Performance of Recycled Concrete Aggregates- New Era for Use in Construction - A Literature Review

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Abstract— The issues of sustainability are of prime concerns these days as we use large amount of natural resources for producing materials such as concrete. The recent trend in construction industry is to use the alternative source of construction materials which can substitute the use of virgin materials in order to reduce environmental impact in terms of energy consumption, pollution, waste disposal and global warming. The present paper gives a brief status of recycled aggregate concrete made out of recycled aggregate, summarizes and critically analyses some of the most important research findings over the past few years. Most studies have shown that the long-term properties of RAC are inferior to those of natural aggregate concrete (NAC), and some researchers have observed that the long-term properties are better than those of NAC. RAC's properties are affected by many factors such as recycled coarse aggregate (RCA) replacement percentage, water-cement ratio, mineral admixtures and mix proportions. The long-term properties of RAC can be improved through better Control of these factors. This paper will be helpful for an understanding of and further research on RAC, and provides an important basis and references for the engineering applications of RAC.

Key words: Recycled aggregate concrete, long-term properties, Compressive strength and Tensile strength.

I. INTRODUCTION

The concrete industry consumes a large amount of natural resources that cause substantial environmental, energy and economic losses as it exploits 50% raw material, 40% of total energy, as well as generates 50% of total waste. Large amounts of solid waste are produced in the process of constructing new buildings and demolishing old ones all around the world. In last 20 to 30 years certain countries have started the reutilisation of construction and demolition waste as new construction material. This is being one of the main objectives with respect to sustainable construction activities. Concrete waste, which falls into the Construction and Demolition (C & D) waste category, is generated when creation of new, or modifications to existing urban infrastructure such as transport systems, communication networks and buildings are made. With the increased urbanisation of the worlds growing population there is also an increase in C & D waste generation. This prompts a realisation that built-in urban infrastructure along with C & D waste contains a large stock of materials, and that efficient management of concrete, steel, bricks, their waste, is necessary to sustain the future growth and increased demand for construction materials.It seems that there is a common understanding and consensus that depletion of natural resources is a real threat, landfill space is becoming scarce, and the waste disposal causes significant environmental and social impact. There is also a general consensus that recycled C & D waste including RC aggregates can be used for construction purposes. The main source of raw material for recycling of concrete waste comes from demolition of concrete structures. The quality and purity of the raw material affect the quality of recycling products and ultimately commercial acceptance of concrete recycling products. This paper includes brief information regarding the properties of RA and its effects on different properties of fresh and hardened concrete (mechanical, durability etc.). It also emphasizes on different processing techniques of RA.

A. Economical Importance Of Recycling Of Construction & Demolition (C&D) Wastes:

In recent past, increase in infrastructural development in construction sector, and high growth rate in population have created a large demand of conventional building materials. Mean time the depletion of good quality aggregates along with the increase in aggregate requirement makes the availability of raw materials scarcer. Moreover, the materials become more expensive due to the increase in transportation costs. Result of that cost of construction materials increase largely. Because of modernization and industrialization have led to the generation of debris from construction and demolition (C&D) wastes. New construction works also generates waste from the left over concrete of ready mix concrete plants, precast concrete plants, and the tested samples in compliance to laboratory applications. These C&D wastes are the largest waste of solid waste in many countries all over the world. Moreover, large amounts of industrial and mining by-products such as fly ash, slag, and limestone powder are being generated annually. All these materials led to an increasing dearth of landfill areas; useful lands becoming dumping yards.

Managing such debris has become one of the important issues in developed countries. Moreover, the global concern about the reduction of carbon footprint is also playing a crucial role during the extraction process of RA than virgin aggregate. It is fact that, extracting and crushing of virgin aggregate cause use of substantial amount of energy and more emission of CO_2 [1]. Hence, the use of RA in construction work as structural grade concrete may consider for economic viability and environmental concern as well reduction of waste materials. The recycling of C&D waste process shown in Fig.1

Fig. 1: Recycling of Aggregates

Presently recycled aggregate concrete (RAC) is being used for structural as well non-structural applications. Recently extensive research works have been carried out to examine different properties of concrete by using RA. Previous studies have indicated that RA could successfully be used as a substitute of natural aggregates to produce concrete, meeting required performance of normal structural concrete [2,3]. It has been widely accepted that it can be used for both commercially and technically.

II. PRODUCTION OF RECYCLED AGGREGATES.

Aggregate generate through the crushing of parent or old concrete such as demolished waste concrete is called as recycled concrete aggregate (RCA). Generally RCAs are mixed with metals, bricks, tiles, and other miscellaneous such as glass, wood, paper, plastic and other debris. Recycled aggregates are generated through the processing of the debris of demolition of structures and other constructions. It includes waste concrete, rejected precast concrete members, broken masonry, concrete road beds and asphalt pavement, leftover concrete from ready mix concrete plant and the waste generated from different laboratories. Brick aggregate, glass aggregates, asphalt and bitumen aggregate, concrete aggregates, tiles and marbles recycled from flooring, finishes and ceramic products are different types of recycled aggregates.

A typical aggregate recycling facility involves a number of steps [4]. Construction, demolition and excavation waste is delivered to the facility and weighed. The hard C & D waste that is capable of being recycled is separated out and stockpiled and subsequently loaded by shovel onto a conveyor which feeds a crusher. (In some cases the material may not need to be crushed and would be conveyed directly to the screens). After crushing the waste is passed over screens for grading into the size of material wanted. In some cases the material is then washed to enhance the quality of the finished products. The output material is then stockpiled ready for further use. The steps of process for aggregate recycling process are shown in fig.2

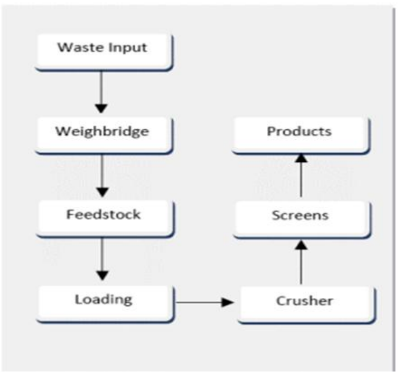

Fig. 2: Typical Aggregate Recycling Process

In Few developed countries like Japan, China, USA and Netherland, the researchers have developed some advanced processing techniques to overcome the adverse effect of RA. By applying these methods, good quality aggregates can be produced by removing the adhered mortar without losing the integrity of original coarse aggregate. The name of these techniques are heating method , ultrasonic treatment method ,nitric acid dissolution method, , heating and rubbing method, mechanical grinding method etc.

A. Properties Of Recycled Aggregate:

Recycled concrete aggregate consists of natural aggregate coated with cement paste residue, pieces of natural aggregate, or just cement paste and some impurities. The old mortar contains fine aggregate, hydrated and unhydrated cement particles. The quality of RA depends on the methods of recycling process to be adopted but the various properties of RA mainly depend on the water/cement (w/c) ratio of the original concrete from which it is obtained[5,6]. A.K. Padmini et al.[7] reported that The water absorption of recycled aggregate increases with an increase in strength of parent concrete from which the recycled aggregate is derived, while it decreases with an increase in maximum size of aggregate. Higher water absorption of recycled aggregate necessitates adjustment in mix water content to obtain the desired workability. The water absorption capacity of RA is 2–3 times higher than natural aggregate and it may range up to 12% for coarse and fine RA [8, 9] The water absorption capacity of RA is more for smaller particle size; since greater is the specific surface area so greater is the mortar content [10]. Limbachiya et al. [11], from the experimental investigation concluded that the relative density of RA or surface saturated density (SSD) is approximately 7–9% lower than that of natural aggregate. Water absorption capacity of RA varies depending on the amount of cement paste attached to the surface of the aggregate particles [12] RA is having inferior mechanical properties such as low crushing strength, low impact resistance and low abrasion resistance than natural aggregate[13].RA is poorly graded due to its poor particle size distribution [14]. RA may be too coarse or too fine as a result of the processing and crushing through various types of crushers. RA may be contaminated with organic impurity such as textiles, fabrics, polymeric materials. Now days the potential use of RA has been acknowledged, there are some factors which restrict the large use of RA in concrete as it affects the performance of concrete in terms of workability, strength and durability. Thus, properties of RA such as particle size distribution, shape and size of aggregate, porosity, absorption, toughness, hardness, strength and the impurity level, are necessarily to be assessed before its use in concrete.

III. RECYCLED AGGREGATE CONCRETE (RAC) FRESH CONCRETE

Recycled aggregates used in concrete production have less density and more absorption capacity than virgin aggregates due attached mortar. Concrete with recycled aggregates have two interfacial transition zones, the existing interface between the original aggregate and the adhered mortar, and the new interface between the old and new mortar. The possibility of improving existing interface is less, and it is very important to achieve an effective new Interface. Concrete prepared from RA using fine or coarse or both, processed from C&D waste either as a partial or 100% replacement of conventional natural aggregates is known as RAC. The various properties of fresh concrete are discussed below.

A. *Water Demand And Workability:*

When concrete is fresh its properties such as workability and wet density are greatly affected by a many factors like w/c ratio, the characteristics of the constituent materials of concrete, especially the aggregate i.e. type of aggregate, maximum size of aggregate, water absorption of aggregate etc. Workability of concrete also gets affected by other physical parameters of aggregate such as surface texture, aggregate size, and shape of aggregate. Tavakoli M et al[15] concluded that if coarse RA is used in dry condition, then the workability of concrete gets obstructed to a great extent depending upon the quantity of RA used. The loss in workability or slump in RAC is quite notable at higher percentage replacement especially when it exceeded 50%. As the size of RA decreases, water demand increases due to more adhered mortar quantity. This higher water demand leads to difficulties in controlling the properties of fresh concrete and consequently influences the strength and durability properties of hardened concrete [16]. Similarly SagoeCrentsil et al. [13] identified that commercially produced RA showed better workability performance than laboratory produced RA as it produces comparatively smoother aggregate. Tabsh and Abdelfatah [17] in their study concluded that RAC demands 10% extra water to achieve the same slump when RA is used instead of natural aggregate. Concrete made from RA, has a harsher and granular texture due to the adhered mortar which causes a higher water demand and more energy for compaction due to inter particle friction [18, 19]. From literature, it has also been found that the slump loss of RAC can be overcome by the incorporation of some mineral admixtures, chemical admixture or super plasticizers or by adding extra water corresponding to the absorption of aggregates [15]. By the use of super plasticizers, water demand of aggregate can be compensated to maintain the desired workability. Yu-chang Liang et al.[20] reported that Surface pre-treatment's can improve the properties of fresh RAC. With a proper surface pre-treatment method, the pores of residual cement paste on recycled aggregates can be sealed and thus the workability of fresh RAC can be improved. The water- cement ratio for the second casting stage can be lowered and thus the compressive strength of RAC can be enhanced. D. Matias et al. [21] investigated in his study that the use of a high-performance super plasticizer is more time-effective in achieving the desired workability and strength when varying the incorporation rate of RA. K.Kim et al.[22] conclude that The higher ratio of recycled coarse aggregates generally resulted in the better flowability of flesh concrete, which was found from the results of both flow curve and slump tests. A roughly negative logarithmic relationship was found between the slump and yield stress of the cases with different ratios of recycled aggregates. Saravana Kumar and Dhinakaran [23] investigated that the water demand could be reduced by 12.5% by the use of RAs admixed with fly ash (20%) and super plasticizer than that of without fly ash and super plasticizers.

B. *Density:*

C.Thomas et al.[24] concluded that The densities of recycled aggregate concretes made with unsaturated recycled aggregate are below those of the control concrete despite the reduction in the effective water/cement ratio. An addition of 20% of recycled aggregate provides density values of around 5% lower than in the case of the control concrete. Ö. Çakır [25] studied the effects of RCA with/without SF and GGBFS, Based on the results, they found an inverse relationship between the density and the water absorption ratio in RCA concretes and this relation is more significant in higher amounts of RCA contents.

K.H. Younis [26] established A strong relationship with very good correlation appears to be exist between the particle density and the strength of RAC. They found that an 8% increase in particle density approximately leads to an increase of 10% in concrete strength, regardless of RA content. Daniel Matias et al [27] find that The concrete's specific density is mostly influenced by the aggregate's density; thus, higher RA particle density results in higher concrete's specific density.

IV. Recycled Aggregate Concrete (RAC) – Hardened Concrete

The mechanical properties such as compressive strength, split tensile strength, flexural strength, and modulus of elasticity, creep, and bond strength are hardened properties of RAC. Mechanical properties of concrete depend upon many parameters such as w/ c ratio of mix, properties of RA to be used in concrete and its microstructure. Researchers have worked on different hardened properties of RAC which revealed that concrete properties get affected by the increase of RA content. Following are the brief discussion on these properties.

A. *Compressive Strength:*

The behaviour of various combinations of recycled aggregate and natural aggregate in compression is as follows. Etxeberria et al.[18] concluded that the concrete made with 100% of recycled coarse aggregate has 20 to 25% less compressive strength than conventional concrete at 28 days, with the same effective w/c ratio and cement quantity. Concrete made with 100% of coarse recycled aggregates requires high amount of cement to achieve a high compressive strength and consequently is not an economic proposition as it is not cost effective. These recycled aggregates should be used in concrete with low- medium compressive strength (20-45MPa). More over the adhered mortar in recycled aggregates is lower in strength than conventional aggregates and the new paste. Consequently the weakest point in concrete made with coarse recycled aggregates employing a cement paste of medium-high strength (45-60MPa) can be determined by the strength of the recycled aggregates or their adhered mortar. Medium compressive strength (30 to 45MPa) concrete made with 25% of recycled coarse aggregate achieves the same mechanical properties as that of conventional concrete employing the same quantity of cement and the equal effective w/c ratio. Medium compressive strength concrete made with 50% or 100% of recycled coarse aggregates needs 4 to 10% lower effective w/c ratio and 5 to 10% more cement than conventional concrete to achieve the same compressive strength at 28 days.

S.C. Kou, C.S. Poon [28] observes that the 28-day compressive strength of the concrete mixtures decreased with an increase in the recycled aggregate content. This was due to: (1) the adhered mortar in original aggregates mechanical and physical properties of recycled aggregates are worse than those of raw aggregates and (2) the higher initial free water content in the concrete mixture due to the higher water absorption of recycled aggregate which was used at the air dried condition with moisture content of the aggregates at mixing much lower than the water absorption. Similarly S.C. Kou,et al [29] reported that The mechanical properties such as compressive strength of the concrete were decreased with the incorporation of the low grade recycled aggregates. In some other studies K. Kim et al.[30] observe that higher ratio of recycled aggregates generally caused the lower compressive strengths of concrete. However, the cases using 30% recycled aggregates showed only small reductions in the compressive strength. Numerous experimental investigations showed that the reduction in compressive strength is not much prominent, when the RA replacement is up to 30%. The possible reasons for this may be due to the lower strength of RA, increased concrete porosity, weak interfacial bond between the aggregate and matrix and the presence of micro cracks and fissures which may reduce the bonding with the surrounding matrix. However RA of good quality (namely, low attached mortar content and water absorption value, high 10% fines value) can be used to fully replace NA to produce concrete with mechanical properties comparable to the concrete that are made with NA. Zhen Hua et al.[31]

It is fact that from the earlier studies that the trend is followed by RAC as there is a decrease in strength with the increase in w/c ratio as that of conventional concrete. Hansen [32] reported that considering other factors almost identical, the compressive strength of RAC depends on the combination of w/c ratio of original concrete and w/c ratio of RAC. The strength of RAC made out of 100% RA can be more than or equivalent to source concrete if the w/c ratio of parent concrete is less than or equal to the strength of RAC intended to be prepared [5]. However, In a study by Limbachiya et al.[33], concrete specimens made with up to 30 % RCA had equal compressive strengths for w/c ratios greater than 0.25 as seen in **Fig. 3**, which shows trends for compressive strengths for three RCA fractions as they vary with w/c ratio. The data for 30 % RCA follows that of 0 % RCA for almost every w/c ratio tested, while the 100 % RCA data lie at compressive strength values below that of 0 or 30 % RCA by about 5 N/mm^2. At the lowest w/c ratios, the compressive strengths for mixes with RCA become more dissimilar to conventional concrete. The reason for this non-linearity between strength and w/c ratio at 50% replacement is not clear. In contrary to this, some authors have observed that compressive strength of RAC is sometimes higher than natural aggregate concrete [34]. It may be due to the lowering of effective w/c ratio in RAC with high rate of water absorption of RA from concrete, which in turn leads to increase the strength. Some other experimental investigations showed that the compressive strength of RAC is equal to the strength of natural aggregate concrete at higher w/c ratio such as 0.40, 0.55 and 0.70. However, the strength is less at lower water cement ratio of 0.25 [35].

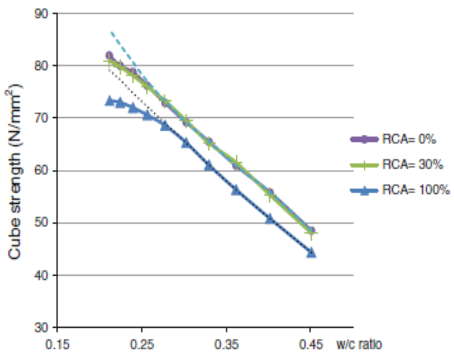

Fig.3: Concrete compressive strength versus water-to cement ratio for RCA contents of 0–100 % (plotted using data from Limbachiya et al.[33]

B. Splitting Tensile Strength:

Splitting tensile strength is less affected by RCA content than compressive strength. Several past and recent tests show that the splitting tensile strength of RCA concrete is comparable to conventional concrete. In some cases, RCA concrete performed superior to NA concrete With respect to tension. According to Exteberria et al.[18], the improvement is due to the increased absorption of the mortar attached to the recycled aggregate and the effective ITZ, which indicates a good bond between aggregate and the mortar matrix. A.K. Padmini et al[16] concluded that the For a given compressive strength of concrete, the split tensile strength are lower for RAC than parent concrete On the contrary, Matias et al. [36] concluded that the increase in split tensile strength is due to the rough surface of RA which provides better adherence to matrix. Butler L et al [37] found noticeable difference in the split tensile strength of RAC by using 100% RA.

C. Behavior Of Recycled Aggregate Concrete In Flexure:

The modulus of rupture, a measure of flexural strength, and the modulus of elasticity (also known as Young's modulus), a measure of concrete stiffness, are often predicted from compressive strength, but these relationships do not represent RCA concrete as well as NA concrete. Several attempts have been made on the modulus of rupture of RAC and the results have shown that the replacement level of RA has little influence on the flexural strength of RAC [38]. Rao et al [39] have reported that there was no significant difference found in flexural strength of RAC even if containing 100% RA in comparison to that of conventional concrete . Recent tests byKang et al. [40] proved that the modulus of rupture is moderately affected by the replacement of RCA. For the RCA replacement ratio of 15–50 %, the modulus of rupture was reduced by only 13 % . In different literature, it has been found that the flexural strength of RAC decreased up to 10%. Moreover in improvement part B.B. Mukharjee et al [41] investigated the feasibility of use of RAC incorporating NS (Nano silica). Flexural Strength of fully recycled aggregate concrete deceased as the formation of a weaker ITZ in RAC compared to that of NAC. This degradation of tensile strength could be compensated by adding NS, which improve the ITZ of RCA by fling the minute pores, present in it and forming a stronger bond between cement paste and aggregates.fig.4 shows The variation of FTS with respect to different percentage of NS, which illustrates that FTS increases with increasing percentage of NS irrespective of type of concrete.

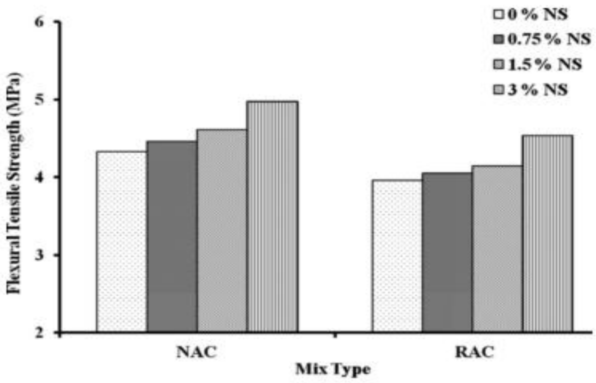

Fig. 4: Variation of flexural tensile strength[41]

D. *Drying Shrinkage And Creep:*

Drying shrinkage is very important properties of RAC which is related with decrease in volume or contraction of hardened concrete due to loss of capillary moisture. A series of investigations on deformation characteristics of the RAC specimens revealed that the creep increases with the increase in content of RA. This is due to the increased volume of total mortar content in case of RAC as compared to the conventional concrete. Creep of concrete is also directly proportional to the content of the paste or mortar present in concrete as drying shrinkage. In RAC, the residual mortar of RA contributes towards more mortar content which results in considerable higher creep. The short comings of RAC due to the use of RA such as drying shrinkage, creep can be minimized by incorporating fly ash whether as addition or replacement. Shi Cong kou et al. (2007) concluded that the drying shrinkage of concrete increased with an increase in the recycled aggregate content. However, the use of fly ash as a partial replacement of cement was able to reduce the drying shrinkage of the recycled aggregate concrete. Further, a decrease in the W/B ratio also led to a reduction in the drying shrinkage. The creep of the concrete increased with an increasing recycled aggregate content. The use of fly ash as a partial replacement of cement was able to reduce the creep of concrete as a result of the greater long term strength development due to the pozzolanic reaction of fly ash. Similarly S.C. Kou [28] concluded that the drying shrinkage of concrete increased with an increase in the recycled aggregate content. However, the use of fly ash as a partial replacement or addition of cement was able to reduce the drying shrinkage of the recycled aggregate concrete. They also concluded the creep of concrete increased with an increasing recycled aggregate content. The use of fly ash as a partial replacement or addition of cement was able to reduce the creep of concrete as a result of the greater long term strength development due to the pozzolanic reaction of fly ash. Moreover to check the effects of surface treatment on RCA properties and on the mechanical strength, S. Ismail et al [42] report that the drying shrinkage values of concrete mixtures with treated coarse RCA were lower than those of concrete mixtures with untreated coarse RCA.

V. Corinaldesi, G. Moriconi[43] in their work concrete specimens were manufactured by completely replacing fine and coarse aggregates with recycled aggregates from a rubble recycling plant. Also RAC with fly ash (RA + FA) or silica fume (RA + SF) were studied. They found that drying shrinkage of RAC does not appear to be a problem. Under restrained conditions, the risk that cracks may form seems to be the same as in RACs and ordinary concrete despite the higher shrinkage of RACs, due to their lower stiffness. Fig. 5 shows the results (average of three samples) obtained up to 90 days.

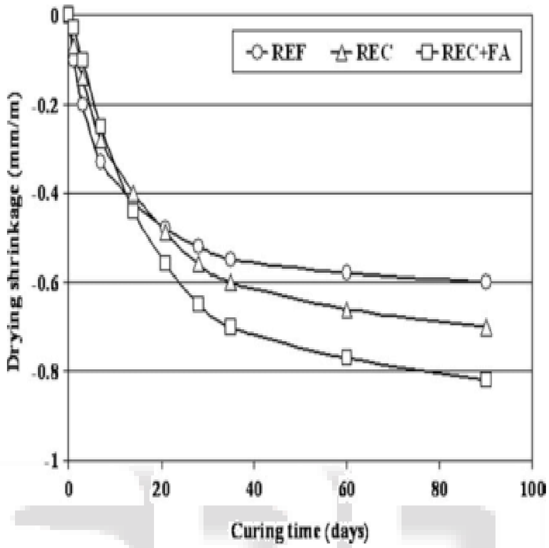

Fig.5: drying shrinkage measurements up to 90 days.[43]

Daniel Matias et[27] al report that the RA concrete revealed higher shrinkage strains than the RC (reference concrete, with NA only); however, super plasticizers, especially high performance water reducing ones, can partially mitigate the occurrence of this phenomenon in RA concrete.

E. *Modulus Of Elasticity:*

Modulus of elasticity is another important mechanical property which represents the stiffness of concrete. It is affected by many parameters such as porosity of aggregate and matrix, dense nature of aggregate and the transition zone characteristics etc. The main factor affecting the RCA concrete modulus of elasticity is the modulus of elasticity for the aggregate itself. This is because the aggregate's porosity and density determines the stiffness of bulk matrix. Substitution of natural aggregate by RA also affects the modulus of elasticity. However, RA content has more has pronounced effect on the modulus of elasticity than that of compressive strength due to its porous nature, low density and weak bond between old ITZ and new ITZ due to presence more capillary voids and cracks. Like compressive strength, similar trend has also been observed for modulus of elasticity with degree of substitution of RA.

Modulus of elasticity of RAC decreases considerably than normal concrete and it reduces with the increase in degree of substitution of RA [7, 39].Similarlarly Improvement of tensile strength with the addition of RCA would usually be associated with an improved elasticity; however, because the ''recycled aggregates are more prone to deformation than raw aggregates,'' the weakness of the aggregate reduces the Young's modulus for concrete when RCA is used (Exteberria et al.[18] Generally, Young's modulus for RCA concrete was lower than that of conventional concrete, but there is significant variation between studies as to how much the modulus is reduced. Variation of results of modulus of elasticity as reported by various researchers with natural aggregate and RA (100%) are presented in Fig.6

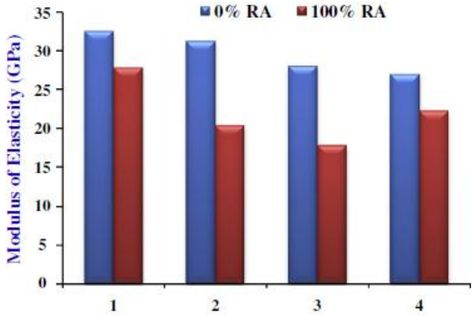

Fig.6: Variation in modulus of elasticity (28-days) w.r.t RA replacement

(1) Etxeberria et al. [18], (2) Rao et al. [39] (3) Xiao et al. [38](4) Kou et al. [44]

Moreover, Limbachiya et al. [1] in their empirical studies also concluded that with the use of 100% RA, approximately 35% reduction in modulus of elasticity was observed.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

This paper has presented relevant research work and findings concerning engineering properties of concrete made with recycled concrete aggregate. This has also included production and the use of RA in concrete. The main conclusions can be summarized as follows:

- Mechanical performance of RAC is generally inferior to conventional concrete.
- The shrinkage and deformation of RAC is higher than that of NAC and increases with the increase in RCA replacement percentage;
- The creep deformation of RAC is about 20–60 % higher than that of NAC and increases with the increase in the RCA replacement percentage.
- The compressive strength of RAC increases with age; the long-term compressive strength of RAC is lower than that of NAC, but the extent of the disparity between RAC and NC decreases with age
- The concrete made with up to 30% of RCA as a partial replacement of the natural aggregate component compares favourably with concrete made entirely with natural aggregate
- Replacing NA in concrete with RCA decreases the compressive strength, but yields equivalent or superior splitting tensile strength
- The modulus of elasticity is also lower than expected, caused by the more ductile aggregate.
- Due to more water absorption of recycled coarse aggregate it may have less workability.
- Influence of content of RA on the modulus of elasticity is significantly higher than other strength properties. The strength properties of RAC may have an inverse relationship with RA content.

A. *Recommendations For Further Studies:*

- Since the qualities of RCA are still highly varied among different sources, there is room for more testing to make sure results of RCA concrete, regardless of the RCA source.
- Further testing and studies on the recycled coarse aggregate concrete is highly recommended to indicate the strength characteristics of recycled coarse aggregate for application in high strength concrete.
- Optimum mix proportioning is to be finding out and proper mix design procedure has to be established
- Limited knowledge on the use of RA in other concrete such as high performance concrete, geopolymer concrete, and precast concrete.
- Further studies required on Pre-treatment of RA with different Chemical components
- Further studies required on Mathematical modelling on the behaviour of RAC.
- Further studies required on adding admixtures such as super plasticizer, fly ash, silica fume. etc into the mixing. To improve performance of RAC.
- More investigations and laboratory tests should be done on the strength characteristics of recycled coarse aggregate. It is recommended that testing can be done on concrete slabs, beams and walls.

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