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THE USEFULNESS OF CONSTRUCTION AND DESTRUCTION WASTE AS RECYCLED AGGREGATES IN CONCRETE

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ABSTRACT: Worldwide, a high proportion of generated total solid waste is Construction and Demolition Waste (CDW), the majority of which ends up in landfills. It has been proposed that this type of waste has potential for being recycled and reused as aggregates in production of fresh concrete, particularly for basic usage. The present study explores how feasible it is to produce concrete with Recycled Aggregate Concrete (RAC) derived from CDW combined with rubber, glass, and flakes. To this end, the study provides a general discussion of the engineering properties of RAC and investigates how the properties of fresh and hardened concrete are affected by the recycled material. To make it more impervious, RAC was subjected to treatment. According to the findings, concrete of satisfactory quality could be produced with the recycled material derived from a site-tested concrete specimen. Furthermore, the properties of compressive and flexural tensile strength varied depending on the differences in size of RAC components, but with regard to compressive strength, the recycled material in the freshly produced concrete was similar to normal concrete.

Keywords: Concrete materials; Construction waste; Recycled aggregates, Rubber, Glass.

1. INTRODUCTION

Among the types of waste produced in abundant quantities at global level is Construction and Demolition Waste (CDW). The rapid pace of urbanisation and urban renewal has intensified construction and demolition activities, which in turn has led to an increase in CDW to 30-40% of total solid waste [1-3]. For example, in Australia, CDW accounts for 44% of total solid waste [4].

Besides growing use of non-renewable resources, the fast speed of urbanisation causes significant accumulations of CDW and concerns related to the environment [5]. Heightened levels of pollution, exhaustion of resources, and land degradation are just some of the major environmental effects that have been associated with CDW [6-9]. Furthermore, the achievement of sustainability and ecological security are jeopardised by the fact that 85-90% of the produced CDW is disposed of in landfills as an adequate waste management strategy is lacking.

Numerous developed and developing countries produce a massive amount of CDW [10]. However, this type of waste is economically viable because it is possible to reuse around 80% of its composition of metal, mortar, concrete, brick, plastic, timber, ceramic, and glass. Thus, CDW can generate significant revenue, especially considering that it accounts for 10-30% of the total solid waste [9].

The key aspect of construction waste management is determining the level of waste production associated with construction and demolition activities. For societal development to attain sustainability, it is important to quantify construction waste and implement relevant mitigating measures. CDW quantification has been the focus of many studies conducted in various countries, including Greece [11-16].

The solid waste yielded by building, renovation, and demolition activities are referred to as CDW [3,17] further included in the definition of CDW the residual, flawed or short-term use construction materials.

Consisting of both soft and hard materials [9], CDW is dominated by concrete, metal, mortar, brick/block, plastic, timber, and glass. Despite the potential for reduction, recycling, and reuse, CDW is often discarded in landfills and therefore can adversely impact the environment [5,18]. The proportion of CDW landfill disposal is quite high in the US (33%), Hong Kong (65%), Canada (35%), the UK (50%), and Australia (20-30%) [18]. However, several authors have suggested that CDW production could be diminished and the waste could be recycled more effectively through the implementation of a comprehensive management strategy [5,9].

Concrete with a compressive strength of 30 MPa or lower can be produced with recycled aggregate. The potential to substitute natural coarse aggregates with CDW recycled aggregates in a proportion of 25-50% to produce new concrete of 30 MPa was investigated by [19]. It was found that, at 28 days, the compressive strength exceeded 30 MPa (39.82 MPa) and was anticipated to increase even more with ageing as the cement became hydrated.

Such findings have led to the conclusion that recycled aggregates from CDW are suitable for use in producing concrete for applications such as driveways, foundation trenching, pipe bedding, surface levelling, shoulders, median barriers, sidewalks, foundation matters for road construction, drainage fill/base, groundwork hardcore, and urban decoration. In fact, there is extensive research evidence that, compared to virgin material, recycled aggregates are more appropriate for road base as their particle sizes are more broadly distributed [1,3]. Therefore, by reusing CDW, a lower amount of inert waste materials needs to be discarded in landfills and use of natural resources could be avoided.

Plasterboard, metals, glass, plastics, floor and wall coverings, carton, cardboard, and tiles are just some of the various types of recyclable materials generated from construction and demolition activities. Bangladesh has a thriving recycling industry, yielding an ample production of recycled domestic stuffs from plastic and cardboard that have been thrown away [20]. Formal recycling is promoted by both demand at regional level and limited availability of recyclable materials for national and international industry at global level. Recyclable CDW is highly sought-after by local industries, household ware producers, and small market shops in rural areas. Being cheaper than new materials, recycled materials possess market competitiveness, even though their quality is poorer. For instance, in 2015, recycled plastics were three times cheaper than newly imported plastics [21]. Furthermore, there is growing demand for recycled glass to substitute fine and coarse aggregates in concrete production and hot-mix asphalt production, respectively [22]. Medina et al. [19] suggested that natural coarse aggregates could be replaced in a proportion of 25% with ceramic waste in new concrete production. The authors also reported that concrete produced with ceramic waste did not negatively impact the quality of potable water, so it was suitable for use in potable water deposits and pipes. Besides the prosperous international market of recyclables, with India, Japan and China generating enormous demand, there is also a proliferation of recycling operations in developing countries calling for recyclable materials. Such activities emphasise how important it is for CDW to be effectively managed to supply recyclable materials of high quality.

Waste disposal in landfills is environmentally detrimental in multiple aspects, such as soil contamination caused by matter with high pH, elevated use of energy for transport purposes, and deterioration of air quality and heat waves, which contributes to global warming [7]. A particular problem that must be addressed in the future is the loss of the aggregated energy associated with discarded waste. This loss can be prevented if CDW is recycled, thus contributing to reduction of emissions [23]. Evidence for such a beneficial impact was provided by an investigation of the environmental effects of GHG derived from primary and recycled aggregates, Coelho and de Brito [24] reported that virgin raw materials always emitted higher levels of carbon dioxide by around 16% compared to recycled aggregates and used up 35% more energy. It is clear that recycling can reduce emissions of different pollutants discarded in landfills.

Nowadays, fresh concrete is increasingly produced with aggregates from concrete demolition waste [25]. At European level, CDW amounts to about 180 million tons or 480 kg/person annually [26]. The significant accumulation of such waste is due to the fast pace of construction [27]. At the same time, exhaustion of natural aggregates occurs at a rapid rate [28]. This issue can be addressed by recycling aggregates from concrete waste.

The demolition of various structures (e.g. buildings, airport runways, bridge supports, concrete roadbeds) can be a source of recycled aggregates [29], which can then be used to produce concrete known as recycled aggregate concrete. In terms of strength, distribution size, and water absorption [30], the original concrete depends on the features of the recycled aggregate concrete. Both natural resource depletion and environmental pollution can be minimised by reusing concrete waste from demolitions [31]. However, prior to recycling such waste for concrete production, several assessments must be conducted to ascertain its characteristics.

Through examination of different sizes of aggregates and different types of materials, including rubble, stone flakes, glass, and rubber, the present work seeks to establish the ideal strength of hardened concrete. Since the properties of treated recycled aggregates have not been studied so far, this work addresses this gap in knowledge by analysing how effective treated or recycled aggregates are as a substitute for common aggregates in fresh concrete production.

Stone flakes are concrete waste fragments employed as aggregates in cases where the local availability of concrete aggregates is restricted. Therefore, an additional objective of this work is to examine the impact of using rubber tire chips in different ratios (50, 75, and 100%) instead of mineral coarse aggregates.

2. RECYCLED AGGREGATES

At global level, fast-paced industrial development is responsible for accelerated loss of natural aggregates and generation of massive quantities of CDW [32]. This issue can be addressed by producing concrete with recycled concrete aggregates and other types of waste. Old concrete consists primarily of recycled aggregates and landfill disposal can be significantly attenuated through recycling [32].

As explained by Shahidan et al. [32], to produce concrete with RCA, existing concrete has to be broken, removed and crushed into a material of particular dimensions and quality. Concrete recycling contributes to sustainability by preventing depletion of natural resources and minimising disposal of CDW, and therefore it is a highly significant strategy. Higher water absorption and lower specific gravity are the main properties characterising recycled aggregates [30]. Furthermore, compared to natural aggregates, recycled aggregates have a lower density but are more porous [33]. Recycled aggregates are suitable for use in concrete production once they have been subjected to a number of mechanical processes, such as crushing and sieving to achieve the desired dimensions [34].

Extensive research has been conducted on glass aggregate concrete mixtures, some of which have been demonstrated to have exceptional potential, while others exhibited fast failure. The implications of adding polypropylene fibre to concrete have also been studied, revealing that such supplementation enhanced compressive strength [35]. Meanwhile, Ahmad [36] reported that the impact on the environment could be reduced by using rubber in asphalt as this not only minimised reliance on new raw materials, but also enhanced asphalt pavement performance and lifespan according to variables like particle size and asphalt surface properties, source, and microstructure. Effective mixtures should be monitored constantly over a long term in order to better understand the settings in which use of glass waste in concrete is suitable. The recycled materials of limestone aggregate [37], flakes, rubber, and glass are illustrated in Fig.1, while the physical properties of recycled aggregates are listed in Table 1.

A key aspect for structural concrete application is that, compared to Natural Aggregate Concrete (NAC), Recycled Aggregate Concrete (RAC) has a poorer quality, due to the fact that some mortar and cement paste adhere to the stone particles in recycled aggregated after demolished concrete is crushed, giving RAC a lower density than NAC. Moreover, although RAC and NAC do not differ much in terms of the energy required for their production, it is likely that higher energy expenditure is required by the recycling process.

A. Aggregate [37]

B. Flakes

C. Rubber

D. Glass

Fig.1 Recycled: A. aggregate, B. Flakes, C. Rubber, and D. Glass

Table 1 The physical properties associated with recycled aggregate Jordanian limestone

Physical & mechanical properties	Rowaished Limestone			Ma'an Limestone		
	Type A (High density)	Type B (Medium density)	Type C (Low density)	Type A (High density)	Type B (Medium density)	Type C (Low density)
Absorption (%)	3	7.5	12	< 3	3-4.2	4.2-7.5
Density (kg/m^3)	2560	2160	1760	2560	2560-2160	2160-1760
Compressive strength (Mpa)	55	28	12	>55	55-28	28-12
Flexural Strength (Mpa)	6.9	3.4	2.9	>6.9	6.9-5.2	5.2-3.4
Surface abrasion (mm)	10	10	10	<33	33-37	37-44

3. EXPERIMENT METHODOLOGY

Recycled aggregates and glass were procured from CDW, broken concrete, pavement, airport runways, and concrete roadbeds, while rubber and flakes were respectively derived from recycled tires and quarries. These materials were subjected to crushing followed by sieving and were distinguished as either fine or coarse, according to particle size.

Both fresh and hardened concrete samples were prepared. The cylindrical dimensions of the samples were 150x300 mm, while the cubical dimensions were 150x150 mm and 100x100 mm. Around 250 samples were required for the tests conducted on hardened concrete, namely, the ponding test, compression test, split tensile test, and flexural strength test. Concrete mixtures were produced via the conventional ASTM standard [38-43], which was also the basis for the preparation of beams. The employed aggregates varied in size from fine to coarse. Each sample was subjected to curing for 3, 7, 14 and 28 days. The curing of cubes and beams and the method for assessing hardened concrete are shown in Fig.2.

Owing to local recycling requirements [44], the construction industry has begun to explore the use of glass waste and other uncommon materials in Portland cement concrete. The high reactivity between the silica in glass and the alkalis in cement paste can cause concrete to expand and crack [45]. Therefore, it is necessary to devise a method for using glass waste as aggregate in concrete production that would make the concrete adequately strong and durable. Research has been conducted on different gradations of sizes of glass particles supplemented at different proportions of the overall content of aggregates. For instance, to achieve RAC of enhanced strength and durability, milled glass waste was employed as secondary material. Milled glass waste has been empirically examined for its potential as partial cement substitute to address the limitations of recycled aggregates and produced concrete. The used mix design for recycled materials and associated weights are detailed in Table 2 and Table 3.

Fig.2 Cube and beam curing and testing of compressive and flexural strength

Table 2 The mix design for the recycled materials

Samples	designation	Mix percentage				
		Cement	Water	Sand	Fine	Coarse
1	Rubble (Coarse)	1	0.5	2	2	2
2	Standard	1	0.5	2	2	2
3	Rubble (Coarse)	1	0.5	2	0	2
4	Rubber (Coarse)	1	0.5	1	1	1
5	Rubber (Coarse)	1	0.5	2	0	2
6	Rubble (Coarse)	1	0.5	3	0	2
7	Rubber (Fine)	1	0.5	1	1	1
8	Stone Flakes (Coarse)	1	0.5	2	2	2
9	Stone Flakes (Coarse)	1	0.5	2	0	2
10	Stone Flakes (Coarse)	1	0.5	3	0	2
11	Glass (Coarse + Fine)	1	0.5	2	0 Agg 2 G	0 Agg 2 G
12	Glass (Coarse + Fine)	1	0.5	2	1 Agg 1 G	0 Agg 2 G
13	Glass (Coarse)	1	0.5	2	2 Agg 0 G	0 Agg 2 G

Table 3 The mass and specific weight associated with cubes and beams

Samples	Mass Cubes (kg)		Mass Beams (kg)	Specific Wt. (kg/m^3)	Beam Weight (kN/m^2)
	Dry	Wet	Dry		
1	7.53	7. 90	11.15	2230.22	0.223
2	7.12	7.84	10.61	2120.89	0.212
3	7.73	7.90	11.46	2290.96	0.229
4	2.06	2.10	10.08	2015.00	0.211
5	1.93	1.99	9.65	1929.00	0.193
6	7.90	8.11	11.71	2341.33	0.234
7	2.07	2.11	10.34	2067.00	0.207
8	8.11	8.18	12.01	2401.18	0.241
9	8.16	8.32	12.09	2417.78	0.242
10	8.04	8.12	11.90	2380.44	0.238
11	2.33	2.35	11.63	2325.00	0.233
12	2.26	2.29	11.31	2262.00	0.226
13	2.34	2.37	11.69	2337.00	0.234

4. RESULTS AND DISCUSSION

Tables and graphs are used in this section to outline the results obtained from the analysis of the recycled aggregates and additional materials. Thus, the results in Figs.3 to 5 indicate that the 8th and 9th designs achieved the best tensile strength (24.1 and 30.0 N/mm^2, respectively) with maximum substitution, which was higher than the strength of standard concrete. With regard to rubber, the best tensile strength was achieved by the 7th design (10.47 N/mm^2) and the 3rd design (10.93 N/mm^2). By contrast, the coarse rubber designs (1, 3-6) yielded minimal strength. In short, maximum strength was associated with the stone flake aggregates, whilst the rubber aggregates displayed reduced tensile strength, with the lowest strength of 6.7 N/mm^2 being associated with the 5th design. Meanwhile, by comparison to the standard design, higher records were obtained by the designs related to the stone flakes. The likelihood of bleed water blocking, and implicitly, a weaker transition zone (higher w/c ratio in the area surrounding the aggregates), increased the bigger the aggregate particles were [46]. Furthermore, failure was very likely to occur due to the direct proportionality between the increase in void fraction and the increase in aggregate size.

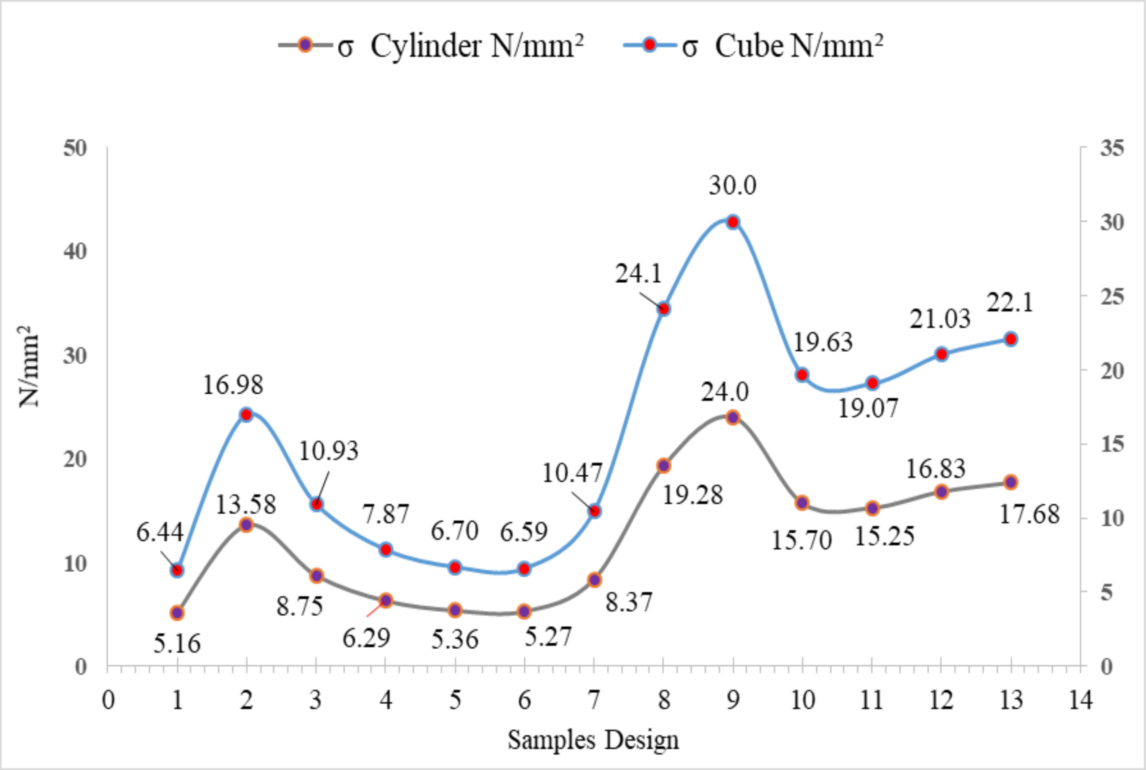

Fig.3 Results for compressive strength and tensile stress.

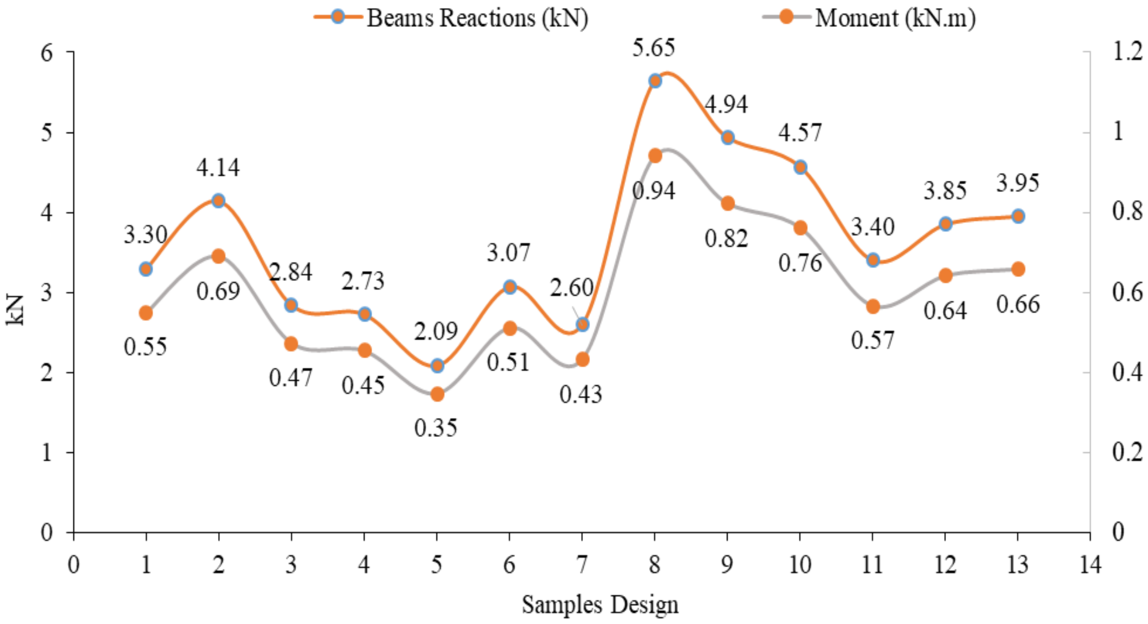

Fig.4 Results for reaction and moment forces

Fig.4 shows that the reaction and moment were consistent with the records for tensile strength. Moreover, among the rubber designs, the 6th design was associated with a height force suggesting full substitution of fine aggregate (Fig.5). Additionally, unlike standard concrete, the concrete with inclusions of rubber tire chips displayed lower compressive strength and flexural strength.

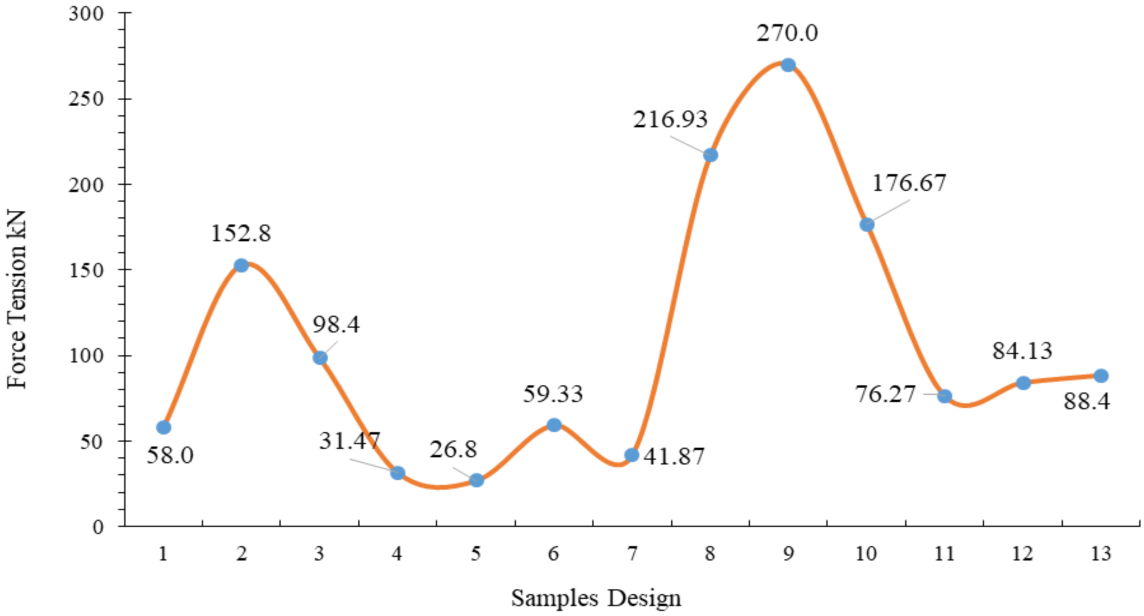

Fig.5 The F-force associated with the various recycled material designs

5. COMPRESSIVE STRENGTH

Table 4 provides the results regarding the loads associated with the samples. At 28 days, there was a significant increase in compressive strength, from 6.7 MPa for coarse rubber to 675 MPa for coarse stone flakes. Among all the samples, the maximum strength was achieved by flake aggregates of different sizes, while standard concrete was associated with the second highest strength (~46.8 MPa). Notably high strength (20.0 MPa) was attained by glass aggregates of different sizes as well. Meanwhile, the compressive strength exhibited by samples of cured coarse-to-fine rubber was in the range of 6.7-10.7 MPa. The samples of rubber displayed variation, as shown by the graph, with the 3rd design yielding a significant load of 46.8 MPa. The compressive strength of concrete increases in direct proportion with the increase in the mean size of aggregates (MSA) [47]. A bigger inter-facial transition zone (ITZ) arises in the case of larger aggregates, representing a weak binder zone surrounding the aggregates that has high sensitivity to cracking [48]. Thus, the likelihood of crack formation is heightened. The trapping of water beneath sizable aggregates can lead to internal bleeding, which in turn leads to the creation of a zone with suboptimal bonds [49-52]. An empty space forms with the evaporation of the trapped water.

Table 4 The loads achieved by the samples for different designs

Sample #	Cubes Designation	Cubes Loads (kN)			Beams Loads kN
		#1	#2	#3	#1
1	15*15	353	339	343	6.6
2	15*15	371	362	413	8.28
3	15*15	465	443	496	5.68
4	10*10	64	97	75	5.45
5	10*10	65	61	75	4.17
6	15*15	343	364	338	6.14
7	10*10	111	110	93	5.2
8	15*15	565	552	510	11.29
9	15*15	685	690	650	9.87
10	15*15	440	447	438	9.14
11	10*10	174	187	211	6.8
12	10*10	235	196	200	7.7
13	10*10	241	205	217	7.9

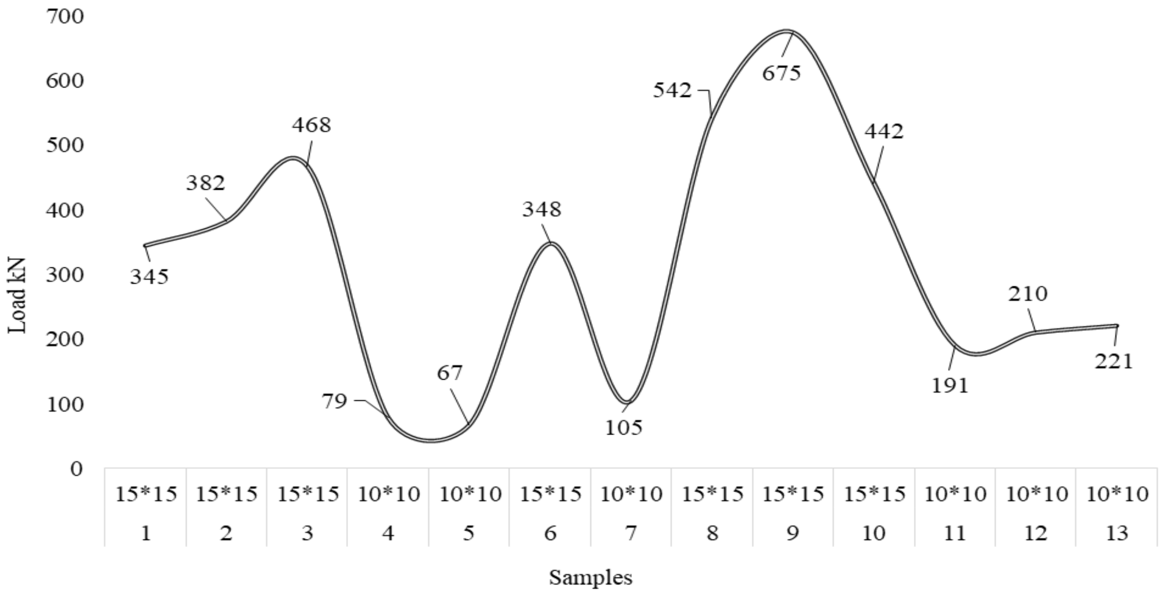

Fig.6 Average load test for different sample designs

As can be seen in Fig.7 and 8, the samples displayed a marked increase in average compressive strength from 8.35 MPa for coarse rubber to 55.3 MPa for stone flakes. Among the samples, the maximum strength was achieved by flake aggregates of different sizes, while standard concrete had the second highest strength of 38.2 MPa. Notable strength (20.0 MPa) was also achieved by glass aggregates of various sizes. Meanwhile, the compressive strength associated with samples of cured coarse-to-fine rubber was in the range of 8.3-17.9 MPa.

Furthermore, high strength was demonstrated by flexural beams (10.1 MPa), standard design (8.28 MPa), and glass design (7.47 MPa). By contrast, samples of rubber were associated with the lowest strength of 4.94-6.18 MPa. Compared to the flexural strength, the compressive strength decreased by nearly two-fold. The samples with rubber tire aggregates displayed ductile failure and suffered marked dislocation prior to fracturing.

Samples of plain and rubber tire concrete were used for assessment of flexural toughness. According to the results, samples with rubber tire chips were tougher than control samples. Powdered tire rubber could better adhere to cement paste owing to changes to its surface. Meanwhile, there was a reduction in density, flexural strength, compressive strength, and modulus of elasticity.

In spite of this, samples became tougher and less porous when rubber particles were added. Therefore, coarse aggregates could be replaced with treated tire rubber particles in cement-based materials used in the construction of driveways and roads.

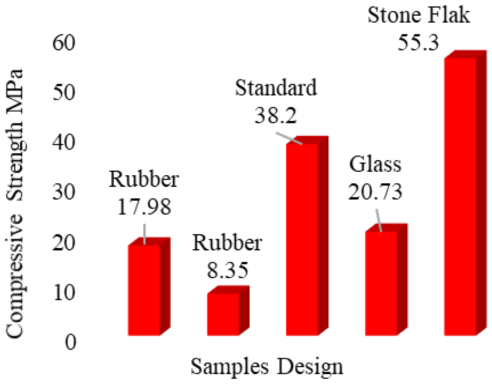

Fig.7 Average cube strength displayed by the recycled materials

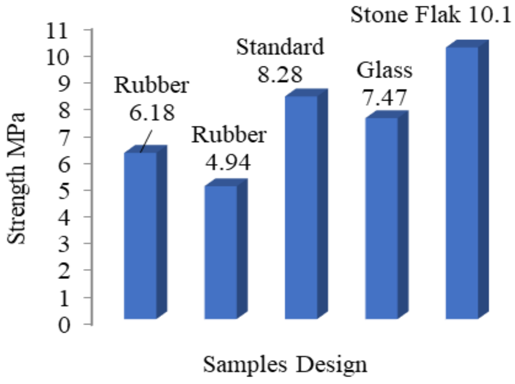

Fig.8 Average beam strength displayed by the recycled materials

Mahdi Naeini et al., [53] studied the possible Stiffness and strength characteristics of demolition waste, glass and plastics in railway capping layers and concluded the feasibility of using recycled C&D materials, higher stiffness of RCA provided the opportunity for adjusting the sensitivity of the layers to repeated loading by the inclusion of supplementary materials.

6. CONCLUSION

In numerous developing countries, CDW is a growing issue for the construction sector, due to the rapid and ever-increasing pace of infrastructure development and building. However, this kind of waste can be an economically viable solution to minimise reliance on natural resources and satisfy the material demands of various construction projects. The present work sought to determine the best strength for concrete aggregates of different sizes within various designs. According to the results obtained, the flake aggregates performed best on the split tensile test and the compressive strength test, exhibiting a strength that was around 175% better than the standard design. On the other hand, contrary to expectations, the main strength was unaffected by the glass aggregates. Furthermore, ideal results were associated with the coarse size of aggregates since the highest values were achieved for the split tensile test and the compressive strength test following 28 days of curing. Acceptable results were also achieved by glass and rubber, suggesting that they were viable materials for certain structural components.

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