International Journal of Emerging Technology and Innovative Engineering
Volume 2, Issue 1, January 2016 (ISSN: 2394 – 6598)

RECENT DEVELOPMENT ON USE OF DEMOLISHED CONCRETE AS COARSE AGGREGATES

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ABSTRACT:

Growing demand of infrastructure to meet the need of increased and migrated population to city centers results in construction of new buildings and roads. This result in increased consumption of natural aggregates also produce huge quantum of demolished concrete. This waste is generally dumped in landfills which are at far distances in urban area. Transportation of this waste thus creates the economical and environment problems. To overcome these problems idea of recycled aggregates has started and is active area of research. This article studies the recent developments of using demolished concrete as aggregates. It is believed that the study will prove a good starting point for new researchers and will be helpful for further research in the field.

Key Words: Alternative Aggregates, Recycled Aggregates, Green Concrete, Demolished Concrete.

1. INTRODUCTION

Starting with living in natural shelter; caves; peoples always kept on looking for safe and sound place to live. Which may give them safety against natural hazards i.e. rain, storm, wild animals, and against disturbance i.e. privacy and theft. With passage of time, mud and wood provided peoples the source to construct required shelter. Both of the materials remained intact for centuries and peoples created drastic and amazing structures out of it. Lime and stone were other components which not only added durability to the structures but also facilitated the peoples to construct structures of their choice. To this end structures made of these materials are yet amazing and wonders to present era. A big revolution was observed with advent of concrete in 1760. It was not until the development of newly found material stabilized in 1824. Since then faster pace of development of infrastructure is observed. Number of buildings in all cadres of structures i.e. single unit, multi-story buildings and sky scrapper increased drastically with the increase in population, particularly shift/migration of rural population to urban area.

Main aggregates of conventional concrete are cement, sand and stone. When properly designed for desired strength results in paste which becomes hardened with time. The self-weight of this material is far higher than other material like mud-construction, wood-construction etc. However, the durability and lesser maintenance cost made concrete the most widely used material in construction industry. With time and modern techniques of construction and to deal with the population problems existing buildings were and are being demolished to erect new better looking and with more space are being constructed. The waste resulting from demolishing the concrete structures were deposited in un-used areas of the cities. Lack of space to dump this waste is the main problem all over the world now. Some portion of this waste is utilized to raise the ground level particularity in road construction. But amount of waste used in this regard is less compared to the amount need to be treated well. Therefore, there is growing interest to make use of this material as an alternative aggregate in concrete construction.

This paper deals with the recent developments of using recycled concrete as aggregate in concrete construction. It is hoped that the article will give good insight of the topic and will prove a good starting point for new scholars and will be land mark for further research in the area.

2. SECONDARY AGGREGATES

In normal concrete, aggregates used are sand and different sizes of stones. Roughly 70% to 80% of concrete volume is of aggregates, and was generally believed that aggregates are filler in concrete having little effect on finished concrete. But it is already proved through research that these component contributes much in determining stability, workability, durability and strength of the concrete. Two main issues with conventional concrete remained hot since long. First is the finding of alternative ingredients or materials to enrich the strength and second is the use of waste obtained from demolishing of existing concrete structures. In this regard secondary and recycled aggregates have been studied.

Secondary aggregates are those materials which can be used as aggregates but are not conventional parts of normal concrete, i.e. clay, slate or metallurgical waste. But it is found that these aggregates have strong regional properties. Standardized use of such aggregates can be limited to particular region only. Ceramics[1][2], crushed bricks[3][4][5], fine recycled aggregates[6], fiber composites[7], steel fibers[8][9], plastic plates[10], fly ash[11], polymers[12], bentonite[13], FRPs[14], glass[15][45] and foundry sand[44], are the few among many which have been studied. Among these materials glass has the potential to be used as secondary aggregate. But glass may cause problem due to alkali silica reaction between the cement paste and the glass aggregate resulting in decreased long term durability and thus strength. This problem can be copped by using additives to stop or decrease the alkali-silica reaction. Possible uses of concrete made with glass as secondary aggregate may be footpaths, walkways and similar sort of non-structural works.

3. DEMOLISHED CONCRETE AS AGGREGATE

Recycled aggregates are those obtained from waste of mineral wastes, construction and demolishing of structures. Waste can be defined as any substance or object that the holder wants to discard. A significant proportion of construction and demolition waste is the Portland cement concrete. Various scholars have studied the possibility of using recycled concrete to prepare new concrete with sustainability[16]-[19][40]. The waste is purchased/obtained from the owner and then is processed with dedicated equipment. Proper processing of demolishing waste for using it as recycled aggregate to save the space needed to dump the same and to save the natural resources of conventional aggregates has become the need of the day in many countries. In this regard many countries i.e. Wales, UK, Brazil, European Commission, Japan has started developing essential policies for proper treatment of the waste. The processing can be in-situ (at site where they arise) or ex-situ (some central processing plant). Good cost saving can be achieved by doing in-situ processing however quality compromise may be required in case of in-situ processing. No matter what recycling process is to be used but the aggregates must be clean, i.e. without absorbed chemicals, clay or other coatings which may alter the hydration process of the cement thus the strength.

Generally, concrete with recycled aggregates has higher absorption and lower specific gravity than conventional aggregate concrete. Concrete made with recycled concrete aggregate has good workability and durability but lesser compressive strength than conventional concrete. Variation of compressive strength depend upon water-cement ratio as in conventional concrete. It is found that concrete with recycled aggregates has one third lesser compressive strength and modulus of elasticity of normal concrete[21]. However un-availability of reliable data on subject matter hinders its use.

While using recycled concrete as aggregate following are the few main points which may pose problem to the resulting concrete if not treated properly.

1. Water cement ratio and cement content.
2. Recycled aggregated if contained fines of Portland cement will reduce strength because fines of Portland cement have 8 time more absorption than fines of natural aggregates. However, these fines may be helpful if coarse aggregates are used in road sub-base as it restrict the drainage.
3. Inadequate aggregate soundness.
4. Contamination of recycled aggregates.
5. Packing density and drying shrinkage of recycled aggregates, both differ from those of natural aggregates, thus can lead to variation of concrete properties.
6. Percentage of admixtures if used.
7. Durability of recycled aggregate itself, particularly long term durability.

4. RECENT DEVELOPMENTS

Use of recycled materials is discussed by Vyncke et al. [22][23] with good details of barriers due to data and other problems. Recycled concrete has been widely used for base layers in roads and air-field pavements[24][25] but the recycled material was used in varying percentage less than 100%. The first big project with 100% recycled material is carried out in Christchurch, Brazil[26]. The 300 m long stretch on golf links road is a busy section of road behind a shopping mall with high number of heavy service vehicles. The project is serving the purpose well.

Hendriks et al[27] used recycled concrete as coarse aggregate to study its properties. He used recycled aggregates up to 20% by weight of normal aggregates. The author concluded that with 20% replacement there is little effect on basic properties of new concrete. But reasonable difference in properties may be observed if the percentage of recycled aggregates is increased. Since recycled aggregates has higher water absorption rate, thus increasing percentage of recycled aggregates will need to control water-cement ratio. Kikuchi et al[28] also conducted the similar sort of study but with different percentage of recycled aggregates and concluded that extent to which properties of new concrete are affected depends on water absorption, soundness and crushing value of the recycled aggregates.

Poon et al[29] made use of recycled aggregates to study and develop technique for bricks and blocks. They used construction and demolition waste as replacement of both fine and coarse aggregates. According to their test results there was little effect on compressive strength of brick and blocks with replacement of coarse and fine natural aggregates at level of 25 % and 50%, but they obtained reduced compressive strength with higher level of replacement. Further the authors observed increase in the transverse strength of bricks and blocks with increase in the percentage of recycled aggregates. They also tried 100% replacement of natural aggregates and obtained compressive strength not less than 49 MPa (7105 psi) at 28-day curing, which is the minimum requirement of BS code for pavements. The authors also used fly ash as fine aggregate and compared the test results with results of blocks prepared from cement alone and observed a decrease in compressive strength for blocks with fly ash.

To save the sources of virgin aggregates of concrete and the natural landfills where generally waste is dumped, Fong and Yeung[30] discusses waste management problems in Hong Kong and elaborated production and application of recycled aggregates with emphasis on the difficulties in promotion and its use in concrete production.

Fong et al[31] mentioned that about 14 million tons of waste is being obtained from construction and demolition each year in Hong Kong. It possesses a great problem to dump it properly. Therefore, to reduce burden on the landfills of Hong Kong they started a test project in West Land Park of Hong Kong where most of the structures are built with recycled aggregates. Although RILEM[32] specifications are generally followed for using recycled aggregated but to carry out this project the authors adopted Hong Kong Work Bureau specifications[33] for use of recycled aggregates. These specifications make use of local condition and trends of construction in Hong Kong. Before moving to real project the authors tested 40 samples of concrete with recycled aggregates from construction and demolition for C20 and C35 grades. Natural aggregates were replaced with recycled concrete aggregates in range of 20% to 50%. Water-Cement ratio adopted for test samples was in the range of 0.466 to 0.603 for C35 to C20. Based on their tests they achieved 28-day compressive strength in the range of 47.3 MPa to 32.8 MPa for C35 to C20 grade concrete. On the other end Knights[51] found that concrete for compressive strength of 45 MPa can be produced using 60% of recycled concrete aggregates.

In another study about mechanical loss of strength in concrete with recycled aggregates, Coppola et al[34], argues that this loss is mainly due to the quality of the aggregates used. However, this loss is completely eliminated when the aggregates are recycled concrete of same or higher grade than new concrete in which they are supposed to be used. However prior knowledge of the grade of demolished concrete is difficult without some testing. Which certainly will increase the cost component of new concrete.

Oad and Memon[35] used old concrete from Nawabshah City as partial replacement of natural coarse aggregate to test the compressive strength of concrete cylinders. The authors used 0%, 5%, 15%, 25%, 35%, 45% and 50% replacement of natural coarse aggregates with coarse aggregates from old concrete with concrete mix ratio of 1:2:4 and 0.45 – 0.6 water cement ratio. The authors argued that variation in water cement ratio is to keep the concrete workable as increased percentage of aggregates from old concrete demand more water due to old mortar attached with it. Based on the testing of 324 cylinders the authors report that maximum of 26% loss in strength with 50% replacement of natural aggregates. Hence conclude that coarse aggregates from old concrete can effectively be used as replacement of natural coarse aggregates in areas where load bearing power of the concrete members is less important.

Memon and Bhatti[36] used old concrete to study the flexural behavior of reinforced concrete beams. The authors used old concrete to replace natural coarse aggregate in the percentage of 50%, 60%, 70% and 80% and tested 30 model RC beams of dimension 36"x6"x6" at curing age of 28 days. In all the beams 1:2:4 mix with water cement ratio of 0.45 – 0.55 is used. The outcome of the research shows that minimum and maximum reduction in flexural strength is 12% and 26.6% respectively (with 50% replacement of natural coarse aggregates) in comparison to beams made with 100% natural aggregates. The authors also studied the crack pattern of the beams and conclude that although the first crack appeared at lesser load than reference concrete but the behavior and position of crack remained same in both cases.

Strength, deflection and cracking behavior of reinforced concrete slabs made by partially replacing natural coarse aggregates (50%, 60%, 70% and 80%) with coarse aggregates from demolished concrete is studied by Bhatti and Memon[37]. In this research work all the reinforced concrete slabs are cast with 1:2:4 concrete mix and 0.45 – 0.55 water cement ratio. Based on the testing authors observed that average reduction in load carrying capacity is 7.1% for 50% replacement of natural aggregates. Maximum deflection recorded is 4.4 mm which is with in allowable limits of ACI 318. In this experimental study cracking behavior of all slabs is also observed and it is found that cracking pattern remained almost same for all models however reduction in cracking load with increased percentages of recycled aggregate is recorded. Based on result it is concluded that coarse aggregates from demolished concrete can effectively be used in reinforced concrete slabs with 50% replacement of natural aggregate with recycled aggregate from demolished concrete.

Fire is one of the hazard to structures, response of reinforced concrete structures during and after fire has remained active research area. To study this effect on concrete cubes made with coarse aggregate from demolished concrete as partial replacement of natural aggregate Buller and Memon[38] tested 180 cubes at 3, 6, 9 and 12 hours in fire (1000^{0}C). All the cubes were prepared using 50% replacement of natural coarse aggregate with coarse aggregate from demolished concrete and 1:2:4 mix. The cubes were cured for 7, 14 and 28 days. Six cubes of each batch and curing age are then exposed to fire for 3, 6, 9 and 12 hours followed by testing for compressive strength. The obtained results of 28-day curing, in comparison to result of 7 and 14 days curing are better with about 6% reduction in strength for 3-hour fire and about 25% reduction for 12-hour fire. 12 hours is normally good enough time to control fire, hence can be said that even if fire prolongs for 12 hours recycled concrete can survive up to 75% of its strength. Also the authors observed from obtained results that associative form of decrease in strength and associative behavior of cubes remained same.

Corinaldesi et al[39] in their article studied size effect of recycled aggregates and found that recycled aggregates up to 15 mm, although containing masonry rubble up to 25-30% proved to be suitable for making concrete even with 100% substitution of fine and coarse aggregates. The authors in their study also found that fractions up to 5 mm if reused as aggregate for mortars, allowed excellent bond strength between mortar and bricks. However, they found that mechanical performance of mortar itself remained lower. They also concluded that rubble powder which is the finest fraction of recycling process can also be effectively used as filler in self-compacting concretes.

McKay[41] conducted a study about the recycle and re-use of the waste and suggest to acknowledge and balance between four E's; Ecology, Energy, Equity and Economy by making use of recycled aggregates. Mehta[42] studied the waste quantitatively and suggest the use of this waste in terms of recycled aggregates. In his article the author says about one billion ton of drinking water and 8 billion ton of sand and gravel are being used worldwide if 0.6 w/c cement ratio and 75% aggregate content by mass are assumed. He also points that construction and demolition waste contributes more than 450 million tons in European Union. Looking at the current pace of development of construction industry worldwide, virgin aggregate recourses are at high risk. This can only be avoided by making use of the waste for preparation of new concrete.

Moriconi[43] studied performance and cost comparison of the concrete with recycled concrete aggregates and normal concrete. According to his study cost saving can be achieved by making in-situ use of demolition waste without making any compromise to the performance. However, some properties of hardened concrete i.e. ductility and durability need to be controlled by proper mix design.

Sani et al[46] studied the structural and leaching behavior of concrete with recycled concrete as aggregated. Their results demonstrated that both of the behaviors under goes modification. The authors found that total replacement of natural aggregates results in increased porosity and reduced strength. They suggest addition of fly ash to overcome the strength reduction. However, this addition even cannot cop the porosity problem, thus ion leaching rate expressed for unit of specific surface area is lower and directly related to percentage of pores. The authors studied calcium release rate by performing calcium, sodium and potassium analysis and found that despite of high porosity of concrete, calcium release rate is lower for concrete with recycled concrete aggregates. Thus suggest that properly engineered recycled aggregates will have a positive environmental effect.

To study feasibility and mechanical properties for producing high-flowing concrete with recycled aggregates, Jau et al[47] conducted the research work. High flowing concrete is the concrete with high workability and proper cohesiveness without causing segregation and bleeding. In their work they used crushed waste concrete with compressive strength in range of 3000 psi – 5000 psi as recycled aggregates. Fly ash in range of 25% to 30% and super-plasticizers were also used to cop the problem of strength reduction. Jau et al[47] tested 18 samples and compared the result with normal aggregate concrete. Based on the observations of comparison they concluded that, surface of recycled aggregates is highly porous and rough. Compressive strength of concrete to be recycled must be at least 3000 psi to produce high flowing concrete. Slump flow of concrete with recycled concrete aggregate is 2.04%-8.7% higher right after mixing and 0.7%-10.0% after 45 min. workability can be increased by using fly ash but it has negative effect on compressive strength. They found that 28-day compressive strength with 25% replacement with fly ash is higher than that of normal aggregate concrete, however strength development with fly ash is slowing down at late age, and is really problematic for higher water-cement ratio specimen. The authors also studied bond strength in their work and found that variation in bond strength for concrete with recycled aggregates is higher and is slightly less than normal aggregate concrete.

Compressive stress, water absorption and modulus of elasticity of concrete with recycled aggregates is studied by marcio el al[48]. Their findings show that compressive strength and modulus of elasticity with 10% and 20% replacement of aggregates are nearly similar to normal aggregate concrete. But results were far from those obtained at 40% replacement when 100% replacement was used. The authors argue that water absorption ratio is important property for concrete to resist static and dynamic strains without suffering degradation in its micro-structure. Thus water absorption and specific gravity of recycled aggregates are related to modulus of elasticity. They found that modulus of elasticity values of concrete with 40% recycled aggregates is nearly equal to concrete with natural aggregates. They also found that use of recycled aggregates in concrete has little influence on cost of concrete. Although this information differs from the findings of Moriconi[43], however marcio et al[48] aggress that there is cost difference when replacement of aggregates is more than 30%.

Bara and Vazquez[50] found that recycled concrete can provide strength equivalent of corresponding strength of concrete with natural aggregates if the cement percentage is increased by 7.2% for 40 MPa concrete.

Poon, Shui and Lam[52] in one of the study for effect of different moisture conditions on concrete with recycled concrete aggregates used air dried, oven dried and saturated surface dried samples. They found that air dried samples maintained strength despite of percentage of recycled aggregates changed. Strength of oven dried samples increased whereas strength of saturated surface dried decreased. They also found that strength of oven dried samples was higher than saturated surface dried samples.

Poon, Azhar and Kou[53] in their study for recycled aggregates for concrete applications argues that existing policies for using 100% recycled concrete aggregates for higher grade concrete must be made more liberal. Facilities and opportunities must be introduced for pre-cast industries as quality control is more effective there. Also quality assurance system must be developed to assure the quality of recycled aggregates and products made of it.

5. CONCLUSION

Increased rate of development of infrastructure increased the demand of aggregates which in turn produced danger of elimination of sources of virgin aggregates. On other hand proper dumping of waste from construction and demolition waste is another issue which must be dealt properly. Generally, the waste is dumped in landfills but the growing volume of waste have posed great difficulty in dumping it properly. Therefore, to save the landfill area, and sources of virgin aggregates reuse of construction and demolition waste has got interest of scholars and policy makers. In this regard several countries have already started nationwide projects to formulate policy and code for recycling and reuse of the waste. Simultaneously several scholars around the globe have conducted research to study the properties of concrete made by making use of recycled aggregates. However, industry yet fells difficulties in adopting this new material. The difficulties are mainly due to un-availability of the sound data about recycled aggregates. Induction of local conditions of recycled aggregates and un-awareness of both public and construction personals. Low cost reprocessing facilities may also be the problem in this regard. This article reviews the recent development of using recycled concrete aggregates. It gives good insight of the work done in the field. It is hoped that the article will serve good starting point for new researchers and for future research in the field. Literature review indicates that still there is need for further work to be done to have clear understanding of the properties of recycled concrete aggregates. Existing policies must be made more liberal and opportunities must be introduced at government level especially for pre-cast industry as quality control over there is easier.

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