CONCRETE AND PAVER BLOCKS USING UPCYCLED COARSE AND FINE AGGREGATES

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Abstract*: Due to rapid urbanization enormous quantity of Construction and Demolition Waste is generated in developed cities. CDW includes various categories namely ceramic, masonry, bricks, concrete, glass, timber, steel, soil etc. The quantum of CDW generated in metropolitan cities of India is around 3,500MT per day. Attempts made so far is to recycle CDW in to aggregates. Hence utilization of upcycled concrete aggregates as a partial replacement of fine and coarse aggregates may avoid illegal dumping and landfill. Present work is focused on utilization criteria of crushed concrete aggregates gained from CDW, in the production of concrete and paver blocks. This paper presents the properties of upcycled fine and coarse aggregates of crushed concrete, sourced from local dump site. The upcycled fine and coarse aggregates is used in part replacement with manufactured sand for various proportions 10, 20, 30 and 40% (by weight) for proportioning concrete and paver blocks. Blocks were cast at commercial manufacturing plant, Bengaluru, using commercial grade concrete and paver blocks casting machine which is used in mass production. Durability and Strength parameters of concrete and paver blocks arepromising and found feasible to use. It was noticed that there is improvement in strength at a replacement level 30% of Upcycled Fine Aggregate (UFA) and 20% of Upcycled Coarse Aggregate (UCA) in blocks, however strength loss at higher replacement level was very minimum. Microstructure analysis has revealed the factors governing strength in blocks preparedby upcycled aggregates. Costs of blocks manufactured using upcycled aggregates are more economical in large scale production.

***Keywords*: Crushed concrete waste, upcycled fine aggregate, upcycled coarse aggregate, Concrete blocks, Paver blocks, Micro structural analysis, Cost saving.**

1.0 INTRODUCTION

Disposal of solid waste has become a major environmental problem in cities like Bengaluru. As a result of escalatingconstruction activities, construction and demolition waste symbolize a substantial percentage of the overall solid waste. The Department of Ministry of Environment, Forest and Climate Change notified the construction and demolition waste management rules. Based on survey data by the CPWD-2015[1], shows that about 530 million tons of construction anddemolition waste is generated annually. The gradual increase in consumption of cement in India from 2009 to 2017 is 39.8%. CDW in India consists of 65% of cement based waste which is shown in **Figure 1.1**, among which concrete waste has got more potential for recycling and reusing as a building material in construction industry.

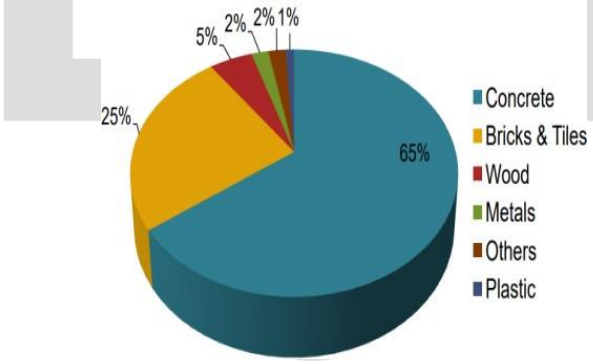


Figure 1.1: Composition of CDW in India.

Construction and Demolition waste may be divided into five categories viz., concrete and metals, wood, miscellaneous and unsorted debris. More precisely, it may contain, concrete, bricks, tiles and ceramics, wood, glass, plastic, bituminous mixtures, ferrous & non-ferrous, contaminated soil and stones, gypsum based materials, waste electronic and electrical equipment and hazardous substances [2].

2.0 SCALE AND INTENT OF RESEARCH

The present study focused on evaluating the mechanical properties of concrete and paver blocks proportioned with

upcycled coarse and finer aggregates. Investigate the effect of crushed concrete waste on properties of concrete and paver blocks and to compare cost for the replacement of fine aggregate and coarse aggregate in proportioning. **Figure 1.2** demonstrates difference between recycling and upcycling aggregates.

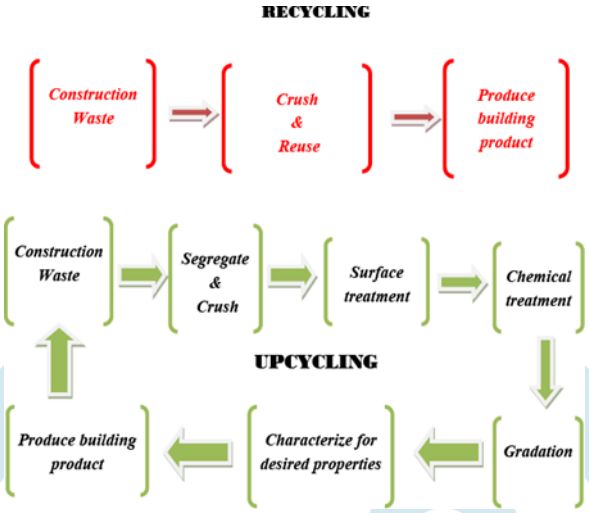


Figure 1.2: Recycling and Upcycling building materials

2.1 Concrete waste

The collected concrete waste from dumpsites is crushed manually into smaller pieces and later crushed using mechanical jaw crusher into aggregates. Crushed concrete is segregated as finer aggregate (passing 4.75mm and retained on75µ) and coarser aggregate (passing 12.5mm and retained on 4.75mm) BIS sieves.

(a) 75µ – 4.75mm **(b) 4.75mm – 6.3mm** **(c) 10mm – 12.5mm**

Figure 2.1: Sample of crushed aggregates

The concrete debris is crushed manually to the maximum size of 60mm [3]. Using Jaw Crusher further pulverized to a smaller size, passing 20mm and downsizes. The pulverized sample is treated with dilute hydrochloric acid (0.5% Concentration) for a period of 24 hours to remove all thedeleterious and cementitious materials adhering to the surface of the aggregates. Surface dry aggregates are subjected 200 revolutions in a pan mixer, which enabled the aggregates to break down its flakiness. Angular and sub angular aggregates are further graded as per the requirement to size of 12.5mm, 6.3mm and 4.75mm and downsize. The materials passing BIS 6.3mm sieve and retained at 4.75mm are considered as coarse aggregate material for concrete block production and materials passing BIS 12.5mm sieve and retained at 10mm areconsidered as coarse aggregate material for paver block production. **Figure 2.1(a, b &c)** represent the gradation of aggregates which are sieved 75µ – 4.75mm, 4.75mm – 6.3mmand 10mm – 12.5mm respectively [4].

3.0 CHARACTERIZATION OF UPCYCLED AGGREGATES

Upcycled fine aggregates and natural fine aggregates were analyzed for desired properties as shown in **Table 3.1**.

Table 3.1: Physical properties of Natural Fine Aggregates(NFA) and upcycled fine Aggregates (UFA).

Physical properties	**NFA (75□-4.75mm)**	**UFA (75□--4.75mm)**
Specific gravity	2.61	2.48
Water absorption	2.2%	10.8%
Fineness modulus	3.88	3.61
Bulking	6%	8%
Bulk Density	1610 kg/m^3	1580 kg/m^3
Zone	II	II

The specific gravity of natural fine aggregate is higher thanthe upcycled fine aggregates and water absorption of upcycledfine aggregate is higher than the natural fine aggregate because upcycled aggregates are found porous in nature, due to which bulk density is reduced [5&6]. However, gradation ofNFA and UFA are maintained same. The physical properties of natural and upcycled coarse aggregates is presented in **Table 3.2**, Specific gravity of various proportions of upcycled coarse aggregates blending with natural aggregates is shownin **Table 3.3**.

Table 3.2: Properties of natural and Upcycled CoarseAggregates (UCA)

Physical properties	**NCA (4.75-6.3mm)**	**UCA (4.75-6.3mm)**
Specific gravity	2.7	2.45
Water absorption	1.12%	7.1%
Los Angeles abrasion (%)	38	23
Aggregate crushing value	34%	38%

Table 3.3: Specific gravity of blended UFA and NFA

NFA (%)	**UFA (%)**	**Specific gravity**
100	0	2.61
90	10	2.57
80	20	2.58
70	30	2.58
60	40	2.58

4.0 CONCRETE BLOCKS PROPORTIONING WITH UPCYCLED AGGREGATES

Upcycled aggregates of concrete debris are used in proportioning and production of concrete blocks. In the proportioned mixes of concrete blocks OPC 53 grade conforming to Indian standards are used as binder. Bindercontent throughout the studies is maintained as constant.

Upcycled fine aggregates passing 4.75mm and retained on 75µ are used, passing through 6.3mm and retained on 4.75 mm aggregates are used as coarse aggregates. Upcycled coarseand fine aggregates are replaced at an incremental increase of 0%, 10%, 20%, 30% and 40% by weight. Manufactured sandis replaced by upcycled fine aggregates of same gradation(conforming to Zone II) and natural aggregates are replaced with upcycled coarse aggregates of same gradation.

Concrete blocks are of dimension 40cm x 20cm x10cm, compacted at a pressure of 140 kg/cm^3, the compaction pressure is maintained as uniform in all mixes and at all replacement levels. The cast concrete blocks are studied for their strength, water absorption and densities as per the requirement of BIS 2185 (part 1):2005. Concrete blocks of all proportions and mixes are cured for curing period of 3, 7 and
28 days. Adequate care is taken to ensure uniformity in dimensions, mixing, casting, color, shapes, stacking and curing are maintained with minimum variations. However the test results of six samples is considered for all studies conducted on concrete blocks.

5.0 PAVER BLOCKS PROPORTIONING WITHUPCYCLED AGGREGATES

Paver blocks are proportioned using upcycled coarse and fine aggregates. Paver blocks are proportioned using OPC 53 gradecement as binder, manufactured sand as fine aggregates and crushed rock as coarse aggregate. Mix proportions are arrived as per BIS 15658-2006; proportion of concrete mix is 1:6.46:1.34 and mortar mix proportion is of 1:6.46. Upcycled coarse and fine aggregates are replaced in incremental increase of 0%, 10%, 20%, 30% and 40% by weight with manufactured sand and crushed rock (natural coarse aggregates). Manufactured paver blocks are cured for a periodof 3, 7, and 28 days and their strength, water absorption and densities are studied. Uniformity in mixing, compaction energy, casting, curing and dimensionality is maintained.

6.0 BEHAVIOUR OF CONCRETE BLOCKS WITHUPCYCLED AGGREGATES

Studies are made on concrete blocks to evaluate the performance of blocks manufactured using upcycled coarse and fine aggregates.

6.1 Effect of UFA on compressive strength of concreteblocks

The observed compressive strength of concrete blocks proportioned using upcycled fine aggregates with manufactured sand at various replacement levels is shown in **Table 6.1.**The compressive strength obtained is maximum at 30% replacement of upcycled fine aggregate. About 32% of compressive strength is increased by replacing UFA at 30% replacement level. **Figure 6.1** gives the compressive strength of concrete blocks proportioned using upcycled fine aggregates. From the F**igure 6.1** it is also seen that strength of concrete block at 40 % replacement of UFA is higher (i.e.19%higher) than the normal blocks which are manufactured commercially. The strength improvement is observed in blocks due to presence of unhydrated cementitious particles in upcycled fine aggregates or improved surface texture of aggregates due to surface treatment [7].

Table 6.1-Mean compressive strength of concrete blocksproportioned with upcycled fine aggregates

Concrete block mix	Replacement level of Fineaggregate in %	Mean compressive strength inMPa		
		3 days Curing period	7 days Curing period	28 days Curing period
CB	0	2.6	3.95	4.5
CBF10	10	2.7	3.80	4.8
CBF20	20	3.1	4.10	5.3
CBF30	30	3.2	4.60	5.95
CBF40	40	2.5	3.75	5.55

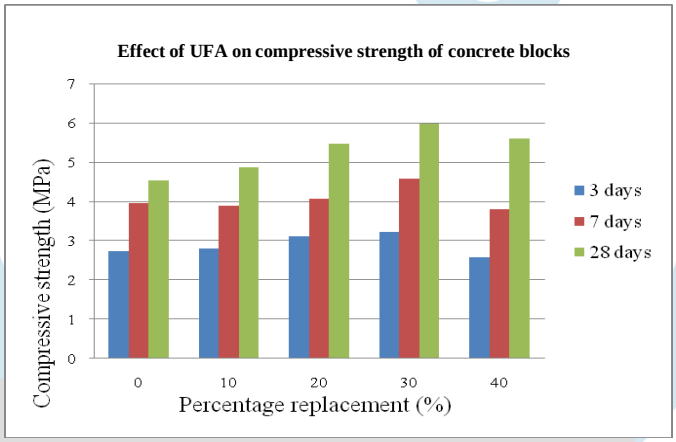


Figure 6.1: Effect of UFA on compressive strength ofconcrete blocks.

6.2 Effect of UCA on compressive strength of concreteblocks.

The compressive strength of CB after 3, 7 and 28 days is 2.6MPa, 3.95MPa and 4.53MPa respectively. All the concrete mixes proportioned with manufactured sand and upcycled aggregates achieved the target strength of 4.5 MPa at 28 days curing period. Subsequently, compressive strength increases with increase in UCA up to 20%. Compressive strength of mixes has shown an increased trend due to usage of treated aggregates i.e., Saturated aggregates at surface dry condition and presence of traces of unhydrated cementitious materials inupcycled aggregates. Mean compressive strength of concrete blocks with upcycled coarse aggregates is shown in **Table 6.2.**

Table 6.2-Mean compressive strength of concrete blocksproportioned with upcycled coarser aggregates

Concrete block mix	Replacement level of Coarse aggregate in %	Mean compressive strengthin MPa		
		3days Curing period	7days Curing period	28 days Curing period
CB	0	2.6	3.95	4.5
CBC10	10	3.25	4.25	4.36
CBC20	20	3.63	4.70	5.48
CBC30	30	2.96	3.28	5.32
CBC40	40	2.46	3.15	4.60

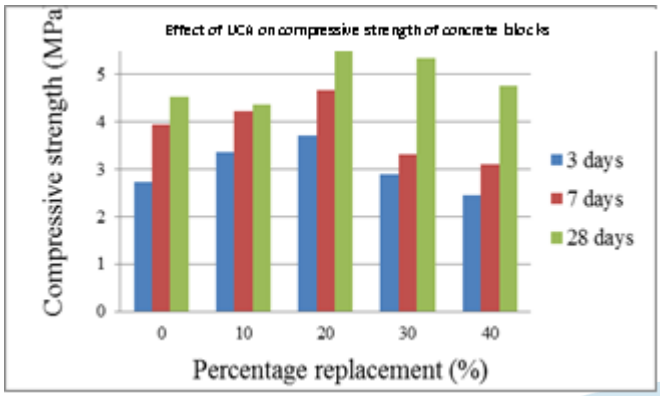


Figure 6.2: Effect of UCA on compressive strength ofconcrete blocks.

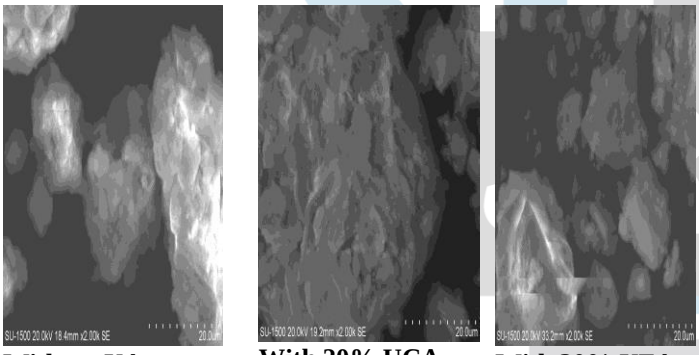
Maximum compressive strength is obtained at replacement of virgin coarser aggregates with 20% upcycled coarse aggregates. About 23% of compressive strength is increased by replacing 20% natural aggregate by upcycled aggregates [1, 2 &3]. **Figure 6.2** represents variation in compressivestrengths with percentage replacement of upcycled coarse aggregate. Since 30% replacement of UCA showing greater strength than normal concrete block it is also recommended to use.

6.3 Initial Rate of Absorption (IRA) of concrete blocks

Initial rate of water absorption test was conducted as per ASTM C-67. Results show that IRA of concrete blocks without upcycled aggregate was 0.33 kg/m^2/min and for concrete blocks with 30% and 40% upcycled aggregate was 0.47 kg/m^2/min and 0.55 kg/m^2.

6.4 Scanning electron microscope (SEM) analysis ofconcrete blocks

Microstructure analysis of the concrete blocks with different amount of upcycled aggregate content (0. 10%, 20%,30% and 40%) was studied by the Scanning electronmicroscope analysis for different magnifications. The major axis length was measured as 1.55 micrometer and the minor axis length was calculated as 1.5 micrometer. Here, the major axis length was almost equal to the minor axis length and the elongation was calculated as the ratio of the major axis length to the minor axis length, which was 1.0. This indicates that theparticles are circular in shape. The area of the particle was measured as 1.88 square microns and the perimeter was calculated as 4.87 microns. The roundness of the particle was calculated as 0.99, which represents that the particles are almost spherical in shape [8]. This helps in achieving strength,SEM images have been shown in **Figure 6.3**.



Without UA **With 20% UCA** **With 20% UFA**

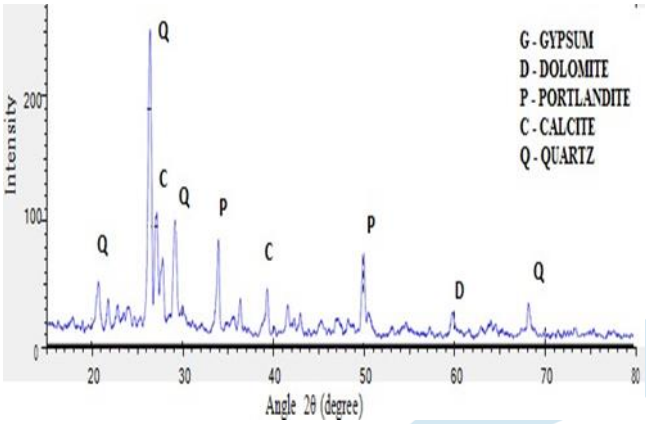
Figure 6.3: SEM images of concrete block.

6.5 X-ray Diffraction (XRD) analysis of concrete blocks

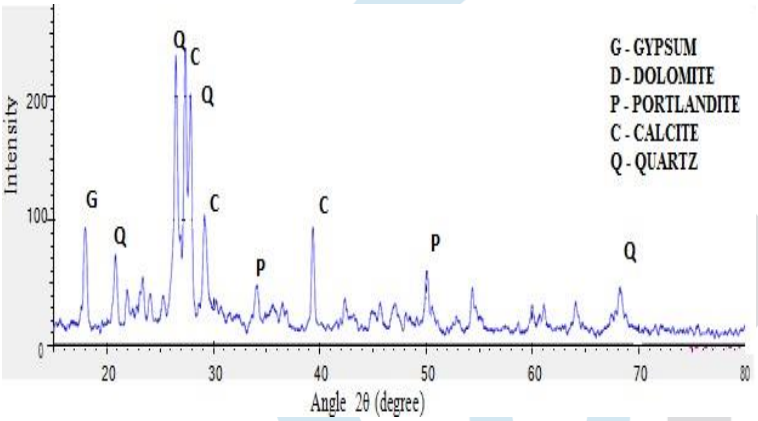
The XRD diffractogram of the concrete blocks with and without upcycled aggregate showed the presence of several mineral groups, such as the normal components of concrete (quartz – SiO_2, calcite–$CaCO_3$ and calcium silicates),hydration products (ettringite – $Ca_6(Al(OH)_6)_2(SO_4)_3(H_2O)_{26}$) and mineral binders (portlandite – $Ca(OH)_2$ and gypsum $CaSO_4.2H_2O$). **Figure 6.4** show peaks of minerals present andare listed below.

Quartz (SiO_2), Portlandite ($Ca(OH)_2$), Gypsum ($CaSO_4.2H_2O$), Ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$), Calcium Silicate ($Ca_2SiO_4$), Calcite ($CaCO_3$), Albite($NaAlSi_3O_8$), Sanidine ($K(AlSi_3O_8)$), Phlogopite $KMg_3AlSi_3O_{10}(F,OH)_2$, Hematite ($Fe_2O_3$). From the X-ray Diffraction analysis of concrete block, the graph of intensity verses 2θ is plotted for concrete block without upcycled aggregate, with 20% replacement of UCA and 30% replacement of UFA as shown in **Figure 6.4**. Without upcycled aggregate, maximum peak is showing at 26 degree. It represents that amount of quartz is maximum at 26 degree. Along with quartz, calcite, gypsum, portlandite and dolomite also present in some extent. Similarly, with 20% UCA and 30% UFA it is shown in the figure that, large amount of quartz, calcite, gypsum and dolomite were present and due to which strength of the concrete blocks increased

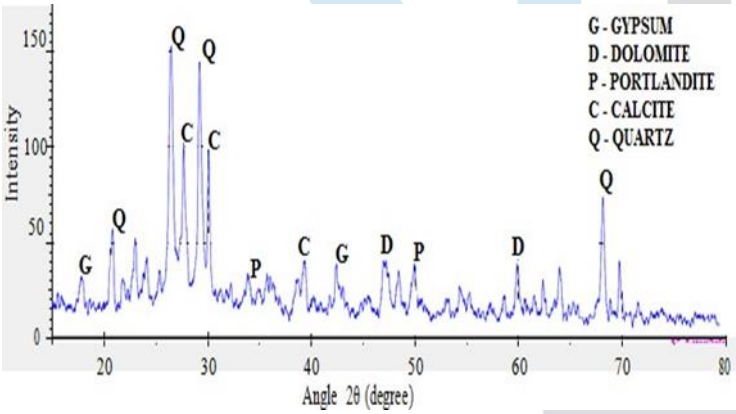
[7].



(a) **:**without Upcycled Concrete Aggregate



(b) **:** with 20% Upcycled Concrete Aggregate



(c) with 30% Upcycled Finer Aggregate Figure 6.4: XRD images of concrete blocks with upcycled aggregates**.**

7.0 BEHAVIOUR OF PAVER BLOCKS

Studies are made on paver blocks to manufactured using upcycled coarse and fine aggregates. The mean flexural strength (for single point loading) of paver blocks with upcycled fine aggregates at different replacement levels is as presented in **Table 7.1**. Mean flexural strength of six samples paver blocks at a curing period of 7 and 28 days is found. **Figure 7.2** Shows the variations of flexural strength of paver blocks with and without replacement of upcycled finer aggregates [8]. Mean value of test results of paver blocksFlexural strength of conventional paver block obtained at 28 days curing period is 1.34MPa. With replacement up to 30% upcycled fine aggregate flexural strength obtained is3.15MPa. Thus, maximum strength is obtained at 30% replacement of fine aggregate.

Table 7.1: Mean flexural strength of paver blocks with upcycled fine aggregates.

Paver blocks mix	Replacement level of UFA in %	Mean Flexural strength in MPa	
		7days Curing period	28 days Curing period
PB	0	1.21	1.34
PBF10	10	2.18	2.20
PBF20	20	2.42	2.68
PBF30	30	2.52	3.15
PBF40	40	2.16	2.41

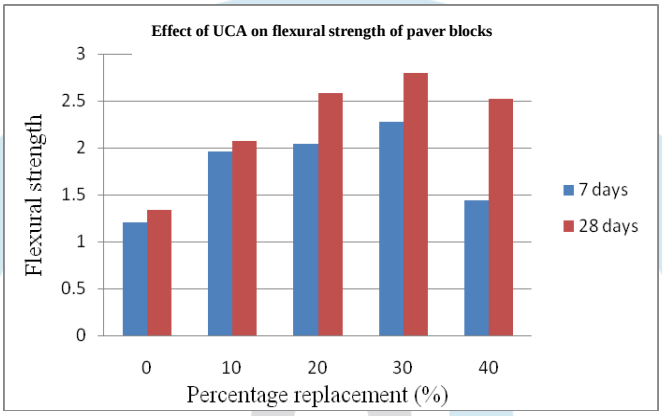


Figure 7.2: Effect of UCA on flexural strength of paverblocks.

Flexural strength of conventional paver block at 28 days curing period is 1.34MPa. With replacement of 30% upcycled fine aggregate flexural strength achieved at 28 days curing period is 2.78MPa. Maximum strength is obtained at 30%replacement of fine aggregates. **Figure 7.2** displays that at 40% replacement of upcycled coarse aggregate are also give a higher flexural strength than the conventional paver block.

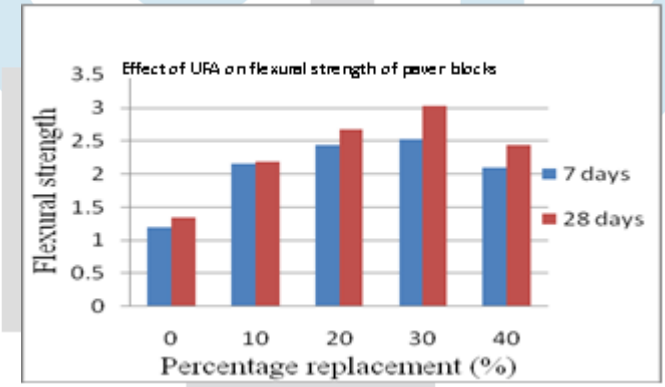


Figure 7.1: Effect of UFA on flexural strength of paver blocks.

7.2 Scanning electron microscope (SEM) analysis of paverblocks

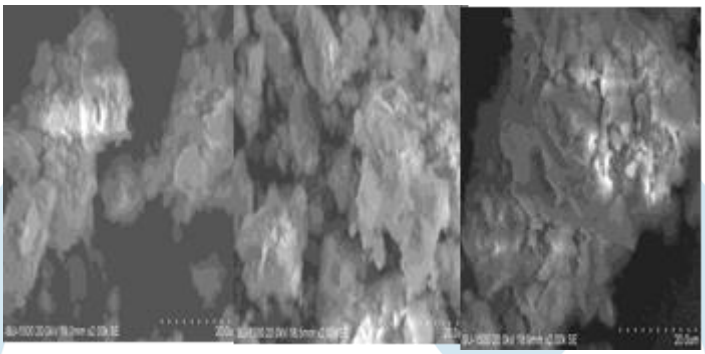
Microstructure analysis of the concrete blocks with different amount of upcycled aggregate content (0. 10%, 20%, 30% and40%) was studied by the Scanning electron microscope analysis for different magnifications. The SEM images have been shown in **Figure 7.3.**

7.1 Effect of UCA on flexural strength of paver blocks

The mean flexural strength of paver blocks proportioned by replacing Natural coarse aggregates with upcycled coarse aggregate is shown in **Table 7.2**. Flexural test results of six samples are taken and their mean flexural strength of blocks at7 and 28 days curing period. Flexural strength of paver blockswith and without replacement of upcycled coarse aggregates isshown in **Figure 7.2.**

Table 7.2: Mean flexural strength of paver blocks with upcycled coarse aggregates.

Paver blocks mix	Replacement level of UCA in %	Mean Flexural strength in MPa	
		7days Curing	28 days Curing period



Without UA **With 20% UCA** **With 20% UFA**

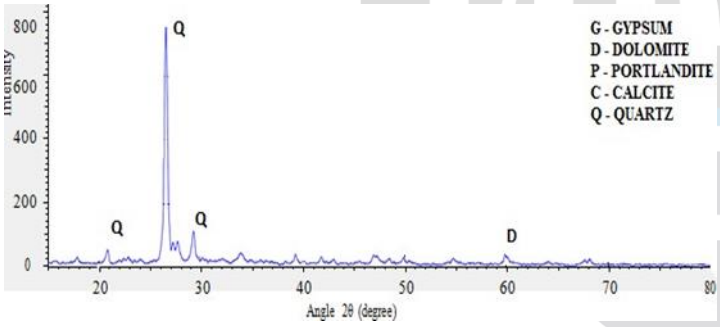
Figure 7.3: SEM images of paver block.

7.3 X-ray Diffraction (XRD) analysis of paver blocks

From the X-ray Diffraction analysis of paver block, the graph of intensity verses 2θ is plotted for paver block without upcycled aggregate, with 30% replacement of UCA and 30% replacement of UFA as shown in **Figure 7.4.** The XRD diffractogram of the paver blocks with and without upcycled aggregate showed the presence of several mineral groups. From **Figure 7.4 a** without upcycled aggregate, maximum peak is observed at 26 degree. Which represents thatmaximum amount of quartz is at 26 degree. Along with quartz, presence of some amount of dolomite and calcite is also observed.

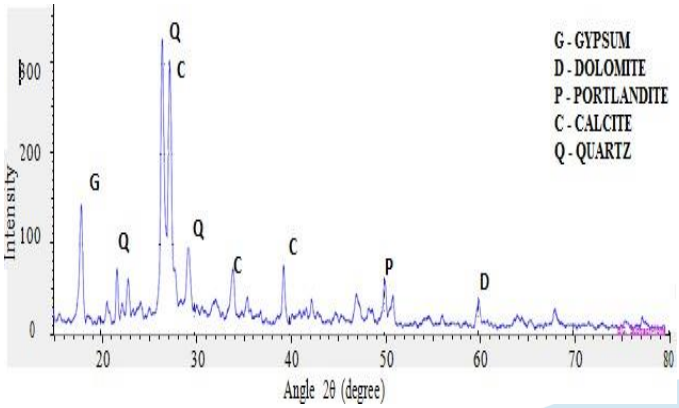
The realistic expenditures incurred during manufacturing concrete and paver blocks viz., man power, electricity, raw materials, transportation, overheads, contingencies and miscellaneous expenditures. However, procurement of concrete waste from dumpsites, processing aggregates from waste is also considered in cost calculations per block.

8. 1 Cost Comparison



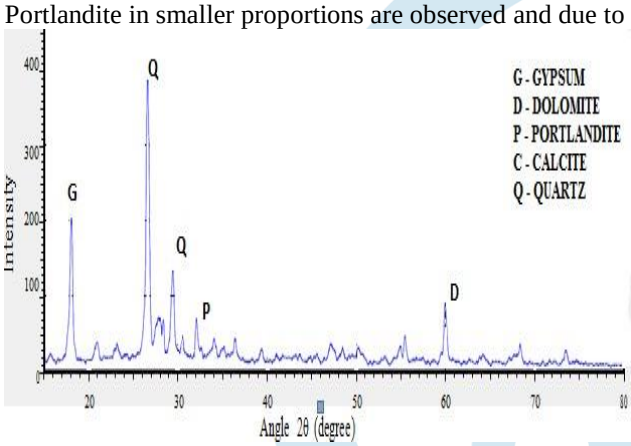
(a) **:** without Upcycled Aggregate

Similarly, for 30% UCA replacement level is as shown in **Figure 7.4 b**, large amount of quartz along with calcite, gypsum and Portlandite in smaller proportions are observed and due to which higher strength of the paver blocks is obtained[8&9].



(b) **:** with 30% Upcycled concrete aggregate

Similarly, for 30% UFA replacement level it can be seen in the **Figure 7.4c** that, large amount of quartz along with gypsum and Portlandite in smaller proportions are observed and due to which higher strength of the paver blocks is obtained.



(c) **:** with 30% Upcycled Fine Aggregate

Figure 7.4: XRD images of paver block with variousreplacement levels of upcycled aggregates.

8.0 COST ANALYSIS OF CONCRETE AND PAVERBLOCKS:

The cost analysis has been done for concrete and paver blocks, which are manufactured at commercial manufacturingplants. Blocks are manufactured at commercial plants to ensure consistency in production of blocks and to understand the realistic scenario of manufacturing process. Considering Cost comparison is carried out for both concrete and paver blocks with and without upcycled aggregates coarse and fine aggregate at various replacement levels and it is as shown in **Table 8.1** and **Table 8.2.**From the cost analysis, it is shown that cost of concrete blocks reduced by utilizing upcycled fine and coarse aggregate by 8.7% and 2.69%respectively in comparison with normal concrete blocks. Similarly cost of paver blocks with upcycled fine aggregate and upcycled coarse aggregate is 6.8 and 3.27 percentages lesser than the normal paver block respectively.

Table 8.11-Cost comparison of Concrete Blocks.

Cost Analysis Per Concrete Block								
Type	**Cement (kg)**	**FA (kg)**	**CA (kg)**	**UFA (kg)**	**UCA (kg)**	**Total Cost Per Block (Rs)**	**Percentage Reduction in Price**	**Percentage increase in strength**
Normal Concrete Block	0.857	12	6	0	0	20.69	-	--
30% Replacement of FA	0.857	8.4	6	3.6	0	18.89	8.7 %	32.22 %
20% Replacement of CA	0.857	12	4.8	0	1.2	20.15	2.69 %	18.22 %

Table 8.2- Cost comparison of Paver Blocks.

Cost Analysis Per Paver Block								
Type	**Cement (kg)**	**FA (kg)**	**CA (kg)**	**UFA (kg)**	**UCA (kg)**	**Total Cost Per Block (Rs)**	**Percentage Reduction in Price**	**Percentage increase in strength**
Normal Paver Block	0.94	6.08	0.63	0	0	12.51	-	--
30% Replacement of FA	0.94	4.24	0.63	1.84	0	11.66	6.8%	135 %
30% Replacement of CA	0.94	6.08	0.46	0	0.17	12.10	3.27 %	107 %

9.0 Concluding remarks:

Following are the conclusions drawn on utilizing upcycled aggregates in manufacturing solid concrete blocks and paver blocks.

1. It is noticed that there is an improvement in thecompressive strength by 32% and 23% for a replacement of fine aggregate with 30% UFA and coarse aggregate with 30% UCA respectively in concrete blocks. Microstructure analysis revealed the elements governing strength in blocks prepared using upcycled aggregate [9].
2. Improvement in flexural strength is observed at 30% of UFA and 30% of UCA replacement in paver blocks respectively.
3. It was found that mechanical properties of concrete and paver blocks are satisfactory as per codal recommendation at lower replacement level of upcycled aggregates. Strength enhancement is observed in blocks prepared by treated aggregates [10].
4. It is also noted that water absorption capacity of the upcycled aggregate is higher than the natural aggregates because of increase in porosity [11].
5. Costs of blocks manufactured using upcycled aggregates are economical up to 7.3 % compared to the normal paving blocks and 8.6 % compared to the normal concreteblocks in large scale production [12].

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DECLERATIONS

Availability of Data and Materials: The materials for research purpose are self-financed, test performed in the concrete laboratory,

Department of Civil Engineering, RVCollege of Engineering, Bengaluru.
Competing Interests: Development of sustainable building blocks using upcycled aggregates produced from constructionwaste.
Funding: Self
Author Contribution: Sole author- continuation of researchwork.
Acknowledgement: Post graduate- structural engineeringstudents, Department of Civil Engineering, RV College of Engineering.
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