Impact and Analysis of Packing Particle Optimization of Recycled Concrete Aggregate in Concrete to Save Natural Resources – A Review Based
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Abstract:
An sustainable alternative to NCS aggregates are the recycled concrete aggregates which are obtained from waste concrete. By a comprehensive experimental investigation, the strength & durability properties of concrete are to be evaluated. In the experimental study, various variables are to be considered such as w/c ratio, cement content in concrete & replacement percentage of coarse aggregates. The various types of mechanical properties compressive strength, modulus of elasticity, splitting tensile strength, flexural strength etc are to be studied. The various types of durability properties such as water absorption, sorptivity, acid attack resistance and chloride permeability are also determined. In order to increase the efficiency of various practice engineers in mix designing of RCA concrete, a proper mix designing methodology should be developed.

Nomenclature:
CCA = Crushed Coarse Aggregate
CA = Coarse Aggregate
DR = Damping Ratio
fc = Compressive strength of Concrete
ft = Tensile strength of Concrete
fck = characteristic strength of concrete
HSC = High strength concrete
HS – RA = High strength recycled aggregate
ITZ = Interstate facial Zone
LS – RA = Low strength recycled aggregate
NA = Normal Aggregate
NSC = Normal Strength Concrete
NCA = Normal coarse aggregate
PPD = Particle Packing Density
PPO = Particle Packing Optimisation
PD = Packing Density
PDia = Particle Diameter
PSD = Particle Size Distribution
PP= Particle Packing
RA = Recycled Aggregate
RAC = Recycled aggregate concrete
RCA = Recycled concrete Aggregate
RR = Replacement Ratio
RCC = Reinforced Cement Concrete
SF = Silica Fume
SP = Super plasticizer
Vs = Volume of Solids
Vv = Volume of Voids
WA = Water Absorption.

I. INTRODUCTION
Construction industry is facing a challenge due to increasing of C & D waste and depletion of natural resources. This industry due to depletion of natural resources is very much concern about sustainable construction development. This development in harmony with the earth’s ecosystem is defined as an economic activity. Alternatively, the present needs are being fulfilled and are being beneficial for generations. It also prevents future generations to carry out extensive research work on construction materials for meeting the demands of construction industry. In majority the Nations are facing the problem in handling & disposal of C & D waste which is being generated due to an increase of urbanisation. Due to this reason, more emphasis is being given to utilise the by products of construction industry & of waste materials. The use of waste materials in construction industry is very much beneficial not only for the environment but also very economical & also have numerous indirect benefits. As per...
In developing various methods for achieving the optimise design of concrete mix. As the concrete functioning is being reduced in the greenhouse gases footprints up to 65% and Marinković et al., 2010). It had been found that there was a considerable information for the usage of RCA (Verian et al., 2016; Serres et al., 2016; Knoeri et al., 2013; environmental protection point of view, the recycling & reuse of construction waste is necessary. It will help in limiting the exploitation of natural resources & there will be a limited impact on environment. The use of RCA in conventional concrete is being promoted by many researchers to reduce the use of NA (Rahal 2007; Tam 2005; Xiao, J. Zhang, Li & Poon 2012). As many studies shows that there were variations in the mechanical strength of concrete mixed with RCA as compared to those conventional concrete having NA as an ingredient (Rahal 2007; Singh 2014; Xiao, J. Zhang, Li & Poon 2012). It is only due to the method used to obtain RCA & being produced from old concrete which are obtained from demolished structures, by mechanical crushing (Wagh et al., 2013). This crushing process have several stages & help in achieving desirable shapes & sizes (RILEM 1992) & results in producing non homogeneous & round – shaped aggregates, which hinders their wide use (de Juan & Gutierrez 2009). The use of RCA have positive influence on the environment & economics than that of NA. Because, it helps in preserving the natural resources by reducing the opening of new mining areas & hence conserves the environment (Mack et al., 2018). It also helps in the consumption of fuel which is associated with hauling i.e fuel consumption during the transport of NA to the construction site is more than that for the RCA reqd. There will be a reduction of construction waste by the use of RCA which usually ends up in landfills (Mack et al., 2018). It also reduces construction cost. At Purdue University, USA, a study was conducted & it was found that by the use of RCA, there was a potential of reducing cost as much as $2.26–$2.93 per ton (without considering additional potential saving from landfill) of pavement concrete (Verian et al., 2013). A benefit cost analysis model (BCA) was developed & which provides considerable information for the usage of RCA (Verian et al., 2013). According to a study by Environmental Council of Concrete Organizations there is an estimated saving of up to 60% by using RAs as a replacement of NAs (Environmental Council of Concrete Organization, 2018). Based on the life cycle cost analysis of concrete the overall environment benefit of using RCA has also been reported by several studies (Ding et al., 2016; Serres et al., 2016; Knoeri et al., 2013; Marinčković et al., 2010). It had been found that there was a reduction in the greenhouse gases footprints up to 65% and saves up to 58% of the energy consumption by the use of coarse RA obtained from the C&D waste in Hong Kong & this study was done by Hossain et al. (2016). It had also been found that RCA may be designed in such a way to match the quality of concrete made with virgin aggregates without the need for additional cement. Beltran et al. (2014) was studied that at w/c ratio of 0.5, RCA use was responsible in increasing the compressive flexural strengths of concrete when extra cement was added upto 34 kg/m³ into the mixture. According to Etxeberría et al. (2007), replacing natural coarse aggregate with RCA at 25% and 50% weight-base replacement levels improved the compressive and tensile strengths of concrete when adjustments in the mixture proportion were applied, such as increasing the amount of cement, lowering w/cm, adjusting the amount of ad- ditive and aggregate proportion. Verian (2012), Verian et al. (2011a) and Jain et al. (2012a) have also indicated that concretes containing 30% coarse RCA (w/cm: 0.43) outperformed the control concrete made with NA only (w/cm: 0.44). RCA have higher water absorption capacity in addition, due to the presence of old mortar attached to the surface (Huang 2015; Sodorova et al., 2014). So, fresh & hardened concrete having RCA have effect on their properties because these aggregates are having high water absorption capacity & to have similar workability by the use of these aggregates in conventional concrete, it is desirable to add extra quantity of water in the mix. By adding extra amount of water, the w/c ratio will increase & in return the strength of RAC (Huang et al., 2016; Wardeh, Ghorbel & Gomart 2015). Many studies have also shown that there was a modification in porosity of RAC with an increase in the replacement ratio of RCA & it leads in the reduction of mechanical strengths with high porosity (Gomez –Soberon & Kou et al. Cited in Wardesh, Ghorbel & Gomart 2015). The quality of concrete from which RCAs are obtained also depends upon the mechanical strengths of RAC (Xiao, J., Li & Zhang 2005). The higher packing density of aggregates there will be small size voids & these voids are to be filled by cement paste. These voids requires less amount of cement paste to fill the space in concrete. So, with less cement requirement, minimum voids & maximum density concrete can be generated. In addition this, as the cement requirement is less, there will be a less requirement of water (Raj, Patil & Bhattacharjee 2014). In the mix design, material properties & moisture content of RCAs are to be considered for the requirement of water in concrete (Wardeh, Ghorbel & Gomart 2015). By using particle density method, this study is devoted to material, mechanical properties, durability properties of RAC. As a multiphase material, the properties of concrete depends upon the characteristics of its various ingredients such as binding material, CA, FA, admixtures & water, performance of cement paste & ITZ. As cement in concrete is very expensive & play their role for the generation for huge amount of carbon dioxide. So, the maximisation of packing density of aggregates will help in obtaining the economical cost of concrete production & result in sustainable development. Design of concrete mix is the basic essential tool for obtaining the required properties of materials & to achieve the economy in designing the mix. In the recent years, a huge development is being achieved by construction industry & achieved success in designing various mixes such as HPC, SCC & RAC.

The technology in designing various mix conc. is responsible in developing various methods for achieving the optimise design of concrete mix. As the concrete functioning is being
studied in two states i.e, Fresh state & Hardened state & then the suitability of design is being considered.

**Comparison of IS Code Method & Particle Packing Optimisation of Mix Design**

The packing density mix design method is the only method suitable for designing & proportioning of various concrete mixes such as normal concrete, HSC, ecological concrete, no-fines concrete & SCC. Optimisation of concrete composition means to manufacture the concrete with right amounts of various particles in the interest of researchers since more than a century. The optimisation of particle packing density of concrete means to select the particles in such a way that they fill the voids between larger particles with small size particles. By this optimisation technique, a concrete with dense & stiff particle structure can be obtained. Most of the early researchers have also proposed methods on aggregates packing that to achieve the ideal distribution of particle size. The prediction of water demand in concrete & quality of ingredients used in the mix can be based upon geometrical based particle packing models The voids between the aggregates particles are being filled by cement paste in the mix. The particles of the aggregate are then disperse by excess paste & which was responsible for lubricating mix by a paste having a thin coating of around each aggregate. By the density of aggregate packing which was higher, the Vv to be filled by cement paste will be smaller & excess amount of paste will help concrete to achieve the desired lubrication & which improves workability. s per the code of Indian standard method of mix design, from various curves, W/C ratio is being decided whereas in packing density, types of various correlation curves are not suggested by this code. But in case of PD methods attempts was being done to develop curves which must be correlated between fc versus w/c ratio & comp. strength of the paste content. These curves help in reducing the mix design trials. These curves also helps in deciding the w/c ratio & paste content as per the decided target strength or grade of concrete. OPC complying BS 12: 1996 & Blast furnace slag cement was being used by Wong & Kwan [1]. Fennis & Walraven [3]. In the mix, the particle size of agg. larger than 1.2 mm were being used by Wong & Kwan [2]. The cementitious material which complies ASTM C1240-03 condense silica fume being used in their research work by Kwan & Wong [2]. Superplasticisers which were of two types i.e. polycarboxilate & Polymer which was cross linked, naphthalene based formaldehyde condensate were being used in research work by Kwan & Wong [2]. The cementitious materials having PDs contains OPC, pulverised fly ash & condensed silica fume were measured by Kwan & Wong [2]. It was found for non blended materials that by the addition of a superplasticiser an increase in the packing densities of OPC & pulverised FA, a decrease in the PD of condensed SF by the addition of polycarboxylate based SP. The PD is being measured on account of lowering the cement content in concrete was studied by Fennis & Walraven [3]. By centrifugal consolidation, it was described that how to determine the packing density of powders. Based on observed experimental data, polarizations & fluorescence microscopy of samples, this method was assessed. The designing of mix was divided into 3 stages as proposed by Kwan & Wong [1]. In the first stage, the water demand was being finalised by the PD of the cementitious materials. In the second stage, paste demand was determined by the particle size of aggregate lesser than 1.2 mm. In the third stage, mortar demand was being determined by the aggregate particles larger than 1.2 mm. While designing a mix, it is always reqd to obtain maximum aggregate packing i.e. to obtain the densely compose aggregates & it was studied by Glavind & Pederson [5]. It helps in achieving the economy because to fill the void space in the form of cavities between the aggregates it requires minimum amount of binder. It also helps in making the conc. more workable. It also helps in improving quality of hardened concrete. The required amount of aggregate for least void content from a trend the is linear & similar to the Fuller who had his own theoretical gradings. It was studied by V.L.Kantha Rao & S.Krishnamoorthy [6]. For designing the mix from the point of view that to obtain the void contents in smaller amount, it is reqd to obtain the CA & FA in the desired amount of ratio from the empirical equation which would be fitted for the linear trend as stated above. To achieve the minimum void ratio of a binary particulate system at a particular combination as showed by the aggregate mixtures was studied by Powers [7]. This was defined as the ratio of a particulate system between Vv & Vs. From the above analysis, it is clear that to obtain economical design means to minimise the voids by increasing PP, mix design by PD method is suitable.

**Production of RCA**

There are large number of construction materials which can be recycled & such materials can be used as a substitute for NA in construction. Various others had suggested that such materials would not be only limited to concrete bricks (Kabir et al. 2012; Cachim 2009; Khalaf & DeVenny, 2005), glass (Henry and Morin, 1997; Polley et al., 1998; Nemes and Józsa, 2006; Xie et al., 2003; Shayan, 2002; Du and Tan, 2013; Shao et al., 2000; Federico and Chidiac, 2009; Meyer et al., 2001; Ismail and AL-Hashmi, 2009; Canbaz, 2004), ceramic (Binici, 2007; Torkittikul and Chaipanich, 2010; Medina et al., 2012; Senthamarai et al., 2011; Pacheco-Torgal and Jalali, 2010; Senthamarai and Devadas Manoharan, 2005), rubber (Atahan and Yücel, 2012; Najim and Hall, 2012; Papakonstantinou and Tobolski, 2006; Richardson et al., 2012; Sukontasukkul and Chaikaew, 2006; Topcu, 1995; Batayneh et al., 2008; Sukontasukkul, 2009) etc. By the crushing process, recycled concrete aggregated can be obtained & which can be used as aggregates in new concrete production. RCA production process can be designed in such a optimisation way that there will be a efficient use of RCA in terms of both quality & quantity. It is an important factor to be kept in mind that by several different factors the quality of RCA is driven such as the presence of contaminants, quality of original concrete (Noguchi et al., 2015) and the processing of the RCA itself (ACI Committee, 2001). Various steps are involved in the recycling process of concrete such as source concrete breaking and removal, removal of any contaminants (i.e. steel mesh, rebars or dowels), crushing the concrete and sizing the RCA concrete preparation &beneficiation process (removal of any additional contaminants such as old mortar) (ACI Committee, 2001).

**Packing Densities**

By sieve analysis, a reqd gradation of particles can be achieved & which in results on the combination gives a densely compacted arrangement with few voids. By adopting the Fuller equation & grading curves, desirable packing densities can also be achieved. By the different studies, it was found that there was a potential use of the combination of Coarse & Fine RCA in concrete application.

**Consideration for using fine RCA**

In the mixture, the use of fine RCA depends upon the higher mortar & impurity contents present in the old concrete from

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which it was obtained in comparison to coarse RCA. Evangelista et al., 2015 had studied that the rough surface texture, high absorption, angularity of fine RCA particles was contributed by the adhered & loose mortars. The behaviour of fine RCA with these deficiencies in the mix was studied & it was found that workability of concrete was affected due to these deficiencies in fine RCA (Obla et al., 2007) & moreover, there was reduction in the strength of concrete, volumetric instability also increases significantly (i.e. creep, shrinkage & coefficient of thermal expansion). Fan et al.(2015) had found that the mortars containing fine RCA ranging from 25 % to 100 % had experienced higher drying shrinkage than the designed specimens at all tested ages (7,14,21 & 28 days) as this constituent was having higher porosity & this porosity enabled to rapid evaporation of water in the mix. As observed by Smith (2018) that the strength of concrete was degraded due to more impurities incorporated in the fine RCA. Similarly, Zaharieva et al., (2003) also suggested that fine RCA use in the concrete mix should be prevented because of negative effects on the concrete. Evangelista et al. (2015) had found that the fine RCA of smaller size fractions (125–500 μm) possess high mortar content while bigger size fractions (1–4 mm) present in a mix produces considerable amount of cracks at the paste – aggregate ITZ. An estimation given by Obla et al. (2007) that there was an additional economical burden by the amount of about $2/ton was required to separate the RCA into coarse and fine fractions as compared to coarse fraction only by the aggregate producer. Fine RCA which was derived from concretes that are specifically made in laboratory conditions by Evangelista and de Brito (2007). Resources, Conservation & Recycling 133 (2018) 30–49 31 were crushed afterwards by K.P. Verian et al. (Evangelista and de Brito, 2007) had studied that the fine RCA which was made in the laboratory can be used with replacement ratio up to 30% without having significant effect to the mechanical properties (compressive strength, split tensile, elastic modulus, and abrasion resistance). Evangelista and de Brito, 2007 had obtained these results by crushing and sieving concretes specifically produced and cured in the laboratory & these were totally different from the actual exposure condition experienced by concrete in the field. Several studies in mortar applications have proved by the use of fine RCA gives similar or even more better compressive strength than the use of virgin aggregates which were having more porous & irregular surface & moreover, there was an enhancement of the interlocking bond between the aggregate & paste by the use of fine RCA (Neno et al., 2014; Topcu and Bilir, 2010). The increased in strength overtime may be due to the hydration between the unhydrated OPC particles existing in the RCA with the presence of water in the new RAC mix (Braga et al., 2012).

**Characteristic of RCA:**

The differences between the characteristics of RCA and NA had been reported in many studies by various researchers (Verian, 2012; Verian et al., 2013; Beltrán et al., 2014; Verian et al., 2011a; Jain et al., 2012a; Olorunsoyo and Padayachee, 2002; Poon et al., 2004; Gomez Soberon, 2002; Khatib, 2005; Medina et al., 2014; Kou and Poon, 2013; Ann et al., 2008; Abbas et al., 2009; Fatihfazl et al., 2009; Jain et al., 2012b; Kapoor et al., 2016; Evangelista and De Brito, 2010; Silva et al., 2015; Gesoglu et al., 2015; Gokce et al., 2004; Katz, 2003; Limbachya et al., 2000; Sagoe-Crentsil et al., 2001; Thomas et al., 2013; Shi et al., 2016; Snyder, 2016). These differences are, but not limited to, mortar content, specific gravity, absorption, Los Angeles (L.A.) abrasion resistance, soundness resistance, and the chemical components.

**Mortar content**

Verian, 2012 had observed that adhered mortar on the surface of original concrete aggregates becomes the part of the RCA product. This adhered mortar which is less dense & more porous than the aggregate matrix is responsible in creating a lighter system in the RCA. There was an increase in the absorption capacity & decreased in specific gravity of RCA due to the presence of these adhered mortar as compared to NA (Kisku et al., 2017). RCA use with a surface containing attached mortar layers will be responsible in creating two types of ITZ (Old & New) in the conc. mix. Leite and Monteiro, 2016; Le et al., 2017 found that the distribution of porosity of the new ITZ greatly influenced by the initial moisture condition of the RCA & the strength of RCA source concrete. As examined previously by Verian (2012), Verian et al. (2013) that cross – section of epoxy – embedded RCA particles determines the two types of ITZ (old and new) percent of mortar adhered to their surfaces by using an optical microscope. It was also found that the probability was up to 28.9 % to find the old mortars that was attached to the surfaces of RCA (Verian, 2012; Verian et al., 2013). RCA aggregates used in their study by Etxeberria et al. (2007) had reported that the old mortar contaminants are about 20 % & 40 % for two different RCA fractions (10/25 and 4/10 mm). The adhered mortar can occupy up to 20–30% of the RCA’s volume as found by Etxeberria et al. (2007), Li (2008); The amount of attached mortar as much as 24 % & 38 % on two types of RCA as found by Afroughsabet et al. (2017) in his study. Roessler et al. (2013) reported the amount of reclaimed mortar content (RMC) of the coarse RCA at different sizes.

**Specific gravity**

RCA generally have lower specific gravity than that of NA as found in literature. RCA have a specific gravity ranges from 2.45 to 2.70 (the only exception is the specific gravity of recycled sanitary ware, which is 2.97) (Vieira et al., 2016) as compared to 2.40–2.89 of NA. The presence of old mortar attached to the RCA is responsible for the lower value of specific gravity of RCA compared to NA (ACPA, 2009).

**Absorption**

Adhered mortar of the old concrete on the surface of RCA particles results into a higher absorption capacity of RCA as compared to NA (ACPA, 2009; Verian, 2012; Olorunsoyo and Padayachee, 2002; Levy and Helene, 2004).

**L.A. abrasion test mass loss**

Due to the impact of the steel balls and the aggregates while performing LA abrasion test, there will be a considerable % mass loss of the aggregates. RCA have higher mass loss values during the abrasion test than for NA. Snyder et al., 1994 had found that during the crushing process, there was a higher mass loss caused by the presence of the softer old mortar & the particles that were cracked.

**Soundness durability**

The soundness test on RCA and NA in his study was conducted by Verian (2012), Verian et al. (2013) regarding the application of RCA as coarse aggregate in pavement concrete. This test was involved in freezing and thawing of aggregates in a brine solution and is used to determine the resistance of aggregate to disintegration by repeated- rapid cycles of...
Potassium, chloride and sulfate leachate concentration
RA having the amount of ionic species were greatly influenced by the exposure condition of the structure (that was crushed and used as the RA source) during its service life. Verian (2012) has reported in his study that the average potassium ion concentration obtained from the leachate solution of RCA derived from SR-26. It results into the increase risk of ASR on concrete containing RCA. The amount of chloride ion was more than double as found from the leachate solution of RCA than that of virgin aggregate (Verian, 2012). Rahal (2007) was found that RCA content had higher chloride content than that of NA (0.3% vs. 0.14% of cement mass). RCA concrete becomes more prone to corrosion due to higher chloride content & other chloride related deterioration due to the use of rebars in the concrete. RCA had less sulfate ion than that of NA & this indicates that the potential of RCA in reducing the risk of internal sulfate attack in concrete as compared to NA (Verian, 2012).

Characteristic of concrete containing RCA Aggregate
The performance of RAC concrete than that of NAC is greatly affected by the different quality of RCA as compared to NA (Verian et al., 2013; Etxeberria et al., 2007; Rahal, 2007; Ann et al., 2008; Limbachiya et al., 2000; Levy and Helene, 2004; Kou et al., 2011; Saravanakumar et al., 2016; Federal Highway Administration, 2018).

Workability
In the case of ordinary concrete, workability of RAC in the case of ordinary concrete is mainly governed by the grain size distribution, shape & quantity of water in the mix. As for rounded shape RCA produced from the crushing process contributes into the increase of slump values but this was due to varying in the proportions of RCA content & also due to less amount of FA in comparison with NA (Amario Mayara et al., 2017). Slump test results proved that NA replacement with different percentages RCA had no negative impact on consistency of the mix (2017). Workability for RAC & NAC was measured by slump test & slump values showed that soaked aggregates having lower values than unsoaked aggregates. The main reason for this is that no more additional free water was available to assist workability in case of soaked aggregates & absorption of water assists workability in case of unsoaked aggregates as since water was not absorbed instantaneously during mixing but it takes some time. Reason for the delayed WA could be that cement mortar had higher surface area as compared to CA which results in delays of lubrication or absorption of pore water (Mwasha Abrahams et al., 2018). There was a decrease in the concrete workability with the percentage increase of NA replacement. A slump of 5 – 20% was observed when 100% of the NA were replaced with RCA. Old mortar adhered on the surface of RCA & this mortar was responsible in causing internal friction of higher amount inside the green mix. It was due to this reason there was reduction in the workability of RAC (Thomas Job et al., 2018). RCA have lower slump than NAC at the w/c ratio. Workability of RCA was decreased due to higher WA capacity, more irregular shapes & rougher surfaces. Workability of RCA can be improved by the use of admixtures (water reducers/plasticizer), fly ash & by the combination of both but limit the amount of water (Verian Pin kho. et al., 2018). Workability of green concrete is affected by the interactions of RA & NA (Nakhli Ben Ammar et al., 2019).

Density & Water Absorption
The specimens of NCA concrete had obtained the lower water absorption & greatest density. It is well known that the aggregate structure requires linked & open cracks for the WA & these cracks occurs in the RCA during the crushing process. As expected for all mixtures, water absorption of RCA concrete increases with the increase of RCA content. The water absorption of the RCA concrete also increases due to the great amounts of impurities in the RCA conc. RCA concrete, an inverse relationship between water absorption & density was observed (O Cakir, 2014). Incorporation of SP results to be more effective for reducing the WA by capillarity than by immersion. As water reducing admixtures lead to cement matrices with lower permeability due to higher compactness & low w/c ratios. The quality of cement matrix is more dependent for water absorption by capillarity than the water absorption by immersion. By the use of SP both the properties were significantly improved (Brito, J. de et al., 2016). Concrete density was decreased with an increase of RR of CA. Lower bulk density of RCA than NA was only due to adhered mortar on its surface. The density of green concrete with same w/c ratio & increased cement content was increased. Highest sp. gravity of the ingredient of concrete was of cement. Highest cement content is responsible for highest density of RCA mixes (Thomas Job et al., 2018). Density of RCA concrete was decreased by the increased amount of RCA in concrete (Verian, 2012; Etxeberria et al., 2007; Xiao et al., 2005; Gomez Soberon, 2002).

Compressive strength
The inc. amount of RCA is responsible for the decrease in the fc of RCA conc. There was a dec. in concrete strength for about 24% at 28 days after 100% replacement level. There was a more significant strength reduction at over 50% replacement level. The specimens containing 5% & 10% SF contents had inc. in comp. strength with relative to those specimens which were having 30% & 60% GGBFS contents by replacing of the NA with RA at 28 days (O Cakir, 2014). The minimal differences between the cNA & rNA series were exhibit & analysis regarding NC mixtures with increasing SP content (R=0%). The results also proved that the values of strength agree with usual tendency analysed in the lit. In case of RC produced with crushed NA (cNA), so this concludes that there was a dec. in the strength of the NAC due to the addition of recycled material in the similar mix & recycled replacement ratios were also clearly influenced by this amount of addition of recycled materials in the similar normal concrete mix. In this context, these results evidence that the recycled concrete strength behaviour was completely different for RAC mixtures with rounded natural aggregates (rNA). Therefore, the results of rounded natural aggregates show that there was not a dec. in the strength properties & also these rounded natural aggregates produces an increase of up to 15% compressive strength. For the mixes with a RR of 50% & a cement content of 300 kg/m³ & 0.5 w/c ratio, the values of the fc were approximately 40 – 42 N/mm². The results for RAC mixes with RR of 100% by adding the rounded natural aggregates in the conc. mix were satisfactory regardless the volume dosage of cement but in case of mixtures which were manufactured by the adding the crushed natural aggregates (cNA) needs compensation by quantity of cement by volume to reduce the fall in strength as per the requirement. By using the recycled material, the differences in fc with the environmental savings were minimal for cement doses higher than 300 kg/m³ & it may be recommended to produce RAC with can (Laserna. S. et al., 2016). By the incorporation of RA, the attributed strength
are significantly affected. By using high quality of the recycle aggregate used not proves to maintain the characteristic of mix but the mix produced by incorporating high quality RA’s results into suitable lower mechanical properties than the parent concrete. If concrete mix design was being done to achieve higher targeted concrete strength then the RCA effect would possible be into more noticeable as because the new cement matrix could have better properties than the adhered old mortar on the surface of the RA (Brito, J de, Etal2016). Dodds Wayne, et.al2017 had confirmed by the following results as illustrated below that there was an incry negative impact on the fc at all ages for CEM I & CEM II by including Coarse CCA

a. Compressive cube strength at 28 days
1) The fck at 28 days of 44 MPa was obtained by 24 samples out of 40 samples.
2) Lower strengths of concretes with greater amount of CCA & GGBS with B source having greatest negative impact followed by C & A sources respectively.
3) The fck of conc. mixes 0 A, 36 A & 0 C can only be achieved for concrete containing 100% coarse CCA.
4) The fck with coarse CCA contents upto 60 % for A & C sources was met for CEM III/A concretes.
5) When B source was used then in comparison to source A, a low amount of coarse CCA content of 30% then same type of binder be used.

b. Compressive cube strength at 91 days
1) Concretes which were manufactured with greater amount of GGBS showed results in the stipulated time of 91 days that they had sufficient strength and also had latent hydraulic effect of GGBS with more of the CEM III/A concretes mixes
2) The concretes who were unable to achieve the desired characteristic strength were 50 B, 65 B & 65 C who were mixed with 100% coarse CCA content.
3) The fck of above concretes of having a confidence level of 0.997, 0.066 & 0.849 respectively.
4) From above concretes, 65 B concrete has more risk of non-compliance.
Zhao Yuxi et. 2017 had showed in the results that lower comp. strength of RAC was only due to pre wetting process. This was only due to release of prewetting water & it results into an increase of effective w/c ratio around RA. Further, this increase of effective w/c ratio of conc., many crystals of Ca(OH)$_2$ in the directional arrangement results into making of ITZs loose & porous. The 28 days fc of concrete decreases when there was increase in percentage replacement of RCA. These results were analysed depending upon NA replaced (PG or Gr) & types of mix (M1 or M5). The average of 3 cylinders tested was represented by each data point (McGinnisJ. Michael . et. al 2017). As showed in the results that lower comp. strength of RAC was only due to pre wetting process. This was only due to release of prewetting water & it results into an increase of effective w/c ratio around RA. Further, this increase of effective w/c ratio of conc., many crystals of Ca(OH)$_2$ in the directional arrangement results into making of ITZs loose & porous (Zhao Yuxi et. Al 2017). Mwasha Abrams. et.al 2018 had illustrated below, the comp. strength results for all the categories of aggregates were achieved positive.

i. Compressive Strength & Curing Time Relationship for RAC
HS-RA produced concrete with higher fc as observed & it was due to that HS-RA was coated with strong mortar paste. In this way, it was able to resist more loading before failure & it results into higher fc. The results showed that RAC strength was more dependent on its parent concrete strength due to the extension of the old mortar paste strength.

ii. Ratio of compressive strength Natural aggregate concrete strength to Recycled Aggregate concrete compressive strength
The difference in strength gains was found by the ratio of fc gains by NAC’s & RAC’s. These ratios of average fc after 7, 14, 28 days that in relation to NAC, for LS-RAC a max. diff of 42 % in fc was recorded. It means that at 14 days, NAC was 42% stronger in fc & after 28 days it was reduced to 35%. As showed in previous researches that an average reduction of fc for LS-RAC was 30-40%. For HS – RAC, a 17 % of maximum diff was recorded & it means that at 7 days, NAC was only stronger by 17% & then after 28 days it was reduced to 14 %.

iii. Ratio of compressive strength to density
RAC had higher fc & lower densities than NAC as showed in results. It was found at 7, 14, 28 days for the fc & density ratios for the different manufactured concrete that higher ratios were maintained by NAC followed by HS-RAC & then by LS-RAC. It was observed between the ratios of NAC & HS-RAC had a minor gap with a very similar ratios after 14 days. The values of maximum strengths achieved for NA, HS-RAC, LS-RA were 106.22, 82.67 & 76.89 MPa respectively.

iv. Relationship between Packing Density & Compressive strength
There was no general trend observed for NAC samples that confirmed the proportional relationship between packing density & fc. Higher fc of 106.22 MPa was resulted for the packing density of 70.4 kg/m$^3$. As in similarity in case of HS-RAC, highest fc of 82.67 MPa was recorded for both packing densities of 75.1 & 74.0 kg/m$^3$ & similarly in case of LS – RAC, highest fc of 76.89 MPa was recorded for PD of 70.4 kg/m$^3$.

c) Effect of Soaking the Recycled Aggregates before Mixing
By weighing the dried aggregates, it can be concluded about the WA capacity at a given duration of RA having different sizes. For conducting this test, RA of sizes 20, 12.5 & 9.5 mm were selected. These aggregates are then soaked for 1.60 & 1440 min. It was found that all the particles had soaked the water immediately. So, it was concluded that soaking of aggregates for long time not required. It was also found that particle sizes 20mm & 9.5mm also had the app. the same WA capacity but particles 12.5 mm have 40% WA. It was only due to the reason that particle size 12.5 mm belongs to the category of RA & which was having attached old mortar on it while particle sizes 20 & 9.5 mm belongs to the category of NA Thomas Job et.al 2018 had illustrated that when 25 % of the natural aggregates were replaced by RCA, there was a minimal reduction in strength (1.5-5%). Due to this reason, in the mix design no change is required. A reduction of fc was 11-19% was observed due to 100% replacement of NA with RA. Highest cement content quantity at constant w/c ratio & replacement level of the aggregate only then higher compressive strength was obtained. For the same w/c ratio, due to the increase of cement content, there was an increase in the colloidal binding paste in the mix. Due to this reason, strong interfaces results in the binding of aggregate with the cement & increases the strength of concrete. It also indicates
that to achieve the target strength of control conc mix with 100% RCA requires higher amount of cement content is required (Thomas Job et al. 2018).

**Flexural strength**

The flexural strength decreases by 2-5% was observed when 25% of NA was replaced in the mix. With the replacement of 100% aggregate then the decrease of 7 – 17% flexural strength was observed. The rough surface texture of RCA will influence in the reduction of flexural strength (Thomas Job et al. 2018).

**Tensile strength**

The tensile splitting strength of NCA concrete was higher than the RCA concrete. The specimens containing SF had an increase in the TSS by replacing of the NCA with RCA but there was decrease in the TSS of the specimens GGBFS by replacing the NCA with RCA. There was a suitable development of the TSS of the concrete as compared to fc of the specimens who were having RCA content. The ratios are lower in the RCA concretes incorporating SF than the ratios of the RCA concretes incorporating GGBFS. The ratio of tensile splitting strength to compressive strength of NCA conc. is 7.8 – 10%. The ratio of TSS to fc of RCA is 7.7 – 11.4%. It is found that the difference between the limits i.e upper & lower of the ratios of NA concrete is lower than that of RA concrete (O’Cakir 2014). TSS was decreased with the increase in replacement percentage of agg. The transition zone formed in RAC is of poor quality with the increase in water content & as a result lower strength was obtained. TSS of concrete increases with the increase in cement content with the mix had same w/c ratio. The increase of cement content developed a stronger ITZ & results in the improvement of the hydrated cement properties. The reduction in tensile strength of concrete due to both adhered cement mortar on RA & increase in the WA at the surface of aggregates (Thomas Job et al. 2018). The tensile strength of concrete containing RCA was reduced up to 10% when coarse replaces RAs the coarse NAs. The tensile strength of concrete was reduced further by 10 – 20% when both coarse & fine NAs replaced by RCA (Verian Pin kho et al. 2018).

**Modulus of elasticity (E)**

As the RP increases due to the lower bulk density & stiffness of RCA, static modulus of elasticity of RAC decreases. For RCRC & RPC, maximum reductions of elastic modulus are respectively 18% & 22%. Due to the difference between the shape & surface of RPA & RCRA, RCRC mostly have higher toughness than of RPC. RAC have little higher poisson’s ratio & comparable than that of conventional concrete (Zhou Chunheng, et al. 2017). Elastic modulus was decreased with the increase in the RCA percentage. This modulus was determined in the precracking stage. The variation in the modulus of concrete was due to the presence of inherent cracks in the transition zone. During the crushing process, micro cracks were formed within the RCA. At the interface between the adhered old mortar & the aggregate results in the reduction of the stiffness of the composite system. Due to this reason, it results into lower modulus of elasticity of concrete (Thomas Job et al. 2018).

**Freezing-thawing resistance**

Salem et al. (2003) and Verian (2012) indicated that concrete made with NA due to the higher porosity, which subsequently leads to higher absorption and poorer mechanical performance of concrete made with RCA. Another study Gokce et al. (2004) showed that quality & manufacturing of old concrete & the availability of RCA from these concretes plays an important in providing the amount of resistance to freezing & thawing. In the research they indicated that when RCA derived from air-entrained concretes had better resistance than RCA from derived from non – entrained concrete subjected to 500 FT cycles.

**Drying shrinkage**

Mindess et al. 2003 had showed that the paste content & w/c ratio of the concrete affects the extent of occurrence of drying shrinkage. Higher the amount of paste content in RAC due its reclaimed & new mortar results into a higher magnitude of drying shrinkage as compared to NC (Verian, 2012; Verian et al., 2013; Beltrán et al., 2014; Khatib, 2005; Evangelista and De Brito, 2010; Sagoe-Crentsil et al., 2001; Snyder, 2016; Sturtevant, 2007). According to the study by Building Contractors Society of Japan (Building Contractors Society of Japan, 1978), as reported by the ACI committee 555, range of 20% to 50% of coarse RCA & natural sand in concrete results into higher shrinkage. It was also showed that RAC made with both coarse & fine RCA had 70% to 100% higher shrinkage compared to NC (ACI Committee, 2001). Fan et al., 2015 had also proved that fine RCA was responsible into higher drying shrinkage due to the relatively higher old paste content while the incorporation of coarse RCA results into a higher water absorption.

**Creep**

The amount of RCA in concrete results into the proportional amount of creep occurrence in the concrete as the greater amount of RCA in concrete mixture increased the potential creep (Tam and Tam, 2007; Hansen, 1986). Ravindrarajah andTam (1985) has reported that the RAC manufactured with 30% to 60% RCA had greater creep than concrete manufactured with NA. As creep of concrete is proportional to the amount of paste or mortar in concrete & due to this reason the creep of concrete is higher in case of mixtures which are produced with RCA as compared NCA (ACI Committee, 2001). Kou and Poon (2012) reported that the when RCA used in the manufacturing of concrete then strain in concrete due to creep reached more than 600 μm as compared to less than 500 μm of NC.

**Permeability**

The coefficient of permeability of concrete is dictated by the size and continuity of the pores in hydrated cement paste (Mindess et al., 2003). Concrete made with RCA has permeability two to five times higher than that of NC for mixtures with w/c ratio of 0.5–0.7 (Hansen, 1986).

**Chloride ion penetrability resistance**

The chloride ion penetration resistance of RAC decreases when permeability increases (Verian, 2012; Jain et al., 2012a; Kou et al., 2011; Verian et al., 2011b). Kou et al. reported that RAC had more than 40% lower chloride penetration resistance when made with 100% coarse RCA as compared to NC (Kou et al., 2011; Kou and Poon, 2012).

**Fracture properties**

The quality of the RA and the bond between the aggregate and paste play important role in determining the fracture behavior of concrete.

**II. CONCLUSIONS**

1) RA characteristics are mostly dependent on the type & amount of cement mortar attached to it & also on the quality...
of NC from where RA were obtained. The method of recycling from where RA were obtained have considerable effect on RA in the form of lower density, higher water absorption, higher content of organic & possibly harmful substances ,higher level of crushability ,reduced abrasion resistance & reduced resistance to frost.  
2) When RA originates from many different sources then there will be a unevenness in its quality in the sense of its variable properties than NA. Therefore, concrete manufacturers follows a common practice by making a thorough analysis of the properties of RA before using them.  
3) Depending upon the characteristics of the waste concrete, RAC can have a satisfactory, even high level of performance in terms of being a feedstock for the production of recycled aggregates & its characteristics gives us the idea regarding the amount of its compressive strength. By recycling method & expertise in the designing the conc. mix, pointed out that fine fraction of RA have a bigger impact in reducing the quality of concrete. Therefore, it was advised to replace the fine fractions of the aggregate with natural resources mostly with river sand for designing the structural RAC. 4) Concretes which are made up of using RA of original concrete with higher comp. strength than the target value of the strength of new concrete often gives better performance than natural concretes. In the sense of original concrete have most equal, frequently even lower strength values compared to the target value of new concrete. It had been a proven fact that the presence of RA in concrete reduces the bulk density of conc.& affects the hardened properties of concrete but it imparts more abrasive resistance to concrete.  

III. REFERENCES  

[14]. Verian Kho Pin .et.al “Compared with the conventional concrete the properties of recycled concrete aggregate & their influence in new concrete production”  