Lightweight Low Carbon Concrete Using Secondary Aggregates- A Review Study

Amanpreet Kaur [1], Sunita [2]
[1] Assistant Professor,
Civil Engineering Department, Punjabi University, Patiala
apk@pbi.ac.in
[2] Assistant Professor
Civil Engineering Department, Punjabi University, Patiala
Sunita.ce@pbi.ac.in

Abstract*: Increased urbanization and industrialisation have made concrete the most widely used material. Due to natural resources scarcity, not only raw materials as constituents can fulfil the requirement. The prime need is to reduce the overall carbon footprint and solid waste management by using recycled concrete, agricultural and industrial waste material. This paper reviews some researches of obtaining lightweight concrete using waste and recycled materials such as agricultural waste, plastic waste, expanded clay aggregates and scrap rubber tyres. The physical and mechanical properties of these materials have also been discussed in this paper. A comparative study has been done showing compressive strength, flexural strength, workability, durability of lightweight concrete and conventional concrete to promote the idea of using these materials in concrete.

***Keywords*: Lightweight concrete, Agricultural waste, Recycled aggregates, Plastic waste**

(Article history: Received: 22nd September 2021 and accepted 20th December 2021)

I. Introduction

Lightweight concrete is used where the dead load of structure is to be reduced. Lightweight concrete is lighter than conventional concrete. It has low density ranging between 1800- 2000 kg/m3 and low thermal conductivity. Faster building rates can be achieved by using lightweight concrete. Our major goal must be to use materials and processes which lead to sustainable and eco-friendly environment. So, for this lightweight concrete with low carbon footprint is required.

A lot of waste is left behind during agricultural production, which is often burned or end up being destroyed or disposed of in environment. Agricultural waste such as coconut shells, oil palm shells, etc. can be used as aggregates in lightweight concrete. It contributes to energy saving, conservation of natural resources and reduction in cost of construction materials. It solves disposal problems of wastes and helps in environmental protection. Their use as fine and coarse aggregates in concrete partially or fully, reduce the burden on the virgin resources. Quarrying of aggregates requires blasting, crushing, screening, hauling and stockpiling which consumes a lot of energy. Also, these waste materials can be locally available and reduce the CO_2 emissions due to transportation of aggregates which is another cause of pollution. A large number of demolished concrete wastes can be recycled as it is easily available, saves transportation and doesn't require quarrying, thus produces less carbon footprint. The coarse aggregates replaced using industrial waste such as scrap rubber tires, clay mineral aggregates, waste plastic produces less carbon footprint. The popular way of achieving LWC is by using LWA [1].

The aim of this paper is to discuss the existing scenario of using agricultural and industrial waste as a replacement to conventional constituents of concrete which can help the concrete industry to identify other such materials available.

II. Agricultural Solid Waste in Lightweight Concrete

A. *Coconut shell and its properties as an aggregate in LWC*

India being the third largest producer of coconut in the world accounts for 11.5 million metric ton production. Coconut shells are waste produced from coconut nuts, which are mostly grown in Southern part of India. The major problem exists in the disposal of coconut shells. Using coconut shells in lightweight concrete production as coarse aggregates is most promising agricultural wastes. Density of coconut shell is 550-650 kg/m3 which is within the permissible limit of lightweight aggregates.

TABLE I. Chemical Analysis of Coconut Shell [4]

Parameter	**Typical test results**	
	Before treatment	***After treatment***
Glucose[15] (%)	01.90	01.90
Fructose[21&22] (%)	02.88	02.88
Sucrose[22] (%)	14.80	14.80
Reducing Sugar (%)	07.50	07.50
Total phenols[18] (%)	05.08	05.08
Ash (%)	0.50-0.60	0.50-0.60
Cellulose (%)	32.36	32.36
pH	6.00- 6.40	6.00- 6.40

TABLE II. PROPERTIES OF COCONUT SHELL [4]

S No	Physical and Mechanical properties of CS	Test Results	BIS Standards
1	Moisture content	4.20 %	IS:2386 Part III-196312
2	Water Absorption	24.00 %	IS:2386 Part III-196312
3	Specific gravity	1.05-1.20 %	IS:2386 Part III-196312
4	Apparent Specific gravity	1.40- 1.50 %	IS:2386 Part III-196312
5	Crushing Value	2.58 %	IS:2386 Part IV-196313
6	Impact Value	8.15 %	IS:5640- 197014
7	Abrasion Value	1.628 %	IS:2386 Part IV-196313
8	Bulk Density (Tamped)	650 Kg/m3	IS:2386 Part III-196312
9	Bulk Density (loose)	550 Kg/m3	IS:2386 Part III-196312
10	Percentage of Voids (Tamped)	38.09 %	IS:2386 Part III-196312
11	Percentage of Voids	47.62 %	IS:2386 Part III-196312
12	Fineness Modulus (Sieve Analysis)	6.26	---
13	Flakiness Index	100 %	IS: 2386 Part I-196311
14	Shell Thickness	2mm - 8mm	---

Concrete with coconut shells produced acceptable structural strength. Due to its smooth surface on one side, concrete has better workability. Due to its low cellulose content, thus the shells absorb less moisture. It has a specific gravity of 1.2. It requires no treatment before use. Their impact resistance is higher than the conventional concrete.

a) Mechanical Properties of Coconut Shell as an Aggregate

Shamjith and Rajeevan [2] in their study of using coconut shells in concrete concluded that replacement in conventional coarse aggregate with 15% proportion of coconut shell with water cement ratio 0.5 gives comparable compressive strength to conventional concrete. As the content of coconut shell aggregates increases the compressive strength decreases. Also, the split tensile strength and flexural strength were examined and it was observed that with 5-15% replacement of conventional aggregates with coconut shells aggregates results in values near to target values which were comparable to conventional concrete.

Prusty and Patro [14] in their review paper quoted many researches and concluded that coconut shell can be considered as a good replacement of conventional aggregates. As coconut shell concrete, with increased curing age gives better compressive strength and decreased with increased percentage of replacement of coconut shells.

Shafigh et al. [7] in their study found that concrete using coconut shell has higher compressive strength than oil palm shell. Gunasekaran et. al [15] in their study lightweight concrete using coconut shells as aggregate examined that with concrete mix proportion 1:1.63:0.81 and w/c 0.42, slump obtained was 55 mm, which showed that CS concrete has a medium degree of workability.

B. Oil palm Shell as an aggregate in LWC and its properties

Oil palm shell is a solid waste material of palm oil industry. Oil palm concrete density is less than normal weight concrete about 20-25% [6, 7, 9, 10]. Their use in lightweight concrete as coarse aggregates provides a comparable compressive strength in concrete as discussed in researches by some authors [2-5]. Oil palm shells have about 50% lower weight than conventional aggregates [1].

TABLE III. CHEMICAL PROPERTIES OF OPS AS AN AGGREGATE [5, 6]

Elements	Results
Ash	**1.53**
Nitrogen (as N)	**0.41**
Sulphur (as S)	**0.000783**
Calcium (as CaO)	**0.0765**
Magnesium (as MgO)	**0.0352**
Sodium (as Na_2O)	**0.00156**
Potassium (as K_2O)	**0.00042**
Aluminium (as Al_2O_3)	**0.130**
Iron (as Fe_2O_3)	**0.0333**
Silica (as SiO_2)	**0.0146**
Chloride (as Cl-)	**0.00072**
Loss on Ignition	**98.5**

TABLE IV. PHYSICAL PROPERTIES OF OPS AS AN AGGREGATE [6]

Properties	Results
Specific gravity	**1.17–1.37**
Bulk density (uncompacted) (kg/m3)	**510–550**
Bulk density (compacted) (kg/m3)	**590–600**
Void ratio (uncompacted) (%)	**63**
Void ratio (compacted) (%)	**57**
24 h water absorption (%)	**21–33**
Aggregate impact value (%)	**4–8**
Aggregate crushing value (%)	**5–10**
Los Angeles abrasion value (%)	**3–5**
Flakiness index (%)	**65**
Shell thickness (mm)	**2–8**
Thermal conductivity (W/mc)	**0.19**
Loss on ignition (%)	**98–100**

Due to significant low Los Angeles abrasion value of oil palm shells about 80% lower than conventional coarse aggregates, OPS aggregates show good resistance to wear. Also, because these aggregates have good absorbance to shock because of the much lower impact and crushing values [7].

a) Mechanical properties of concrete due to addition of ops as a replacement to coarse aggregates

Maghfouri et al. [8] in their research replaced the crushed granite with 20-100 % oil palm shell by volume and concluded that OPS lightweight concretes showed the similar 7 to 28-day compressive strength ratios compared to the other types of structural Light weight aggregate concretes.

In one of the studies by Teo et al. [5] reported that 28- day air dry density of OPS as 1960 kg/m^3 which is within the range of structural light weight concrete and saves 18% weight compared to normal weight concrete. It was further concluded that OPS when cured in water rather than air gives better compressive strength, which was 35-65 % higher than the structural light weight concrete. As compressive strength plays a significant role in designing the concrete mixes.

A high strength lightweight concrete using oil palm shell is examined in many researches. A compressive strength of 56 MPa 28-day, can be achieved with aged OPS using pre-treatment techniques. Aged OPS perform better in providing mechanical bonding. Due to reduction in smoothness of surface [11,12].

Talking in terms of workability, Maghfouri et al. [8], concluded that due to the porous nature of OPS, it results in high water absorption, which further decrease its workability compared to conventional aggregates. Up to 80% OPS substitution it can still show good workability. The value of slump ranges from 50- 75mm for light weight concrete for acceptable workability.

Under moist curing conditions, the splitting tensile strength for all mixes with 20,40,60,80,100 % substitution of OPS by volume is more than 2MPa which is the minimum value for LWC as per ASTM C330. The splitting tensile strength decreased at all ages with increase with the substitution levels of OPS. Even concrete with 100% coarse OPS aggregate has a splitting tensile strength more than 2 MPa which shows that it has standard requirement in term of tensile strength, although this value for concretes containing OPS is less than control mix [8].

Sobuz et al. [13] in one of the studies, examined that flexural strength of 15% OPS substitute concrete is 2.4 N/mm^2 at 28 days which is approximately 14% of its compressive strength. On the other hand, the flexural strength of conventional concrete is nearly about 13% of its compressive strength. Also, the splitting tensile strength test for different mixes with 0%, 10%, 15%, and 20% OPS substitution in concrete resulted in splitting tensile strength of 12% of its compressive strength at 28 days with 15% OPS substitution in concrete, whereas for conventional concrete the splitting tensile strength is nearly about 10% of its compressive strength [14].

III. Waste and Recycled Aggregates

A. Expanded clay aggregates in LWC

Clay is generated as waste by many infrastructure projects and its management is a major challenge. Their use to make lightweight aggregates has resulted in economical and eco-friendly solution. Clay can be readily processed into required granules and when sintered at relatively low temperatures produce low density but high strength aggregates. It is a potential recycling option for clay wastes. To produce lightweight aggregates from clay Na2CO3, SiO2, Fe2O3, and Fe in quantities between 2 and 10% weight are added. They are brown in colour with an internal black core and spherical in shape. [20]

TABLE V. Physical Properties of Expanded Clay Aggregates [19]

SNo	Properties	Results
1	Bulk density, kg/m3	488
2	Apparent particle density, kg/m3	804
3	Saturated and surface-dried particle density, kg/m3	1002
4	Water absorption after immersion for 24 h, %	24.5
5	Crushing resistance, MPa	3.49

a) Mechanical properties of Leca as aggregates in LWC

Prakash et. al [21] in an experimental study on lightweight concrete using Leca determined that compressive strength with 20% Leca of 29.85 N/mm2, split tensile strength of 2.8 N/mm2, flexural strength of 7.14 N/mm2 at 28 days were obtained comparable to conventional concrete.

Vijayalakshmi et. al [20] in their review structural concrete using expanded clay aggregates, concluded that concrete using expanded clay aggregates has higher workability compared to other lightweight aggregate concrete due to their shape and surface texture.

Rumšys et. al [19] in a comparative study of material properties of lightweight concrete using recycled polyethylene and expanded clay aggregates concluded that using 15% pre wetted clay aggregates by weight 1900 kg/m3 density with 70.2 MPa compressive strength was achieved. Also, higher cement hydration produced lower water absorption lightweight concrete.

Ateeq et. al [21] in an experimental study to scrutinize the impact of expanded clay aggregates and metakaolin determined that use of 60% Leca with 24% metakaolin reduces the density up to 33% and provides appreciable compressive strength.

B. Plastic waste aggregate in LWC

Using waste plastic in construction will reduce the solid waste accumulation to large extent. For preserving ecosystem, the use of virgin aggregates should be reduced. Plastic as a waste can be obtained from various products like bottles, plastic auto parts, packaging, mugs, utensils etc. As the use of plastic has increased in the 21st century, the disposal of plastic has become a menace as it is non-biodegradable [23]. The use of recycled plastic aggregate (RPA) as an alternative aggregate material has been considered to lower the environmental influence of both concrete and waste of plastics. Polyethylene terephthalate (PET) is one of the most abundantly available plastic wastes as it is commonly used for plastic bottles and food containers.

TABLE VI. PROPERTIES OF RPA [24]

Property	RPA
Bulk Specific Gravity (OD Basis)	1.2
Bulk Specific Gravity (SSD Basis)	1.23
Apparent Specific Gravity	1.24
Absorption [%]	2.71
Dry Unit Weight (dense condition) [kg/m3]	600
Voids (dense condition) [%]	50
Fineness Modulus	6.4
Particle Shape/texture	Sub angular/Partially rough
Colour	Brown
Type	Crushed
Maximum Size [mm]	10

a) Mechanical properties of Waste Plastic as aggregates in LWC

Castillo et al. [25] in the study lightweight concrete with plastic waste aggregates found that on replacing 15 % natural aggregates with plastic waste aggregate 28 days compressive strength of 20-25 MPa was attained. It was concluded that the density is reduced and flexural strength was increased.

Alqahtani et al. [24] in the study Lightweight concrete containing recycled plastic aggregates found that when lightweight aggregates were replaced with 100 % plastic aggregates, it reduced chloride penetration by 13 %. Also, it reduced the compressive strength between the range 12- 15 MPa, which can be used for non-structural elements. The durability of the concrete was better than that of natural lightweight aggregate concrete.

Ramesan et al. [26] in their experimental study Performance of light weight concrete with plastic aggregate found that with 40 % replacement with plastic aggregate there was increase in the workability by 50 %. Up to 30% replacement with plastic aggregates which was found to be the optimum percentage there is increase in compressive strength of 9.4 % and splitting tensile strength of 39 % when compared to control mix.

Parra et al. [27] in the experimental study using recycled plastic and cork waste for structural lightweight concrete production found that by replacing natural aggregate by 48 % with recycled plastic aggregates the compression strength and density of the lightweight mixtures was reduced to 68% and 19% respectively.

C. Scrap tyres as an aggregate in LWC

Use of waste rubber tires as an aggregate in lightweight concrete reduces the solid waste. Disposal of waste tires has become a major concern at present. The use of waste tire as an alternative aggregate material has been proposed by in many researches.

TABLE VII. PHYSICAL PROPERTIES OF CRUMB RUBBER IN COMPOSITE CONCRETE [28, 29]

SNo	Property	Result
1	Specific gravity	1.72
2	Fineness modulus	4.48 %
3	Water absorption	2%
4	Loose Density	320-490 kg/m3
5	Compacted Density	570- 730 Kg/m3

a) Mechanical Properties of scrap rubber tyres as an aggregate in LWC

Sibiyone et al. [30] in the experimental study of partially replacing waste rubber as coarse aggregate with 10, 20, 30 and 40 % by volume of coarse aggregate, found that the slump value increases if the flap rubber content increases from 0-20%. High percentage of rubber results in higher toughness.

Mushunje et al. [29] in the paper waste tyre rubber as an alternative concrete constituent material reviewed that 10% replacement with crumb rubber is optimum content and size to achieve satisfactory results without any need of surface treatments and blended cement. Sound absorption properties are better in rubberized concrete when compared to the plain concrete.

S.Selvakumar et al. [31] in the study on strength Properties by Partial Replacement of Fine Aggregate of Concrete with Crumb Rubber, found that with 5 % and 10 % replacement the 28th day compressive strength of crumb rubber concrete is 38.66 N/mm2 and 33.47 N/mm2 which is higher as compared to conventional concrete. The splitting tensile strength of crumb rubber concrete is lower than that of normal concrete. The flexural strength resulted in decrease in strength when compared to the strength of normal concrete. Less bonding ability of crumb rubber effects the strength of concrete.

IV. CONCLUSION

The recent trends in low carbon lightweight concrete were discussed in this review paper. As discussed in the article, the use of waste materials as secondary aggregates in lightweight concrete was analysed. The use of agricultural waste such as Coconut Shell and Oil Palm Shell and their optimum percentage as replacement for the conventional aggregates producing comparable results of compressive strength, split tensile strength, workability, flexural strength was discussed. The physical and mechanical properties of lightweight concrete made from waste plastic, expanded clay aggregates and scrap rubber tyres as secondary aggregates was discussed in this review paper. Overall, this review paper focuses on the use of waste material as secondary aggregates for the production of lightweight concrete, which will not only reduce CO_2 emissions in environment but also results in economical solution.

REFERENCES

[1] Farahani JN; Shafigh P; Mahmud HB. Production of A Green Lightweight Aggregate Concrete by Incorporating High Volume

Locally Available Waste Materials. Procedia Engineering, 2017; 184: 778 – 783.

[2] Shamjith KM; Rajeevan B. A Study on the Utilization of Coconut Shell as Coarse Aggregate in Concrete. International Journal of Engineering Research & Technology (IJERT), 2015.

[3] Gautam BR; Gangwani LR. Light Weight Aggregate Concrete by using Coconut Shell. International Journal of Engineering Technology Science and Research, 2017.

[4] Gunasekaran K; Kumar PS; Lakshmipathy M. Study on properties of Coconut shell as an aggregate. Indian Concrete Institute Journal (ICI), 2011.

[5] Teo DCL; Mannan MA; Kurian VJ; Ganapathy C. Lightweight concrete made from oil palm shell (OPS): Structural bond and durability properties. Building and Environment, 2006; 42: 2614-2621.

[6] Shafigh P; Jumaat ZM; Mahmud H. Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: A review. International Journal of the Physical Sciences, 2010.

[7] Shafigh P; Mahmud BH; Jumaat ZM; Zargar M. Agricultural wastes as aggregate in concrete mixtures – A review. Construction and Building Materials, 2014; 53: 110–117.

[8] Maghfouri M; Shafigh P; Aslam M. Optimum Oil Palm Shell Content as Coarse Aggregate in Concrete based on Mechanical and Durability Properties. Advances in Materials Science and Engineering, 2018.

[9] Okpala DC. Palm kernel shell as a lightweight aggregate in concrete. Building and Environment, 1990; 25:291–6.

[10] Basri HB; Mannan MA; Zain MFM. Concrete using waste oil palm shells as aggregate. Cement and Concrete Research, 1999; 29:619–22.

[11] Shafigh P; Jumaat MZ; Mahmud H. Oil palm shell as a lightweight aggregate for production high strength lightweight concrete. Construction and Building Material, 2011; 25:1848–53.

[12] Huda MN; Jumaat MZ; Mohammad AB; Islam S; Al-Kutti WA. Performance of high strength lightweight concrete using palm wastes. IIUM Engineering Journal, Vol. 19, No. 2, 2018.

[13] Sobuz HR; Hasan NMS; Tamanna N; Islam MS. Structural Lightweight Concrete Production by Using Oil Palm Shell. Journal of Materials, 2014.

[14] Prusty JK; Patro SK. Properties of fresh and hardened concrete using agro-waste as partial replacement of coarse aggregate – A review. Construction and Building Materials, 2015; 82 101–113..

[15] Gunasekaran K; Kumar PS. Lightweight Concrete Using Coconut Shells as Aggregate. Proceedings of International Conference on Advances in Concrete and Construction, 2008.

[16] Habeeb GA; Mahmud HB. Study on Properties of Rice Husk Ash and Its Use as Cement Replacement Material. Materials Research, 2010.

[17] Raheem AA; Kareem MA. Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement. International Journal of Engineering Research in Africa, 2017.

[18] https://en.wikipedia.org/wiki/Expanded_clay_aggregate

[19] Rumšys D; Bačinskas D; Spudulis E; Meškėnas A. Comparison of material properties of lightweight concrete with recycled polyethylene and expanded clay aggregates. Modern Building Materials, Structures and Techniques, 2016.

[20] Vijayalakshmi R; Ramanagopal S. Structural Concrete using Expanded Clay Aggregate: A Review. Indian Journal of Science and Technology, 2016.

[21] Prakash RNR; Krishnamoorthi A. Experimental Study on Light Weight Concrete Using Leca. International Journal of ChemTech Research, 2017.

[22] Ateeq QAH; Maneeth PD; Brijbhushan S. An Experiment to Scrutinize the Impact of Lightweight Expanded Clay Aggregates (LECA) and Metakaolin on Structural Lightweight Concrete. International Journal of Innovative Technology and Exploring Engineering, 2020.

[23] Verma S; Kumar A; Rai B. Green Concrete – An Emerging Trend in India. Proceedings of International Conference on Advances in Architecture and Civil Engineering, 2012.

[24] Alqahtani FK; Ghataora G; Khan MI; Dirar S; Kioul A; Otaibi MA. Lightweight Concrete Containing Recycled Plastic Aggregates. International Conference on Electromechanical Control Technology and Transportation, 2015.

[25] Castillo EDR; Almesfer N; Saggi O; Ingham JM. Light-weight concrete with artificial aggregate manufactured from plastic waste. Construction and Building Materials, 2020.

[26] Ramesan A; Babu SS; Lal A. Performance of light weight concrete with plastic aggregate, Int. Journal of Engineering Research and Applications, 2015; pp.105-110.

[27] Parra C; Sánchez EM; Miñano I; Benito F; Hidalgo P. Recycled plastic and cork waste for structural lightweight concrete production. Sustainability 2019.

[28] Haq MU; Naqvi T; Hashmi F., Stabilization of Concrete using Rubber Tyre Waste, International Journal for Research in Applied Science & Engineering Technology, 2018.

[29] Mushunje K; Otieno M; Ballim Y. A review of Waste Tyre Rubber as an Alternative Concrete Constituent Material, MATEC Web of Conferences 199, 2018.

[30] Sibiyone KP; Sundar ML. Experimental Study on Replacing Waste Rubber as Coarse Aggregate, International Journal of ChemTech Research, 2017, pp 287-293.

[31] S.Selvakumar; R Venkatakrishnaiah. Strength Properties of Concrete Using Crumb Rubber with Partial Replacement of Fine Aggregate, International Journal of Innovative Research in science engineering and technology, 2015.

AUTHORS PROFILE

Amanpreet Kaur
Assistant Professor, Civil Engineering Department, Punjabi University, Patiala.
Area of specialization- Transportation Engineering

Sunita
Assistant Professor, Civil Engineering Department, Punjabi University, Patiala.
Area of specialization- Water Resources Engineering