ABSTRACT

RCA: USE AND FUTURE POSSIBILITIES

by
Bushra Marium Islam

Reuse and recycling of concrete is essential for construction purposes. There has been progressive development in construction projects but at the same time it has an inverse effect on the environment. Concrete structures are built and demolished continuously all over the world, generating tons of waste materials which are actually reusable in concrete production itself. This paper emphasis on recycled concrete aggregate (RCA) and many characteristics of RCA. This paper studies RCA's different properties. RCA's replacement in the place of natural aggregate is discussed. The proper amount and researches done on RCA improvement have also been discussed for further in depth study on RCA. RCA is a convenient option for sustainability because demolishing old structures, environmental hazards on different structural etc. are a common phenomenon. They always leave the world with more waste materials that cannot be taken care of naturally. Using these waste materials to create useful structures is one responsible step towards a sustainable world.

RCA: USE AND FUTURE POSSIBILITIES

by
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RCA: USE AND FUTURE POSSIBILITIES

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DEDICATION

I want to start by thanking Allah (The almighty) who has been my support and driving force each day in a new land. I dedicate this thesis to my parents, my absolute heroes, Amirun Nessa and MD Ramizul Islam. I also want to include my two elder sisters, Rumana Islam and Rifath Fatima Islam without whom I would have never achieved what I have today.

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INTRODUCTION

1.1 Overview

In recent years, the world has become more concerned with using sustainable products in every aspect of modern living. As a part of that concern, construction materials are judged not just by their structural and durable qualities, but also by their ecological characteristics. Concrete is the second most utilized material in the world, and there for renovation and reconstruction results in a significant waste stream. Concrete recycling is becoming more important than ever before because it will eliminate this waste stream and reduce the amount of mining required to create new material [2,15].

Mining to extract aggregates causes significant damage to land and the surrounding environment. Impacts include: loss of habitat, noise, dust, blasting effects, erosion, sedimentation, and changes to the visual scene are also considered as very crucial changes while an area is considered for mining. The geologic characteristics of aggregate deposits such as geomorphology, geometry, physical and chemical quality trigger the after effects of mining. The land scape changes vigorously as well as life style of the entire area. The human lives around the area face changes of transportation and environmental changes from the effect of mining. This is a major consideration nowadays as people are more knowledgeable about how the quality of life interacts with environmental quality than ever before. The use of recycled concrete aggregates (RCA) can help reduce these initial problems of construction by providing a new source of construction quality aggregates. One very important environmental benefit of using RCA is to avoid the emissions of greenhouse gases (GHG) associated with mining and processing natural aggregates. The release GHGs are associated with global climate change, health and respiratory issues, and ecosystem instabilities. [39, 40, 49].

Approximation has been made by the United Stated Environmental Protection Agency (US EPA) that about 578 million tons of new concrete were produced in 2011. Also about 200 million tons of waste concrete are generated yearly from construction and demolition and public works projects. From there about 3 million tons of RCA is produced annually by natural aggregate producers, contractors, and recycling facilities. The US EPA mentions that approximately 50 to 60 percent of the demolished concrete is used as recycled product and the rest go to landfill. Concrete being the prominent used construction material, approximately 140 million tons of concrete are recycled each year in the industry, stated by the construction materials recycling association in 2010. Aggregates used in concrete are consumed more than two billion tons yearly in the US. We cannot say that recycling is not introduced in the aggregate sector because about five percent of these aggregates come from recycled sources, weather it is from recycling concrete or other sources.

Using available concrete as an aggregate source for use in new concrete or other applications is an effective way to reduce the waste stream created from demolished concrete and avoid the environmental issues that comes with mining and landfilling. The idea of using RCA supports the green construction and sustainable use of materials. Material produced from demolished concrete and recycled to use as new aggregate is usually referred to as recycled concrete aggregate (RCA) [39].

The properties of ordinary portland cement (OPC) concrete made with natural aggregates (NA) are understood well enough to produce high quality, durable concrete. On the other hand characteristics of concrete made with RCA are less understood. Current studies of recycled concrete, with partial substitution of natural aggregates (NA) by RCA, shows a feasible path for its application and the need of saving energy, improving environmental conditions and providing a solution for the millions of tons of construction waste generated each year. This thesis examines the properties of RCA, and their impact on the properties of concrete when used as a replacement for natural aggregate. The existing state of knowledge on the use of recycled concrete as an aggregate in new concrete is reviewed and suggestions are made concerning what further work is necessary to promote the use of RCA in new construction projects [22, 33, 43].

According to many studies and practical implementation it has been seen that, RCA in new concrete can perform equal to concrete with NA. According to the use and information available, many developed countries are trying to set up a measure to use the construction and demolition wastes to produce new concrete to improve the environment and lessen the greenhouse gas GHG effect [40, 45]

In 2009 an executive order from the office of President Barack Obama stated that 15 percent of construction and demolition debris must be diverted from landfills and recycled [51]. Canada and Europe took the same step to improve the use of construction and demolished waste [1]. In Scotland about 63% of the material was recycled in 2000. The government of Scotland is developing specifications of recycling and code of practice. In Japan, 85 million tons of construction and demolition waste has been generated in 2000. Among that 95% of concrete is crushed and reused as road bed and backfilling material and 98% of asphalt concrete and 35% sludge is recycled [45].

1.2 Use of RCA

In 1997 U. S. Geological Survey (USGS) stated that among the concrete that was recycled minimum 83% used in application over virgin aggregate, 68% recycled products weather from concrete or somewhere went to road base construction, 9% recycled products went to asphalt hot mixes. Only 6% went to concrete mixes. Concrete recycling is becoming popular as the knowledge of environment safety grows in recent days. Taxes and fees to use landfills in urban areas are increasing which is another reason to use RCA in concrete production [1, 15, 46, 49].

Environmental catastrophes like earthquake and hurricanes or manmade catastrophe like demolition ofany structure or war leave concrete wastes that can be used for further useful RCA production and further concrete production. For example, the Nepal earthquake in 2015 resulted in a significant amount of structures either collapsing or requirement demolition. A country cannot run without infrastructure.

Nepal's Department of Roads indicates that the country has 15,000 kilometers roads, which includes 21 highways and 208 feeder roads. Among them more than 2,000 kilometers or 13 percent of the network damaged or destroyed. Approximately 28 percent of Nepal's urban structures were constructed with reinforced concrete. During the earthquake approximately 10 percent of these structures were destroyed. To rebuild these structures and new additional structures, these demolished wastes can be used. No exact evidence were found if these demolished concrete were used as RCA. During that period of time, the most affected structures were unreinforced masonry structures [50]. To build a better infrastructural balance in the country Nepal has to consider more reinforced concrete structures, which will need more aggregates than ever before. If proper use and production of RCA is available, RCA can be a better option for this developing countries as well as developed countries.

1.3 RCA Particle

RCA particle carries the

- original aggregate (from the concrete that has been demolished) and
- the adhered mortar [41].

1.3.1 Adhered Mortar

The adhered mortar portion of the RCA is the hydrated or anhydrate cement paste and fine aggregate that is adhered to the RCA's coarser part. There are two interfacial transition zones (ITZ) of RCA. Both of these zones associate with adhered mortar of RCA. One zone is the original aggregate and the adhered mortar. The second zone is between the new cement mortar and the adhered mortar. The adhered mortar does not necessarily cover the entire RCA particle because of its original aggregate portion exposure.

Figure 1.1 RCA particles with a large amount of adhered mortar [3].

Subjecting RCA to large and sudden temperature variation (approximately excess of 400 degree centigrade) an approximation can be made about how much adhered mortar is present in RCA. This method was carried out by Juan and Gutierrez. It is not a standardized method of finding the amount of adhered mortar present in RCA but its results have been shown to be accurate. High temperature cause calcium hydroxide dehydration in RCA, which in turn will cause disintegration of the cement mortar. After heating in a high temperature for approximately 2 hours, RCAs are cooled in cold water causing internal thermal stresses which makes the adhered mortar very brittle. Approximately 20% to 56% presence of adhered mortar is expected in the RCA particles but more research need to be done to exactly identify the exact range [3].

CHAPTER 2

PRODUCTION OF RECYCLED CONCRETE AGGREGATE

2.1 Production

RCA is a material that is generated from used concrete. This material is a product of concrete structures that have been demolished. Recycling of concrete involves breaking, removing, and crushing of existing concrete into a material with a specified size and quality. ACI 555's document "Removal and Reuse of Hardened Concrete" gives us more information on processing old concrete into recycled concrete aggregates. Reinforcing steel and other embedded must be removed [46, 49].

To produce RCA, concrete pavements are first broken into approximately 24 in. (600 mm) pieces with a large hydraulic hammer. Concrete pavements are demolished by huge instruments which are hooked and mounted excavator. This whole instrument has a bucket attached to it. Reinforcements in this process are removed by magnetic hooks running over the demolished waste. Concrete building elements and structures like beams and slabs, initially broken by vehicle mounted impact hammers than by the use of hydraulic breakers the demolished rubbles of concrete is produced into desired size. Steel in the rubble in this case are removed by hydraulic shears and torches and afterwards finally in the processing plant one last time. Through this many layer process almost 90 to 95% steel is removable. Finally the fact that steel itself is recyclable material, helps the whole process. In the final processing plant with the use of jaw-type crusher it is made sure that all the steel is removed and the crushed resized concrete is safe to use without the steel element.

There are other contaminates that include plaster, wood, plastic, oil droppings, and other nonmetallic building materials. This are also removed at the processing plant. These processing plants are specially designed so that the removal procedure goes smoothly. Recycled concrete processing plants are very similar to those plants where virgin aggregates are processed. Almost same equipment is used with minimum variations for the removal of contaminants that are not usually found in regular aggregate deposits. The aggregate processing plant may an open or a closed system. The closed one is preferred because it allows greater control over the maximum particle size produced [46].

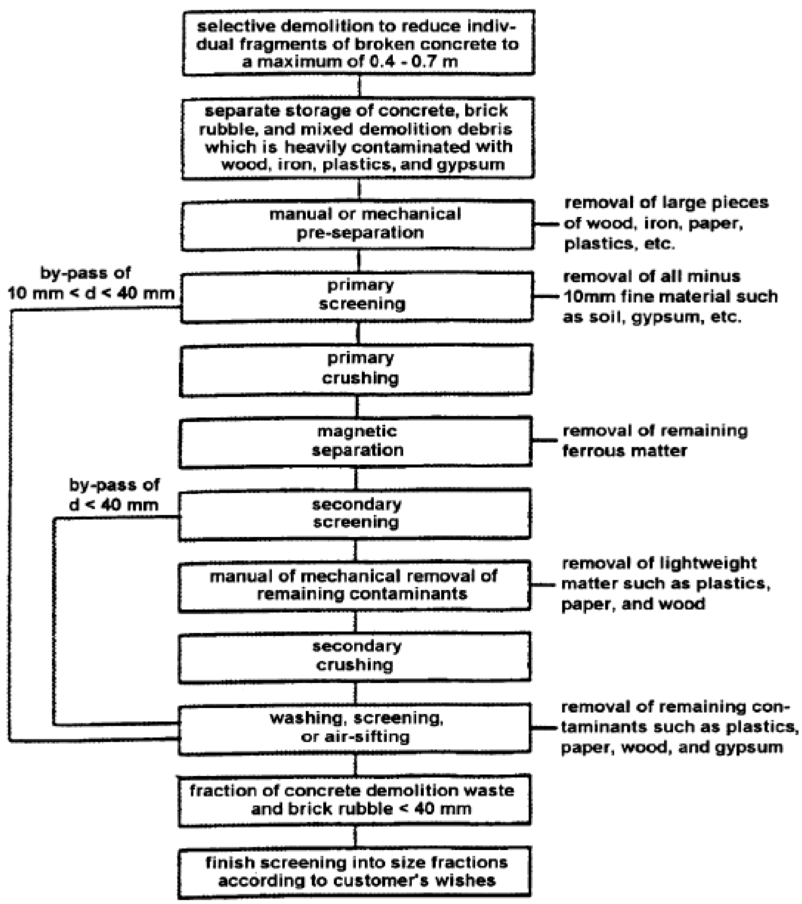

Figure 2.1 Processing procedure for building and demolition waste [46].

The figure 2.1 describes the processing flow chart that goes while recycling concrete and produce recycled concrete aggregate from it. This process involves several screening and crushing procedure in a RCA production plant. A selective aggregate size is maintained.

Generally RCA works better as coarse aggregate, so a minimum fineness size is maintained throughout the time of processing. [10,37,46]. The quality of concrete with RCA can be dependent on the quality of the recycled material. To prevent contamination by other materials for example, asphalt, soil and clay balls, chlorides, glass, gypsum board, sealants, paper, plaster, wood, and roofing materials, precautions must be taken, while production of the aggregate from demolished concrete. Concrete that has under gone deterioration that is used for RCA may result in further deterioration [39, 46]

CHAPTER 3

GENERAL CHARACTERISTICS OF RCA

3.1 Characteristics

The grading procedure for RCA is very much related to the adjustment of the jaw-type crushers at the processing plant. Once the materials have been processed, they should be sized for proper use. After screening on a No. 4 (4.75 mm) screen, the aggregates can meet any desired range by adjusting the setting of the crusher opening. It is reasonably easy to produce acceptable coarse aggregates from recycled concrete [39]. Recycled concrete aggregates produced from weak concretes cannot be expected to pass the gradation whereas if the parent concrete is good enough the aggregates made from that concrete can pass the tests same as NA.

RCA particle carries the original aggregate and the adhered mortar that clings with the crushed concrete particle. The adhered mortar is the product of the parent cement paste and original fine aggregate [41]. Adhered mortar has involvement in some of the important characteristics of RCA. Adhered mortar reduces the specific gravity and increases the porosity compared to similar virgin aggregates. This higher porosity of RCA leads to higher absorption [3,4].

CHAPTER 4

IMPACT OF RCA ON CONCRETE PROPERTIES

Concrete properties tend to be impacted when the NA is replaced with RCA. The impact will be made worse or better depending on the amount of RCA used. Research suggests that a maximum replacement ratio of 30% RCA be used.. A 100% replacement of RCA is still not suggested. Generally RCA used as coarse aggregate is more supported than using RCA for both fine and coarse aggregate [3, 58].

The following section will give an idea of the different concrete properties and how they behave when NA replaced with RCA.

4.1 Workability

Workability refers to the ease of placement. Workability relates to strength and durability with the placement of concrete. If it is not placed well, the strength and durability will get affected. Workability is a measurement of the ability to place concrete and move it around the formwork. Thus how it is related with the finished product. Concrete is workable when it is easily placed and compacted homogeneously, and does not excessively bleed or segregate. Concrete that has poor workability requires more effort to be compacted in place and can result in concrete that has poor strength or durability. Water content in the concrete mix, amount of cement and its properties, aggregate grading, nature of aggregate particles shape, surface texture, porosity, temperature of the concrete mix, humidity of the environment, mode of compaction, method of placement and compaction of concrete are the factors that can influence workability [3,46].

Workability is tested by slump test. Concrete slump test is generally done by using slump cone with the top diameter 10 cm, bottom diameter 20 cm and height 30 cm. Slump test has limited results for concrete containing aggregates larger than 40 mm. The slump test also is not suitable for concrete with a high flow. Depending on its best use the limitations can be ignored [35,46].

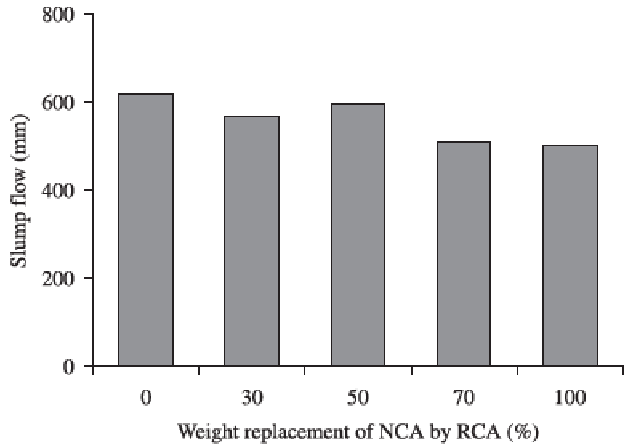

Figure 4.1 Slump of concrete for different RCA contents [4].

In figure 4.1 shows the slump heights as slump flow and the changing of these height with different RCA replacement ration. We can see that with the increasing amount of RCA the workability decreases.

Workability has been shown to be one of the most affected properties when RCA is used in a concrete mixture. More bleeding and less stability was also found in concrete with RCA [34]. The rough texture of RCA comes from the adhered mortar which decreases the workability. The harshness of RCA is due to the adhered mortar which triggers a bad workability [24].

Deficiency in gradation of RCA can also contribute to the poor workability of concrete [46]. The RCA used as coarse aggregates shows lesser decrease in workability than when RCA used as fine aggregate. Approximately 5% additional water while mixing was required for a recycled coarse aggregate concrete to produce a satisfactory workability. Whereas approximately 15% more water was needed to produce the same workability when both fine and coarse RCA was used in concrete [46]. Replacement percentages also have impact on workability. When replacing approximately 30 to 50% RCA with NA, the workability does not decrease significantly. Replacing RCA by 70 to 100% in use instead of NA will show more significant decreases in workability [4].

Workability of concrete using RCA is dependent on particle shape variations in the RCA. The angular shape and rough surface texture of the recycled aggregates lowers the slump value by increasing the inter particle friction of fresh concrete [3,4]. This texture is a result of adhered mortar. Adhered mortar gives a rougher surface due to its inhomogeneous amount over the RCA particles. Adhered mortar also initiates the more angular shape of RCA. While producing the RCA these factors need to be taken account very importantly [3,4,46].

Absorption capacity is one of the very important factors of RCA that impacts concrete workability and the water-cement ratio. High water absorption capacity of RCA has a negative impact on workability. This higher absorption is due to the adhered mortar. Having the RCA in saturated surface dry (SSD) condition is an option to counter this phenomenon but it is not appropriate for big projects. Using the RCA in SSD condition at mixing time often can create deleterious effects on the hardened properties of the concrete, on the contrary air dry RCA can give a better-quality concrete than SSD RCA. Limiting the amount of RCA to 30% while the saturated surface dry (SSD) condition before mixing can prevent the workability issues associated with RCA's increased absorption capacity [24]. Adjusting the water amount while mixing is so far, the most effective way to achieve a required amount of workability. The additional water amount for approximate 50% replacement of RCA is 10% and for 100% replacement of RCA is 20% while an extra 30 minutes of time required achieving the appropriate workability [11]. Superplasticizers or different admixtures can be used to increase the workability without impacting other properties [5, 34]. Use of water reducing admixture can be helpful even when the NA replaced 100% by the RCA. The admixture can be used by not harming any particular properties of concrete. The low strength admixtures in this case are more useful than the high strength ones. ASTM C494 type A admixtures can serve this cause perfectly [47]. When using high percentage of recycled aggregate in concrete, 25–35% of fly ash use could help to have a required slum result like NA. With the highest amount of replacement the fly ash amount should be adjusted as well to get a better workability [32].

4.2 Compressive Strength

Concrete compressive strength is tested for every batch to maintain the desired quality of concrete during casting in batching plant laboratories. Structural member strength is known from the compressive strength of concrete. To determine the strength of concrete, specimens are casted and tested under the action of compressive loads. Compressive strength is calculated by dividing the failure load with the area of application of load. The 28 day curing is done for the test. Lower the water to cement ratio higher strength. That is why w/c ratio is an important factor for strength of concrete. Aggregates (coarse and fine), water, proportioning of cement and various admixtures controls the strength [18].

The replacement ratio of RCA for NA has been shown to be the main factor that impacts compressive strength in concrete made with RCA such that higher replacement ratios result in lower compressive strengths [1]. The porousness of the adhered mortar attached to RCA is one reason of low compressive strength [3,4].

RCA has some qualities that, if used with proper replacement of NCA, can increase the compressive strength. RCA can create better interfacial bonds between aggregate and cement paste because the rough texture and angular shape help particles to form good interlocking. 10% and 12% higher compressive strength can be seen of concrete using RCA compared to NA if the RCA is rough surfaced and angular assuming similar w/cm are used. Angular shape and roughness do decrease workability but superplasticizers are used, this negative sides of RCA can turn give a positive outcome [3, 18, 20].

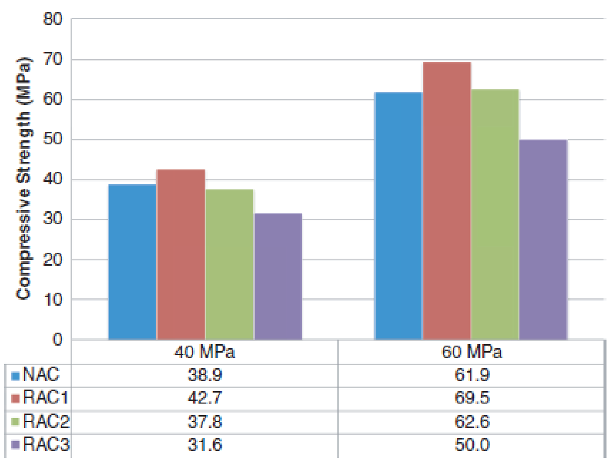

Figure 4.2 Compressive strength of concrete for different RCA contents [3].

The figure 4.2 describes how different compressive strengths are achieved and how some RCA behave even better than NA (RCA1).

Curing is a very important factor when it comes to compressive strength of RCA used concrete. Better and longer period of time for curing gives good results when it comes to concrete used RCA. Different kind of curing processes gives different compressive strength results.. Curing using paint material gave better results than water or air curing When used 25-50% RCA in concrete the air curing process gave the highest compressive strength than water curing [14, 28].

Keeping the w/c ratio same for NA and RCA concrete, an aggregate with a specific gravity of more than 2.5 and an absorption capacity of less than 4.5%, it is possible to have insignificant change in compressive strength between concrete made with NA or concrete made with RCA. The replacement amount should be carefully controlled, but this has shown accurate results with a higher replacement as well [7, 24].

4.3 Porosity and Permeability

Porosity is proportion of total volume of the concrete that is occupied with by voids and generally expressed as percentage. Permeability is a measure of the rate of flow of water through the pores in concrete. While permeability is related to porosity, it is the interconnectivity of the pores that is more impactful on the total amount of permeability than the total amount of porosity. If the pore system is discontinuous, the permeability of concrete will be low, even if the concrete has high porosity [29, 36].

RCA concrete can be regarded as porous concretes since it tends to have permeability values that are higher those of ordinary concretes. The porosity of RCA is higher than that of the natural aggregates, about 10 to 12%. It is observed that the increased porosity of the aggregate caused an increase in the porosity of concrete made with RCA by 3.8% compared to NAC after casting for 90 days. This higher porosity is present due to the adhered mortar which is a porous material [1]. There is an inverse correlation between the volume of pores and the levels of stress to which the concrete can be subjected This relationship should also take into account the distribution of the sizes of the pores and the interconnection between the pores, which will also be important for permeability [29].

The permeability of concrete with 100% RCA replacement was found to have 8.2% more permeable voids than the NA concrete. Due to a higher amount of porous adhered mortar, an increase in porosity of RCA is found which leads to higher amount of permeability in RCA. [4, 36]. It has been seen that when all fine aggregates are replaced by RCA, the relevant cement matrix is more porous than when half of the amount of fine aggregate is replace by RCA. Thus replacing RCA in an accurate amount by checking which amount is giving an acceptable result to concrete properties, is very important [14].

The porosity of RCA concrete is very important because it better describes and correlates the durability properties of concrete. The use of RCA causes an increase in the water permeability of concrete because of the porous nature of adhered mortar. Diffusion capacity of RCA concrete is also increased because of the porous nature. Diffusion is related to cement paste and the transition zone in the interfaces of surrounding aggregates.

When it comes to RCA, because of its already porous nature, the diffusion capacity increases too. This increase is proportional to amount of RCA used. Although the variations in equivalent penetrations can be more or less equal, there is still the risk of maximum penetration at specific points. This penetration may be explained by the fact that an RCA locates itself close to the concrete surface, thus being porous and permitting the entry of fluids. RCA has high porosity levels that can facilitate the flow inside the concrete [36]. This will ultimately cause low durability of the concrete because aggressive agents such as chlorides, water, and carbon dioxide can move through the concrete more quickly.

4.4 Other Properties

Concrete with RCA has an increased water absorption capacity. Concrete with RCA also has decreased bulk density, decreased specific gravity, and increased abrasion loss, increased quantity of dust particles, increased quantity of organic impurities with concrete which is mixed with earth during building demolition, an approximate content of chemically harmful substances [8, 38].

Concrete with RCA also has increased drying shrinkage than concrete with NA because of the high absorption capacity. This increase was more in high strength concrete then in low strength concrete. It is up to 20 -50% high. RCA used concrete has increased creep in between 30-60%. This is because of the adhered cement paste which increases the paste volume of concrete which is proportional to creep. When it comes to splitting and flexural tensile strength the difference between NA and RCA used concrete is not majorly different. This is a good sign for RCA so that NA can be replaced without any unknown changes. On average, a 10-20% decrease might happen if the parent concrete of RCA is bad. A decrease in modulus of elasticity up to 10 to 33% was seen when RCA used as coarse aggregate [38,46].

CHAPTER 5

METHODS OF IMPROVING RCA CHARACTERISTICS

The two main approaches for enhancing the properties of RCA consist of reducing the adhered mortar content and decreasing the water absorption capacity of RCA.To improve the behavior of RCA and make it more acceptable to use then before, many researches are developing. We understand the need of using recycling materials but at the same time, structural safety and work ethic also have to be followed. This is where RCA's contradictory low compressive strength, lower workability etc stop the vast use of it. This qualities can be improved with a proper and elaborate study of following suggestions which are found to be helpful for improvement of RCA.

5.1 Carbonation of Aggregates

Carbonation treatment helps RCA to improve its properties by reducing the porosity of the adhered mortar. Carbonation treatment also reduces the interfacial transition zone around the RCA [35].

In RCA, carbonation treatment will cause a reaction between CO_2, $Ca(OH)_2$ and the calcium silicate hydrate (C-S-H). This reaction will provide $CaCO_3$ and silica gel. This gel helps to fill up the pores of the adhered mortar. This increases compressive strength and decreases drying shrinkage of RCAs. $CaCO_3$ and silica gel will also increase the solid volume of RCA thus increasing the density, and decreasing the water absorption and crushing values of the RCAs [6].

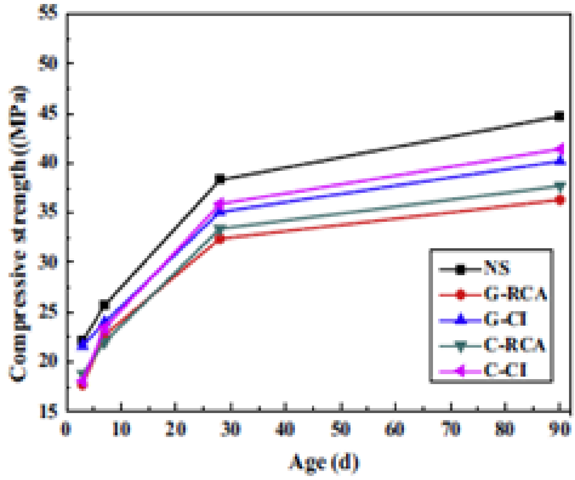

Figure 5.1 Concrete properties after carbonation [8].

Carbonation of reinforced concrete causes a decrease in the alkalinity of the pore solution. This phenomenon has a negative effect. This tend to decreases the pH level of concrete and if the pH level of concrete decreases below 11.5 the protective passive iron oxide layer on the reinforcement steel begins to be destroyed. This increases the risk of corrosion. This effect needs to be tested and verified properly to make sure of its occurrence and prevention [1].

5.2 Chemical Properties

The use of low concentrated acid helps to reduce the amount of adhered mortar. In order to really get an useful result it specifically has to be a low concentration acid. This process also helps surface contact of RCA with cement paste. This use of low concentrated acids depends on the how much of an amount (molarity) can be used and how much time RCA has to be soaked in them. This method needs development but now even with initial experimental uses, this method shows positive results. The molatity of this low concentrated acid should be 0.1M and 0.5 M and the soaking period of RCA in acid should not be more than 3 days to improve compressive strength [9].

RCA’s different behavior from NA came from its irregularity and rough surface. Use of lime and gypsum to increase the hydration reaction can improve the bond strength of RCA and the new concrete. [13, 17].

CHAPTER 6

RECOMMENDATIONS

Recommendations can be suggested to improve the quality of RCA and increase RCA use as follow:

1. During production it should be ensured sure that the process is very smooth and monitored. Improvement of crushing the concrete to produce RCA can improve RCA quality. The better the crushing there will be less adhered mortar attached to RCA [46]
2. Studying the adhered mortar and finding its amount on a certain batch of RCA to be used in the concrete, could be the biggest help towards knowing how that particular RCA batch will work. Getting rid of adhered mortar by temperature increase during RCA production is a good research which should be done further. There should be more research on finding the ways of getting rid of adhered mortar portion of RCA.
3. Carbonation can be a very useful procedure to make RCA improvement. Carbonation creates a gel which forms a layer which reduces RCA's excessive water absorption quality. This leads RCa to be a better aggregate.
4. Using low-concentration of acid is another very effective way to reduce the amount of adhered mortar from RCA surface thus improving its quality of compressive strength. Distinctive further research on this can lead to a big improvement of RCA.
5. Limiting RCA amount to 30% when no other conditions can be changed, can serve as a good use of RCA.
6. For its brittle nature, while processing from parent concrete, RCA should not be use as fine aggregate.

CHAPTER 7

CONCLUSION

The use of recycled concrete aggregate as a replacement of natural aggregate can positively affect the concrete production and the environmental issues that come with concrete production with natural aggregate. Construction is a constant process. The environmental issues comes with concrete constructions are the most common phenomenon in modern world because of growing population on earth. The ways to make it environment friendly is equally very important to protect the same population and give them a better environment to live. The mining and landfilling processes that comes with production of new concrete, which have severe negative effects on environment, can be reduced if RCA is used. The amount of concrete structure demolishment can make to a useful event if RCA can be produced and used from them.

REFERENCES

1. Adams, Matthew P. "Alkali-silica reaction in concrete containing recycled concrete aggregates." Diss. 2012.
2. Oikonomou, Nik D. "Recycled concrete aggregates." Cement and concrete composites 27.2 (2005): 315-318.
3. Butler, Liam, Jeffrey West, and Susan Tighe. "Effect of recycled concrete aggregate properties on mixture proportions of structural concrete." Transportation Research Record: Journal of the Transportation Research Board 2290 (2012): 105-114.
4. Alengaram, Ubagaram Johnson, et al. "Properties of high-workability concrete with recycled concrete aggregate." Materials Research 14.2 (2011): 248-255.
5. Kubissa, Wojciech, et al. "Properties of concretes with natural aggregate improved by RCA addition." Procedia Engineering 108 (2015): 30-38.
6. Zhang, Jiake, et al. "Performance enhancement of recycled concrete aggregates through carbonation." Journal of Materials in Civil Engineering 27.11 (2015): 04015029.
7. Mefteh, Houria, et al. "Influence of moisture conditioning of recycled aggregates on the properties of fresh and hardened concrete." Journal of Cleaner Production 54 (2013): 282-288.
8. Silva, R. V., J. De Brito, and R. K. Dhir. "Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production." Construction and Building Materials 65 (2014): 201-217.
9. Ismail, Sallehan, and Mahyuddin Ramli. "Engineering properties of treated recycled concrete aggregate (RCA) for structural applications." Construction and building Materials 44 (2013): 464-476.
10. Neno, Catarina, Jorge de Brito, and Rosário Veiga. "Using fine recycled concrete aggregate for mortar production." Materials research 17.1 (2014): 168-177.
11. Arulrajah, A., et al. "Geotechnical properties of recycled concrete aggregate in pavement sub-base applications." (2012)
12. Limbachiya, M. C., T. Leelawat, and R. K. Dhir. "Use of recycled concrete aggregate in high-strength concrete." Materials and structures 33.9 (2000): 574.
13. Butler, L., J. S. West, and S. L. Tighe. "The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement." Cement and Concrete Research 41.10 (2011): 1037-1049.
14. Manzi, S., C. Mazzotti, and M. C. Bignozzi. "Short and long-term behavior of structural concrete with recycled concrete aggregate." Cement and Concrete Composites 37 (2013): 312-318.

15. Qasrawi, Hisham, and Iqbal Marie. "Towards better understanding of concrete containing recycled concrete aggregate." Advances in Materials Science and Engineering 2013 (2013).
16. Bhusal, Sushanta, and Haifang Wen. "Evaluating recycled concrete aggregate as hot mix asphalt aggregate." Advances in Civil Engineering Materials 2.1 (2013): 252-265.
17. Sas, Wojciech, A. Głuchowski, and A. Szymański. "Cyclic Behavior of Recycled Concrete Aggregate Improved with Lime and Gypsum Addition." Proc. 4th International Conference on Geotechnique, Construction Materials and Environment. Vol. 1. 2014.
18. Uche, O. A. U. "Influence of Recycled Concrete Aggregate (RCA) on Compressive Strength of Plain Concrete." Pan 8.2 (2008): 0-17.
19. Zhang, Jiake, et al. "Influence of carbonated recycled concrete aggregate on properties of cement mortar." Construction and Building Materials 98 (2015): 1-7.
20. Khayat, Kamal H., and Seyedhamed Sadati. "Recycled Concrete Aggregate: Field Implementation at the Stan Musial Veterans Memorial Bridge." National University Transportation Center (NUTC), Missouri University of Science and Technology, Rolla, MO, USA (2014).
21. Qin, Yinghong, and Haifeng Yang. "Carbonation dominates the acid intake of recycled concrete aggregate subjected to intermittent leaching." Construction and Building Materials 89 (2015): 110-114.
22. Abdelfatah, Akmal S., and Sami W. Tabsh. "Review of Research on and Implementation of Recycled Concrete Aggregate in the GCC." Advances in Civil Engineering 2011 (2011).
23. Volz, Jeffery S., et al. "Recycled Concrete Aggregate (RCA) for Infrastructure Elements." National University Transportation Center (NUTC), Missouri University of Science and Technology, Rolla, MO, USA (2014).
24. Paul, Suvash Chandra, and Gideon PAG van Zijl. "Mechanical and durability properties of recycled concrete aggregate for normal strength structural concrete." International Journal of Sustainable Construction Engineering and Technology 4.1 (2013): 89-103.
25. Aguacil, S., S. Lufkin, and E. Rey. "Expanding Boundaries: Systems Thinking for the Built Environment."
26. Sadati, Seyedhamed, and Kamal H. Khayat. "Field performance of concrete pavement made with recycled concrete aggregate." International Symposium on Environmentally Friendly Concrete-ECO-CRETE, Reykjavik, Iceland .2014.
27. Verian, Kho Pin, et al. "Chloride ion penetration resistance of concretes containing recycled concrete aggregate (RCA)."
28. Abdel-Hay, Ahmed Shaban. "Properties of recycled concrete aggregate under different curing conditions." HBRC Journal (2015).

29. Gómez-Soberón, José MV. "Porosity of recycled concrete with substitution of recycled concrete aggregate: an experimental study." Cement and concrete research 32.8 (2002): 1301-1311.

30. Rajalakshmi, R., and P. Revathi. "Geo-polymerization of recycled concrete aggregate." Development 3.6 (2016).

31. Sayed, M. S. "Fabrication of Concrete Paving Units from Recycled Concrete Aggregate."

32. Kubissa, Wojciech, Roman Jaskulski, and Pavel Reiterman. "Ecological Concrete Based on Blast-Furnace Cement with Incorporated Coarse Recycled Concrete Aggregate and Fly Ash Addition." Journal of Renewable Materials (2017).

33. Kolay, Prabir K., and Moses Akentuna. "Characterization and Utilization of Recycled Concrete Aggregate from Illinois as a Construction Material." Geo-Congress 2014: Geo-characterization and Modeling for Sustainability. 2014.

34. Hosseinian, M., Nili, M., Biglari joo, N. and Ahmadi, S. “Semi-experimental formulas to predict the reactions between mechanical properties of recycled concrete” 2nd International RILEM Conference on Progress of Recycling in the Built Environment 2-4 December 2009, São Paulo, Brazil.

35. Shi, Caijun, et al. "Performance enhancement of recycled concrete aggregate A review." Journal of Cleaner Production 30 (2015): 1e7.

36. Gómez Soberón, José Manuel Vicente, Luís Agulló Fité, and Enric Vázquez Ramonich. "Repercussions on concrete permeability due to recycled concrete aggregate." CANMET/ACI Internacional Symposium on Sustainable development of cement and concrete. VM Malhotra, 2001.

37. Evangelista, Luís, and J. De Brito. "Durability performance of concrete made with fine recycled concrete aggregates." Cement and Concrete Composites 32.1 (2010): 9-14.

38. Malešev, Mirjana, Vlastimir Radonjanin, and Snežana Marinković. "Recycled concrete as aggregate for structural concrete production." Sustainability 2.5 (2010): 1204-1225.

39. Langer, William H., and Belinda F. Arbogast. "Environmental impacts of mining natural aggregate." Deposit and geoenvironmental models for resource exploitation and environmental security. Springer Netherlands, 2002. 151-169.

40. Binstock, Matt, and Maureen Carter-Whitney. “Aggregate extraction in Ontario: a strategy for the future.” Canadian Institute for Environmental Law and Policy, 2011.

41. Adams, Matthew P., and Jason H. Ideker. "RCA's better picture." Roads & Bridges 50.2 (2012).

42. Hansen, T.C., Ed.; Taylor and Francis. "Recycling of Demolished Concrete and Masonry" Oxfordshire, UK, 1992; p. 316.

43. A. Rao, K.N. Jha, S. Misra. "Use of aggregates from recycled construction and demolition waste in concrete." Resources, Conservation and Recycling 50 (2007)

44. Sonawane, Tushar R., and Sunil S. Pimplikar. "Use of recycled aggregate in concrete." International Journal of Engineering Research and Technology (IJERT) 2.1 (2013)

45. Committe, A. C. I. "555: Removal and Reuse of Hardened Concrete-ACI 555R-01." ACI Committee, Detroit (2001).

46. Barbudo, Auxi, et al. "Influence of water-reducing admixtures on the mechanical performance of recycled concrete." Journal of Cleaner Production 59 (2013)

47. Buck. "Recycled concrete as a source of aggregate." ACI Journal, 74 (2977) 212-219

48. U.S. Environmental Protection Agency, Estimating 2003 building-related construction and demolition materials amounts, in: U.S. Environmental Protection Agency (Ed.), U.S. EPA, 2009.

49. Goda, Katsuichiro, et al. "The 2015 Grkha Nepal earthquake: insights from earthquake damage survey." Fronties in Built Environment 1 (2015):8.

50. B. Obama, Executive Order 13514 - Federal leadership in environmental, energy, and economic performance, in: N.A.A.r. Administration (Ed.), National Archives And records Administration, Washington, D.C., 2009.