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A Critical Review on Behaviour of Glass Fiber Reinforced Concrete Using Recycled Aggregates

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Abstract: *Glass fiber reinforced polymer has become an alternative reinforcement in concrete structures due to its excellent corrosion resistance, making it possible to combine with concrete composed of seawater and sea sand. It has been observed that usage of glass fiber increases strength of concrete and repletion of concrete towards acid and alkali. Many researchers have reported that there exists a clear difference between properties such as porosity, water absorption, surface density, crushing value etc. of recycled coarse aggregates (RCA) and natural coarse aggregates (NCA). It has also been established that on replacing normal aggregates with recycled aggregates there is a slow depletion in strength properties where flexural properties depict a clear reduction in strength. It has been further detected that maximum limit of using recycled aggregates is not more than 50 percent. Therefore according to the specific performance requirements of concrete, choosing appropriate raw materials and then designing the most economic, high-quality concrete, based on the proper mix proportion methods, is the best way to overcome the shortcomings of the traditional design materials and this puts forward new thoughts and finding an appropriate mix that can be used for incorporating more percentage of recycled aggregates. It developed a backbone for the study of glass fibers addition in concrete with partial replacement of normal aggregates with recycled aggregates considering the strength parameters and workability. This paper reviews on previous findings on use of RCA and glass fibers.*
Keywords: *Glass fibers, RCA, NCA, workability, repletion, recycled*.

I. Introduction

In recent years, certain countries have considered the reutilisation of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities. The recent study on partial replacement of normal aggregates with Recycled aggregates using 0%, 20%, 30% and 40% of recycled aggregates with 5%, 10% and 15% recycled hydrated cement(RHC) have reported better performance of concrete with 20% RCA and 5% RHC[1]. Similarly many researchers have dedicated their work to describe the properties of recycled aggregate, the minimum requirements for their utilisation in concrete and the properties of concretes made with recycle aggregates. Past studies also depicted that glass fibers are good constituents of concrete and usage of glass fibers ranging 0% to 2% results in increase in flexural strength of concrete[2].

Therefore, usage of glass fiber reinforced concrete with recycled aggregate will give optimum strength and economy. In this study, fracture behaviour of glass reinforced concrete with recycled aggregates will be tested.

II. Literature Review

A detailed study on the researches done is carried out and founded out that using recycled aggregates results in decreasing the strength attributes and increasing water absorption and carbonation whereas addition of glass fiber in concrete give better strength and credibility. Usage of recycled aggregates in concrete in higher percentages will only be fruitful when glass fibers are added with concrete. The research works done by various researchers on glass fiber reinforced concrete are been described in chronological order like in 1974 Junji Takagi et al., investigated the effect of randomly oriented glass fibres on the flexural strength, compressive strength, splitting tensile strength, and Young's modulus of concrete, and concluded that there was an increase in strength with an increase in fibre content[3]. Further in 1996 C. Vipulanandan et al., studied flexural behaviour of a polyester polymer concrete by varying the polymer up to 18% by weight and fiber contents to 6% by weight of PC. In general, addition of fibers increased the flexural strength, failure strain (strain at peak stress), and fracture properties, but the flexural modulus of PC remained almost unchanged. Addition of six percent fiber content and silane treatment of aggregates and fibers increased the flexural strength of 18% PC to 41.6 MPa (6,040 psi), almost doubling the strength of unreinforced 18% PC system[4]. In continuation to this research S. H. Alsayed, et al., in 2001, studied the performance of glass fiber reinforced plastic bars as reinforcing material for concrete structures and revealed that as GFRP bars have low modulus of elasticity, deflection criteria may control the design of intermediate and long beams reinforced with FDRP bars[5]. Then after K. Ramesh, et al., in 2003, studied experimentally the stress–strain behaviour of confined fiber reinforced

concrete (CFRC) and tested nine prisms of size 150x150x300 mm under strain control rate of loading and resulted increase in strength and strain of CFRC[5]. In 2004 J.M.L. Reis et al., observed in their study that the fracture toughness of carbon fiber reinforced polymer concrete can increase up to 29% while glass fiber polymer concrete can increase up to 13% when comparing with epoxy non reinforced polymer concrete[6]. Yeol Choi, et al., in 2005, have conducted an experimental study on the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC) and founded that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength[7]. Further in 2007 G. Barluenga, et al., evaluated the cracking control ability of Alkali Resistant (AR) glass fibers in standard concrete and SCC and founded that amounts of glass fiber around 600 g/m^3 shown the maximum cracking control ability, but larger amounts did not increase the fiber efficiency[9]. Then P. Srinivasa Rao, et al., also conducted durability studies on alkali resistant glass fiber reinforced concrete in 2012 and find out workability, resistance of concrete due to acids, sulphate and rapid chloride permeability test of M30, M40 and M50 grade of glass fiber reinforced concrete and ordinary concrete resulted increase in durability of concrete, reduction in bleeding and increase in acid resistance[10]. In year 2012 may researches were been done like Avinash Gornale, et al., reported that there is an increase in compressive strength, flexural strength, split tensile strength of glass fiber reinforced concrete for M20, M30 and M40 grade of concrete at 3, 7 and 28 days by 20% to 30%, 25% to 30% and 25% to 30% respectively[11] and Kavita Kene, et al., conducted studies using steel and glass Fiber Reinforced Concrete Composites with steel fibers of 0% and 0.5% volume fraction and alkali resistant glass fibers containing 0% and 0.25% by weight of cement of 12 mm cut length and founded that addition of glass fibers results in increase of compressive strength, flexural strength and split tensile strength[12]. Further in 2012 itself Muna M .Abdullah et al., investigated to find out the effect of glass fiber content (0, 600, 1000, and 1400) gm/m^3 on the mechanical properties of glass fiber reinforced concrete at 28 days, resulted increase in the splitting tensile strength by approximately (1, 4.3, 12.5)% and and compressive strength of concrete increased by ratios (3.6, 7.1, 9.3)%. Based on this study the young modulus of GFRC increased by (9.7, 56.6, 84) % due to glass fibers content in concrete[13]. Then Yogesh Murthy, et al., studied the performance of Glass Fiber Reinforced Concrete revealed that the flexural strength of the beam with 1.5% glass fiber shows almost 30% increase in the strength but reduction in slump observed with the increase in glass fiber content[14]. In 2013, G. Jyothi Kumari, et al., studied the behaviour of concrete beams reinforced with glass fiber reinforced polymer flats and observed that beams with silica coated glass fiber reinforced polymer (GFRP) flats showed shear reinforcement failure at higher loads and exhibit fairly good ductility[15]. Further Tassew et al., in 2014, conducted experimental studies using glass fiber volume fractions between 0% and 2% founded that addition of glass fibers into ceramic concrete had little influence on the compressive strength and modulus of elasticity but resulted in significant increases in flexural strength and direct shear strength, regardless of the matrix type or fiber length, while the workability decreased with an increase in fiber content[16]. Then in 2015, Ahmet B. Kizilkanat et al., studied the mechanical properties and fracture behaviour of basalt and glass reinforced concrete for different combinations of 0.25, 0.5, 0.75 and 1.0 percentage of basalt and glass fiber and observed that Fracture energy increased significantly after 0.25% dosage for both basalt and glass reinforced concrete[17].

The studies done on glass fiber reinforced concrete summarizes that use of glass fiber in concrete results in increase in flexural and split tensile strength and there is very less variation in compressive strength of concrete and so glass fiber reinforced concrete can be well applied in flexural members. This review is focused on the possibility of use of glass fibers to increase the use or percentage of recycled aggregates in concrete and so further research works reported by researchers on recycled aggregate concrete is too reviewed for getting an overview of the further scope of research that can be suggested to obtain positive research outcomes.

The researches done with recycled aggregates in been arranged in chronological order starting from 2001 the Leite campaign, at the Federal University of Rio Grande do Sul, Brazil, where the RA used in the production of RCA were coarse and fine ceramic and recycled concrete, several replacement PA/RA ratios were selected within each family of RCA, defined by a predetermined w/c ratio (0.4, 0.45, 0.60, 0.75, and 0.80), and a high percentage of fine RA was used. The hardened concrete was tested for compressive strength, splitting and flexural tensile strength and modulus of elasticity[18]. Then in 2002, F. Buyle-Bodin et al., studied water absorption, air permeability and carbonation of recycled aggregate concrete by using both coarse and fine recycled aggregates and founded that water absorption is more while using recycled aggregates. The carbonation rate of recycled aggregate concrete is also higher which leads to a weaker resistance of recycled aggregate concrete to environmental attacks[19]. In the study done by Said Kenai et al., compared mechanical properties with a concrete to 100% of natural granulates and of a recycled concrete partially replacing 0, 25, 50, 75 and 100% of natural aggregates. Results showed that it is possible to manufacture a concrete to basis of ground of physical feature concrete and acceptable and in the same way comparable mechanics to those of a concrete to natural granulates basis so long as the percentage of granulates recycled is limited to 75% for the thick and to

50% for ends[20]. In the Katz campaign, (2003) at the Israel Institute of Technology, the RA were produced in the laboratory by crushing concrete specimens 1, 3 and 28 days old. The PA were replaced with RA for the following fractions: 2.36-9.5 mm (0.093- 0.374 in) and 9.5-25 mm (0.364-0.984 in) (both coarse), and 0-2.36 mm (0-0.093 in) (fines). Fine RCA was used in small amounts and only to improve workability. The traditional cement class was lower than the white cement class, and that had some influence on the results. The hardened concrete was tested for compressive strength, splitting and flexural tensile strength, modulus of elasticity, water absorption, carbonation penetration and shrinkage. The properties of the RCA with nearly 100% of aggregate replacement, were tested. Various particle size group showed significant differences between the properties of the recycled aggregates where as the crushing age had almost no effect. The properties of the concrete made with RA were inferior to those of concrete made with virgin aggregates. Concrete made with aggregates crushed at age 3 days exhibited better properties than those made with aggregates of the other crushing ages[21]. Steam curing method was used for curing recycled aggregate concrete with fly ash using 0, 20%, 50% and 100% of recycled aggregates with 0.45 water-cement ratio and fly ash of 0%, 25% and 35% by weight replacements of cement and was tested for compressive strength, modulus of elasticity, chloride penetration and shrinkage in Kou Shi C et al., research in 2004 and founded that there in decrease in strength of concrete on increase in content of recycled aggregate in concrete. It was founded that for incorporating higher percentages of recycled aggregate in concrete, fly ash between 25-35% can be used with steam curing[22]. In the Cervantes et al., campaign, (2007) at the University of Illinois, USA, the RCA families were defined in terms of the addition of synthetic fibers in the concrete production. Only the coarse fraction of PA was replaced with different ratios of recycled concrete RA (0, 50, and 100%) and with 0.2% of synthetic fibers. The effective w/c ratio remained constant at 0.51. The hardened concrete was tested for compressive strength, splitting tensile strength, modulus of elasticity and shrinkage. The test results reported that use of 50% RCA with 0.2% synthetic fibers produced a pavement quality concrete with similar fracture and shrinkage properties to that of the virgin coarse aggregate concrete[23]. M. Etxeberria in 2007 experimentally tested shear behaviour and strength of beams considering four concrete mixes with different percentages of recycled aggregates with partial replacement 0%, 25%, 50% and 100% with different transverse reinforcement taking same compressive strength and founded a substitution of less than 25% of coarse aggregate, scarcely affects the shear capacity of RC beams[24]. In year 2009 A. Bordelon et al., studied fracture behaviour of paving concrete made with recycled concrete as a coarse aggregate, virgin coarse aggregate, and a blend of recycled concrete and virgin coarse aggregate with Discrete structural fibres and observed that 50–50 blend of virgin and recycled concrete coarse aggregate produced similar fracture properties to VAC and both were 53% higher than the total fracture energy of the 100% RCA concrete. With the addition of synthetic macrofibres to RCA concrete, the total fracture energy was greater than the plain VAC[25]. Experimental results were used to establish a relationship between some properties of hardened concrete (compressive strength, splitting and flexural tensile strength, modulus of elasticity, abrasion resistance, shrinkage, water absorption, carbonation penetration and chloride penetration) and the density and water absorption of the aggregates by Jorge de Brito, et al., in 2010 and founded The use of concrete with recycled aggregates should always take into consideration that in most cases they perform worse than conventional concrete but that the variability of their properties are similar. Therefore, the decrease in the concrete with recycled aggregate performance in comparison to the conventional one can be anticipated with the knowledge of the substitution rate and of the aggregates properties[26]. In year 2015 Kutalmis Recep Akça et al., replaced normal aggregate with recycled aggregates and used polypropylene fiber 0%, 1% and 1.5% by volume and Compressive strength, splitting tensile strength, flexural tensile strength, static and dynamic modulus of elasticity experiments were conducted in order to determine mechanical performance of the concrete series. It was founded that there is a remarkable increase in split tensile and flexural strength on increment of fibre content[27]. There after Faisal Sheikh Khalid, et al., in 2017 studied on Mechanical Properties of Concrete Containing Recycled Concrete Aggregate (RCA) and Ceramic Waste as Coarse Aggregate Replacement and used 25%, 35%, and 45% RCA and ceramic waste as coarse aggregate in producing concrete and reported that 35% RCA and 35% ceramic waste showed the best properties compared with the normal concrete[28]. Mohsen Ahmadi, et al., replaced natural coarse aggregates with recycled aggregates in percentage by weigths of 0, 50 and 100%, with steel waste fiber obtained from waste tyres percentage being 0.5 and 1% of concrete volume. Main results indicate that by adding recycled fibers into the concrete with recycled aggregates lead to the production of structural concrete by 50% replacement of aggregates. Moreover, adding recycled fibers by 0.5 and 1% of concrete volume reduces the thickness of concrete pavement for the amount of 8 and 16%, respectively[29]. In year 2017 Ngoc Kien Bui researched on properties of recycled aggregate concrete (RAC) by using sodium silicate and silica fume. The method proposed was applied to 100% coarse recycled concrete aggregate compared to untreated RAC was able to improve compressive strength up to 33-50%, splitting tensile strength 33–41%, and elastic modulus 15.5–42.5%. From the experimental data, the compressive strength of the treated RAC can be estimated at any age[30]. The paper by Hasan Katkhuda in 2017 presents the results of a study that investigated the improvement of the mechanical properties of recycled concrete aggregate (RCA)

produced by adding chopped basalt fibers (BF) with contents of 0.1%, 0.3%, 0.5%, 1%, and 1.5% by total volume of the mix to treated and untreated recycled aggregates.

The recycled aggregates were surface treated by pre-soaking them in a 0.1 M hydrochloric acid (HCl) solution for 24 h to remove the adhered mortars to improve the bond between the recycled aggregate and the cement. In addition, chopped BF was added to normal concrete (NA) mixes as a control for comparison. The results showed that using chopped BF minimally enhanced the compressive strength of the concrete mix but significantly improved its flexural and splitting tensile strength. Furthermore, the optimum BF content that produced the same splitting tensile and compressive strength as NA was 0.5% for untreated RCA and 0.3% for treated RCA, while the flexural strength was 0.3% for untreated RCA and 0.1% for treated RCA[31]. Then in year 2018, Christiana Alexandridou et al., have conducted experimental study where concrete mixtures were prepared using partial replacement of natural aggregates with percentages of recycled aggregates ranging from 0% to 75%, results indicate that the compressive strength of recycled concrete ranges from significantly lower (37% reduction) to equal, compared to conventional concrete, depending on the composition of recycled aggregate[32]. Then in 2018 again G. Wardeh et al., studied experimental behaviour of compressive strength and flexural strength on usage of recycled aggregate in concrete and founded that compressive strength on introduction of recycled aggregates results in a decrease in elastic modulus and showed more cracks than conventional concrete members[33]. As per article published in IOP conference series by Kaiyun Wu et al., stated the experimental study of fracture behaviour of recycled aggregate concrete using 50%, 70% and 100% partially replacing normal aggregates and tested initial cracking load and fracture energy. In the experimental procedure and result prediction it was found that initial cracking load was high with normal aggregate concrete which is founded less in case of recycled aggregate concrete. Further the same is depicted in fracture energy behaviour and was founded a remarkable decrease of fracture energy using recycled aggregate concrete[34]. In year 2018 Jianzhuang Xiao, Studied behaviour of Recycled Aggregate Concrete in comparison to partial replacement of Normal Aggregates, where 0, 30, 50, 70 and 100 percentage replacement of normal aggregates were done and checked compressive strength and founded that compressive strength of recycled aggregate concrete (RAC) is lower than that of natural aggregate concrete (NAC) under the condition that water-cement ratios (w/c) are same[35]. As per the review paper written by Ali Akhtar et al., collecting data from 40 countries it was founded that till 2012 the construction and demolition waste generated per year is more than 3 billion and is increasing constantly. The various researches studied in his review paper founded that the use of 30% to 50% recycled aggregate was suggested to achieve the strength requirements which is not sufficient for developing countries India and China[36]. Yijie Huang et al., compared mechanical properties of concrete with natural coarse aggregate, recycled coarse aggregate and coral coarse aggregate considering 50% and 100% recycled aggregate. Compressive strength of specimens were checked and it was founded that on using more percentage of recycled aggregates there is remarkable decrease in compressive strength where as coral recycled aggregates give more strength than 100% usage of recycled aggregates[37]. In the research done by B. Cantero, assessed the performance of structural concretes containing 20%, 25%, 50%, 75% or 100% mixed recycled coarse aggregate, analysing fresh concrete workability, density and air content and hardened concrete compressive, flexural and splitting tensile strength. The decline in strength relative to conventional concrete was smaller at longer curing ages. Concretes bearing up to 50% recycled aggregate exhibited declines in performance of 10% or under in most of the properties studied, even at late ages. In light of the present findings, the mixed recycled aggregates used in this research may be deemed apt for use in structural concrete with a characteristic strength of up to 30 MPa[38]. In the study done by George Dimitriou in year 2018 founded a method to improve the behaviour of recycled aggregate and reported that 50% replacement is the optimum value for usage in concrete[39]. F. Fiol in 2018 used Recycled Aggregates (RA) from structural precast elements substituting 20%, 50% and 100% normal aggregates. Three Control Concretes (CC-30, CC-37.5, CC-45) manufactured with Natural Aggregates (NA), and their corresponding Recycled Aggregate Concretes (RAC-20, RAC-50, RAC-100) are evaluated in terms of physical and mechanical properties. The in-fresh properties results (flowability, viscosity and passing ability) of the RAC were suitable for their use as SSC. Furthermore, the tests of compressive, splitting tensile and flexural strength, as well as density, porosity, water absorption, ultrasonic pulse velocity, stiffness, and both dynamic and static modulus provided results close to those of the SCC with Normal Aggregates[40]. R.V. Silva et al., in 2018 reviewed 130 research papers where the major focus was on fresh properties of concrete and reported that water absorption of recycled aggregates is much higher than normal aggregates and so use of admixtures can help to obtain workability[41].

III. Results and Conclusions

After performing a detailed literature review it has been analyzed that using recycled aggregates is limited to maximum 50% replacement of coarse aggregate as beyond this there is a remarkable decrease in concrete properties like compressive strength, flexural strength and split tensile strength [42]-[50], [55]-[56] and so for using more replacement of normal coarse aggregate it is suggested to use some fibres and on studying

previous researches on glass fibers it was founded that use of S2 glass fiber enhance the properties of concrete [57] and therefore there is a possibility of attaining an optimum mix with more percentage of recycled aggregate and adding a blend of glass fiber to it. Fracture study is being performed on glass fiber and recycled aggregate concrete using ANSYS software [53] which can be used further to check effect of glass fiber on fracture of recycled aggregate concrete.

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