificant levels. The cementing matrix of RAC is advantageous for easy penetration of sulphate ions towards and within concrete. Also, high formation rate of gypsum during the pozzolanic reaction due to plenteous availability of calcium hydroxide [Ca(OH)] in RAC.

D.3. Freezing and Thawing Resistance. Akinkurolere Olufunke Olanike (30) observed a reduction in freeze-thaw resistance
due to the saturation of the aggregates during the test. How-ever, RCAs concrete with lower water binder ratio exhibited better performance of freeze-thaw durability.

D.4. Akali-Silica Reaction (ASR). In addition, RCAs may have been already contaminated by harmful chemical substances as a consequence of the exposure of the old concrete to aggressive attacks during the previous exploitation. For instance, it is crucial to know the content of potentially reactive aggregates in the old concrete and possible continued alkali silica reaction (ASR) so as to avoid the development of ASR in the new concrete containing RCA.

6. Performance Enhancement for Future RCA

A large number of researches have been directed towards the utilization of dumped materials. To increase the performance and durability of the concrete made with recycled concrete aggregates, admixture & fiber can be used.

A. Admixtures. Chemical admixtures are added to concrete in very small amounts mainly for air entrainment, reduction of water or cement content, plasticizing of fresh concrete mix-tures or to control the setting time of concrete. The admixture increases the workability of the concrete at same water ce-ment ratio. Fly-ash and silica fume contribute in increase the resistance of recycled aggregate concrete to sulfate attack meanwhile silica fume contribute significantly in increase the steel corrosion resistance, due to cementing matrix densifica-tion and pore refinement. (28). Compressive strength loss of concretes containing recycled aggregate is less than the concretes containing natural aggregate at early age due to silica fumes usage. Also, water absorption of concretes con-taining the recycled aggregates with silica fumes is reduced significantly especially at later ages(31). Larbi Belagraa (32) reported that the recycled aggregate concrete shows the same performance compared to normal concrete for an admixture optimal dosage of 1.5%.

B. Fibres and Polymer Treatments. Fibres increase tensile & flexural strength of the concrete. Many researchers like (33–36) confirmed that, addition of fibre content in RC is only influen-tial on flexural and splitting tensile strength but the aggregate type influences the compressive strength. Adding fibre to con-crete increases cracking resistance because the fibre bridges the gap between the adjacent surfaces of existing micro-cracks, delays crack formation, and limits crack propagation.(37). On the other hand, there is a positive effect induced by polymer treatments on water absorption capacity of RCA. Polymer treatments emphasize the formation of polymeric film in pore network and allows the significant reduction of water absorp-tion capacity and consequently makes it efficient and resistant in alkali environment.(38).

C. Pre-washing & Surface treatment. Also it is expected that the efforts to surface-treat & wash recycled aggregate with acid will contributes effectively to the strength and perfor-mance of RAC. Sallehan Ismail (39) conducted a study of RCA surface-treated in calcium silicate solution and observed that the calcium silicate provides a coating layer on the RCA and functions as a microfiller that can refill and treat the cracks and pores on the RCA surface. In addition, the calcium sili-cate particles on the RCA surface causes a pozzolanic reaction
during concrete hardening that could improve the microstruc-ture of concrete by strengthening the bonds between RCA and the cement paste and consequently further enhancing the compressive strength of concrete.

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II. CONCLUSION

Recycling concrete is an important step towards eco-friendly construction practices. It reduces the amount of construction and demolition wastes, and at the same time, it lessens the depletion of natural resources. However, the use of recycled concrete aggregates leads to the loss of strength and less re-sistance to deterioration mechanism. These bad behaviors can be resolved through effective removal of the adhered mor-tar paste attached on recycled aggregates which consequently strengthens RAC characteristics. Also incorporating supple-ment admixtures materials such as fly ash, silica fume, etc. and addition of fibres can enhance the mechanical properties considering an appropriate concrete mix design. Therefore, RCA is a potential tool for sustaining green environment and as well as providing adequate level of structural performance in engineering applications if the suggested measures are con-sidered.

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BIBLIOGRAPHY

1. The Freedomia Group (year?) World Construction Aggregates - Demand and Sales Fore-casts, Market Share, Market Size, Market Leaders.

2. Tam V, Lu W (2016) Construction Waste Management Profiles, Practices, and Performance: A Cross-Jurisdictional Analysis in Four Countries. Sustainability 8(2):190.

3. Wang C, et al. (2017) Formation of the 2015 Shenzhen landslide as observed by SAR shape-from-shading. Sci. Rep. 7:43351.

4. Pepe M (2015) A Conceptual Model for Designing Recycled Aggregate Concrete for Struc-tural Applications, Springer Theses. (Springer International Publishing, Cham).

5. A. A, G. OKC, T. TC, H. ZM (2013) Effects of the Parent Concrete Properties and Crushing Procedure on the Properties of Coarse Recycled Concrete Aggregates. J. Mater. Civ. Eng. 25(12):1795–1802.

6. Akbarnezhad A, Ong K, Zhang M, Tam C, Foo T (2011) Microwave-assisted beneficiation of recycled concrete aggregates. Constr. Build. Mater. 25(8):3469–3479.

7. Pepe M, Toledo Filho RD, Koenders EAB, Martinelli E (2014) Alternative processing proce-dures for recycled aggregates in structural concrete. Constr. Build. Mater. 69(Supplement C):124–132.

8. Al-Bayati HKA, Das PK, Tighe SL, Baaj H (2016) Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate. Constr. Build. Mater. 112(Supplement C):284–298.

9. Tam VWY, Tam CM, Le KN (2007) Removal of cement mortar remains from recycled aggre-gate using pre-soaking approaches. Resour. Conserv. Recycl. 50(1):82–101.

10. Güneyisi E, Gesoglu˘ M, Algın Z, Yazıcı H (2014) Effect of surface treatment methods on the properties of self-compacting concrete with recycled aggregates. Constr. Build. Mater. 64(Supplement C):172–183.

11. Ismail S, Ramli M (2013) Engineering properties of treated recycled concrete aggregate (RCA) for structural applications. Constr. Build. Mater. 44(Supplement C):464–476.

12. Mefteh H, Kebaïli O, Oucief H, Berredjem L, Arabi N (2013) Influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened concrete. J. Clean. Prod. 54:282–288.

13. Etse G, Caggiano A, Etse G, Caggiano A (2012) Multiscale failure analysis of fiber reinforced concrete based on a discrete crack model Author ' s personal copy. (November).

14. Liu Q, Xiao J, Sun Z (2011) Experimental study on the failure mechanism of recycled concrete. Cem. Concr. Res. 41(10):1050–1057.

15. Jiu-su LI, Han-ning X, Jian-qing G (2008) Granular Effect of Fly Ash Repairs Damage of. 13(2):177–180.

16. Abd Elhakam A, Mohamed AE, Awad E (2012) Influence of self-healing, mixing method and adding silica fume on mechanical properties of recycled aggregates concrete. Constr. Build. Mater. 35(Supplement C):421–427.

17. Hai-long W, Jun-jie W, Xiao-yan SUN, Wei-liang JIN (2013) Improving performance of recy-cled aggregate concrete with superfine pozzolanic powders. pp. 3715–3716.

18. de Juan MS, Gutiérrez PA (2009) Study on the influence of attached mortar content on the properties of recycled concrete aggregate. Constr. Build. Mater. 23(2):872–877.

19. Joseph M, Boehme L, Sierens Z, Vandewalle L (2015) Water absorption variability of recycled concrete aggregates. Mag. Concr. Res. 67(11):592–597.

20. García-González J, Rodríguez-Robles D, Juan-Valdés A, del Pozo JMM, Guerra-Romero MI (2014) Pre-saturation technique of the recycled aggregates: Solution to the water absorption drawback in the recycled concrete manufacture. Materials (Basel). 7(9):6224–6236.

21. Ogawa H, Nawa T (2012) Improving the Quality of Recycled Fine Aggregate by Selective Removal of Brittle Defects. J. Adv. Concr. Technol. 10(12):395–410.

22. Parekh DN, Modhera CD (2012) Workability Study for Recycled Aggregates. 2(5):1040–1044.

23. Rodrigues F, Evangelista L, de Brito J (2013) A new method to determine the density and water absorption of fine recycled aggregates. Mater. Res. 16(5):1045–1051.

24. Malešev M, Radonjanin V, Marinkovic´ S (2010) Recycled concrete as aggregate for structural concrete production. Sustainability 2(5):1204–1225.

25. Sandrine Braymand, Pierre François, Françoise Feugeas, Christophe Fond (2015) Rheologi-cal Properties of Recycled Aggregate Concrete Using Superplasticizers. J. Civ. Eng. Archit. 9(5):591–597.

26. Katz A (2003) Properties of concrete made with recycled aggregate from partially hydrated old concrete. Cem. Concr. Res. 33(5):703–711.

27. Rashwan MS, Abourizk S (1997) The properties of recycled aggregate concrete . Concr. Int. v. 19 2:56–60.

28. Corral-Higuera R, et al. (2011) Sulfate attack and reinforcement corrosion in concrete with recycled concrete aggregates and supplementary cementing materials. Int. J. Electrochem. Sci. 6(3):613–621.

29. Nandhini KU, Jayakumar S, Kothandaraman S (2016) Flexural Strength Properties of Recy-cled. 5(5):6–11.

30. Olanike AO (2014) Experimental Investigation into the Freeze-Thaw Resistance of Concrete Using Recycled Concrete Aggregates and Admixtures. Civ. Eng. Archit. 2(4):176–180.

31. Çakır Ö, Sofyanlı ÖÖ (2015) Influence of silica fume on mechanical and physical properties of recycled aggregate concrete. HBRC J. 11(2):157–166.

32. Belagraa L, Beddar M (2013) Study of the Mechanical Performance of a Recycled Aggregate Concrete with Admixture Addition. Open J. Civ. Eng. 03(02):99–103.

33. Vodicka J, Vytlacilová˘ V (2016) Examples of Use of FRC with Recycled Concrete in Struc-tures. Procedia Eng. 151:337–344.

34. Spadea G, Bencardino F (1997) Behavior of fiber-reinforced concrete beams under cyclic loading. J. Struct. Eng. 123(5):660–668.

35. Carneiro JA, Lima PRL, Leite MB, Toledo Filho RD (2014) Compressive stress–strain behav-ior of steel fiber reinforced-recycled aggregate concrete. Cem. Concr. Compos. 46:65–72.

36. Akça KR, Çakır Ö, Ipek M (2015) Properties of fiber reinforced concrete using recycled ag-gregates. Constr. Build. Mater. 98:620–630.

37. Sahin¸ Y, Köksal F (2011) The influences of matrix and steel fibre tensile strengths on the fracture energy of high-strength concrete. Constr. Build. Mater. 25(4):1801–1806.

38. Spaeth V, Djerbi Tegguer A (2013) Improvement of recycled concrete aggregate properties by polymer treatments. Int. J. Sustain. Built Environ. 2(2):143–152.

39. Ismail S, Ramli M (2013) Effect surface treatment of recycled concrete aggregate on proper-ties of fresh and hardened concrete in 2013 IEEE Bus. Eng. Ind. Appl. Colloq. (IEEE), pp. 651–656.

