Mixture proportioning and mechanical characteristics of concrete containing biomass residual ash and silica fumes

Syed Mohd. Arif[1] , Sourabh Dhiman[1] , Vineet Pandey[1], Ashish Kumar[2]

[1]Department of Civil Engineering, Chandigarh Engineering College, Jhanjeri, Mohali-140307, Punjab, India

[2] Department of Applied Science, Chandigarh Engineering College, Jhanjeri, Mohali-140307, Punjab, India

Abstract

In this study, researcher looks at what would happen if they replaced a significant amount of cement with silica fume and biomass residual ash (BA) (SF). Three binary and three ternary concrete blends with varying ratios of cement/BA, cement/SF, and water were added in addition to the control and cement/BA/SF were tested in order to identify the different mechanical characteristics of concrete. Three identical specimens were tested for compressive and tensile strengths after seven and twenty-eight days of conventional curing (wet at 20 °C) for each mix of concrete. In comparison to all other mixes, including the control, the test findings showed that the binary mixes with 15% BA and 7.5 SF and the ternary mixes with 15% BA and 7.5% SF had higher strengths.

Keywords: Concrete, Biomass Ash, Silica fume, Compressive Strength, Tensile Strength, Flexural Strength, Ultrasonic Pulse Velocity test.

1. Introduction

Concrete is coarse, cement-bound material that hardens. Binder and aggregate make up concrete. Cement, sand, aggregate, and water make concrete. Cement, water, sand, gravel, or crushed stone make concrete. Due to its longevity, maintenance-free service life, adaptability to any shape or size, and structural capabilities, concrete has been the dominant building material from its first use. Concrete is the primary construction material (Cement, water, sand, gravel, or crushed stone). Moved, put, compressed, cured. Pozzolanic materials such as silica fumes, fly ash, slag, Rice Husk Ash, and Metakaolin improve the workability, strength, durability, and permeability of High Strength Concrete. Metakaolin enhances concrete's strength, sulfate resistance, and air-void network. Pozzolanic processes change concrete and hydration products by eating released calcium hydroxide and generating more calcium silicate hydrate, resulting in improved strength, less porosity, and better durability. Environmental concerns and energy instability have boosted the demand for renewable energy. In the context of the global economic crisis, recycling industrial waste as an active addiction or additive in cement or concrete composites has received scientific attention. Agro-industrial waste in uncontrolled landfills is an environmental danger. Slow degradability and hazardous, accumulating, or hard-to-decompose by-products may cause this. Biomass derives from living things. In the energy context, biomass refers to plant material, although animal husbandry, food processing, and domestic organic waste are all sources. Biomass contains carbon, hydrogen, oxygen, nitrogen, alkali, alkaline earth, and heavy metals.

Biomass as additional material in concrete

Biomass in concrete will reduce the cement industry's carbon dioxide emissions and save energy, boosting renewable energy and economic development. Biomass is an organic material derived from live or recently alive plants or plant-based components. Nearly 40% of the 63 million tons of coal fly ash produced in the U.S. in 2009 were used. Biomass and co-fired fly ash are innovative energy-based substitutes. Current ASTM and ACI rules prohibit using non-coal-generated fly ash in concrete since its technical properties are unknown. Few studies have examined the use of biomass in concrete, and biomass ash as an SCM in conventional concrete has received less attention.

2. Literature Review.

E.R. Teixeira et al. (2019) studies show that the construction industry has been using additive materials, including coal fly ash, in the manufacturing of concrete all over the world. Biomass fly ash is one of many sub/products or wastes that are currently being researched for use into building materials. But utilising a lot of these materials has several disadvantages, one of which is carbonation. Studying the relationship between cement additions and hydration is crucial for comprehending events like this. With the aid of thermo gravimetric analysis, X-ray diffraction analysis, and accelerated carbonation experiments, this research focuses on the study of the hydration and carbonation of cementitious pastes containing biomass fly ash and/or coal fly ash.

Comparing BFA to CFA, we can see that they have a different chemical and mineral composition. The findings demonstrate that the carbonation behaviour of fly ash from biomass and coal is identical. It appears that biomass fly ash adds additional alkalinity to the combinations, which may be advantageous for the ash management and the building materials.

Spyridon Alatzas et al. (2019) According to studies, the majority of agricultural wastes are either burned spontaneously on-site or thrown in landfills. The potential of agricultural biomass residues is presented within the context of this study. According to the findings, Greece's yearly availability of lingo cellulosic biomass is anticipated to be around 2,132,286 tonnes. The three biomass streams with more than 100,000 tonnes per year each are determined to be cotton ginning residue, olive pruning, and olive pits.

Loan T. T. Vo & Patrick Navard (2017) studied in this review, Many strategies have been put out to get over the challenges involved in making biomass-based concrete. These issues are directly related to the structure and makeup of lignocelluloses biomass, regardless of where it originates. It has been amply proven that a number of biomass constituents, such as soluble sugars and low molar mass hemicelluloses, have a negative impact on the production and functionality of concrete. This makes it possible to either choose biomass sources that minimise these limitations or modify biomass to have better sources of biomass-based products. However, even when biomass is "optimised," it will always be hygroscopic, have a light structure with plenty of holes (which is, of course, one of the reasons for using it), be unstable, and have poor mechanical qualities. This article has a summary of the various strategies that have been tried to prevent or at least lessen these consequences. Most of these techniques work well to simplify the concrete preparation process and produce superior finished products. However, the most of them—if not all—have little practical utility as they are generally impossible to implement due to the usage of chemicals that are not environmentally beneficial or exorbitantly expensive.

Kumar Harshwardhan & Kanjan Upadhyay (2017) studied the literature, there are numerous applications for biomass, including the generation of biogas, filler for asphalt, and adsorbent for bricks. More research and updates to the current technology are needed in order to convert this waste more effectively. Agricultural compounds are those that the earth produces when the seasons change. In essence, these compounds are made by nature and are crucial for the existence of consumers like humans and animals. Biomass is the waste generated from animal waste or crop residues. It has physicochemical qualities and is interconnected with the ecosystem from generation to disposal. The research that has been done in the past on the conversion of biomass and agricultural waste is the subject of the current paper. Increased economic value of agricultural waste as a useful product is an endeavour.

Priyanka & Musaib Mehraj Bhat (2015) reported that the strength of concrete rose with a 25% to 35% increase in the amount of ground fly ash. When silica fume is combined with fly ash in an amount ranging from 5 to 15%, the strength decreases. Study results indicate that silica fume, when combined with fly ash, could be used to fix this lack. We can get even greater strength than natural aggregate concrete by adding fly ash and up to 5% silica fume to recyclable aggregate concrete.

Srishaila et al. (2014) investigated the results of his experimental investigation carried out to check the impact of silica fume and fly ash on the behaviour of self compacting concrete which was made by partial replacement of cement by silica fume and fly-ash. In their study class F fly ash used was in various proportions 15%, 20%, and 25% and that of silica fume by 6%, 9%, 12% by weight of cement.

Shanmugapriya& Uma (2013) carried out an experimental investigation on silica fume as a partial replacement of cement in high performance concrete with different percentage of cement replacement i.e. 2.5%, 5%, 7.5%, 10%, 12.5% by silica fume and observed that high performance concrete produced from cement replacement up to 7.5%. Concrete loses compressive strength over this percentage (7.5%). Due to silica fume's high pozzolanic nature and ability to generate a more densely packed C-S-H gel, the percentage of silica fume has a significant impact on compressive strength.

Verma et al. (2012) reported that silica fume as artificial pozzolona and added them in 0%, 5%, 10%, and 15% by wt. of cement in concrete. It was observed that silica fumes increases the compressive strength of concrete by more than 25%. Concrete voids are also reduced with silica fume. A silica fume addition decreases capillary.

3. Research Gaps

Researchers have examined the utilization of biomass ash, biomass energy, and biomass fuels in the production of electricity, as well as the geotechnical properties of diverse biomass. Researchers have studied various forms of biomass energy and biomass fuel; however, few have investigated whether or not it can be used as a supplement to cementing materials, taking into account the mechanical properties of concrete that incorporates biomass and silica fumes, as well as durability factors such as acid and sulfate attack on the components that make up biomass produced by biomass energy. Thus the durability of biomass-based concrete hasn't been explored much till date.

4. Experimentation and result discussion

4.1 Compressive Strength

The outcome of this test to check the compressive behaviour of concrete under compressive forces. The various mix were prepared for experimentation and M12 gives the suitable result with Biomass Ash and silica fume when used in proportion compressive strength at 7 days and 28 days respectively.

Table No.: 1 Compressive strength of Concrete Mix Samples

Concrete Mix	% of Biomass Ash	% of Silica Fume	7 days	28 days
M1	0	0	36.01	44.41
M2	10	0	36.25	45.50
M3	15	0	37.19	46.39
M4	20	0	36.75	44.64
M5	0	5	38.63	44.89
M6	0	7.5	40.31	46.38
M7	0	10	38.84	46.50
M8	10	5	38.76	45.88
M9	10	7.5	40.43	47.05
M10	10	10	38.95	46.03
M11	15	5	39.50	47.17
M12	15	7.5	40.73	47.34
M13	15	10	39.38	46.60
M14	20	5	36.87	44.95
M15	20	7.5	37.13	45.41
M16	20	10	36.93	45.24

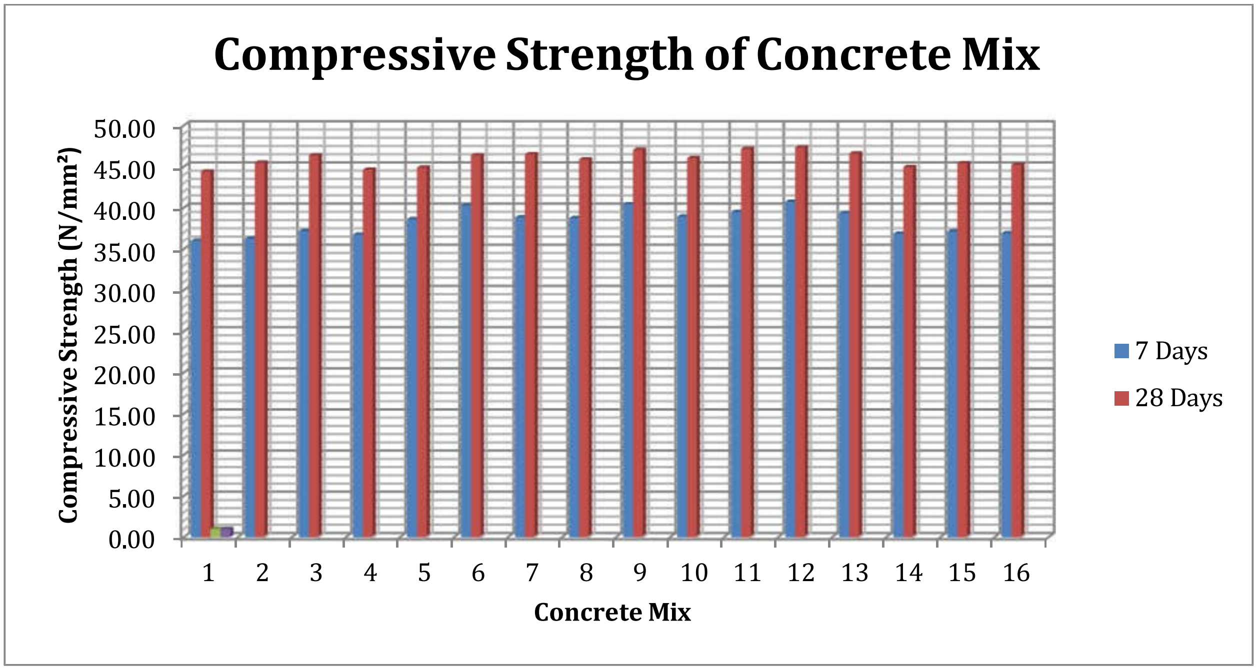

Fig. 1: Compressive strength of Concrete Mix Samples.

4.2 Split Tensile Strength Test

The outcome of this test is to check the tensile strength of the concrete and as per experimentation of various concrete mix design as partial replacement with waste material. It shows when M12 concrete mix is prepared then it gives acceptable results for split tensile strength test.

Table No.: 2 Split Tensile strength of Concrete Mix Samples

Concrete Mix	% of Biomass Ash	% of Silica Fume	7 days	28 days
M1	0	0	2.75	3.04
M2	10	0	2.78	3.09
M3	15	0	2.87	3.10
M4	20	0	2.89	3.13
M5	0	5	2.80	3.07
M6	0	7.5	2.89	3.08
M7	0	10	2.88	3.05

M8	10	5	2.96	3.15
M9	10	7.5	2.98	3.17
M10	10	10	2.98	3.16
M11	15	5	3.03	3.22
M12	15	7.5	3.09	3.27
M13	15	10	3.08	3.25
M14	20	5	2.95	3.12
M15	20	7.5	2.97	3.13
M16	20	10	2.96	3.12

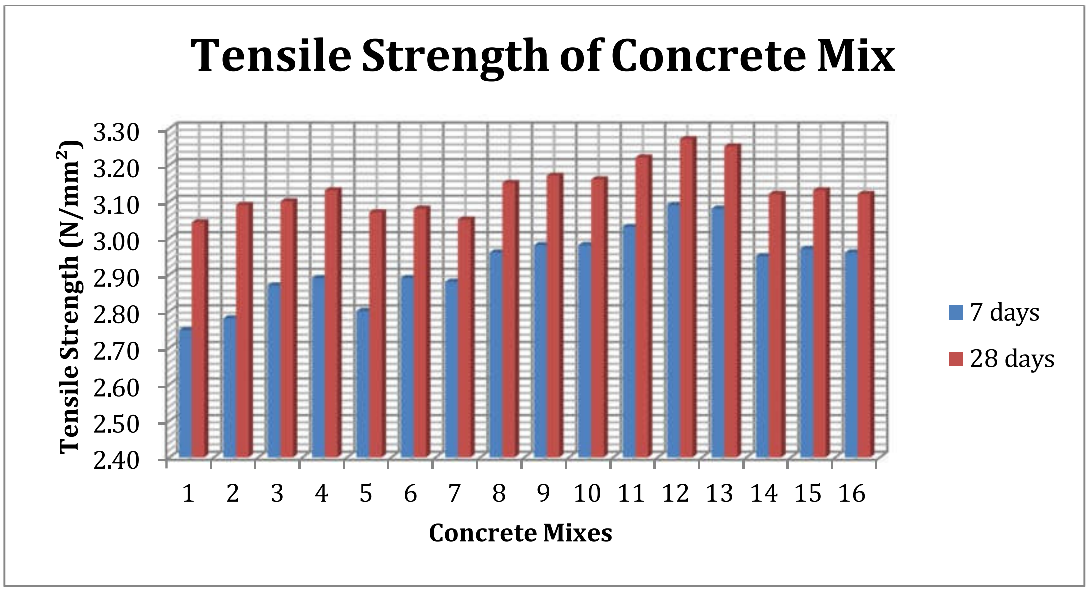

Fig. 2: Split Tensile strength of Concrete Mix Samples

4.3 Flexural Strength of Concrete

The main objective of this test to check the behaviour of prepared mix under flexure and various concrete mixes were prepared. It shows mix designated M12 shows better results when checked for flexure.

Table No. 3: Flexural strength of Concrete Mix Samples.

Concrete Mix	% of Biomass Ash	% of Silica Fume	7 days	28 days
1	0	0	4.58	5.08
2	10	0	4.64	5.14
3	15	0	4.77	5.17
4	20	0	4.72	5.14
5	0	5	4.69	5.20
6	0	7.5	4.79	5.27
7	0	10	4.77	5.25
8	10	5	4.82	5.42
9	10	7.5	4.88	5.50
10	10	10	4.82	5.40
11	15	5	5.01	5.52
12	15	7.5	5.07	5.62
13	15	10	5.01	5.51
14	20	5	4.90	5.40
15	20	7.5	4.86	5.26
16	20	10	4.83	5.18

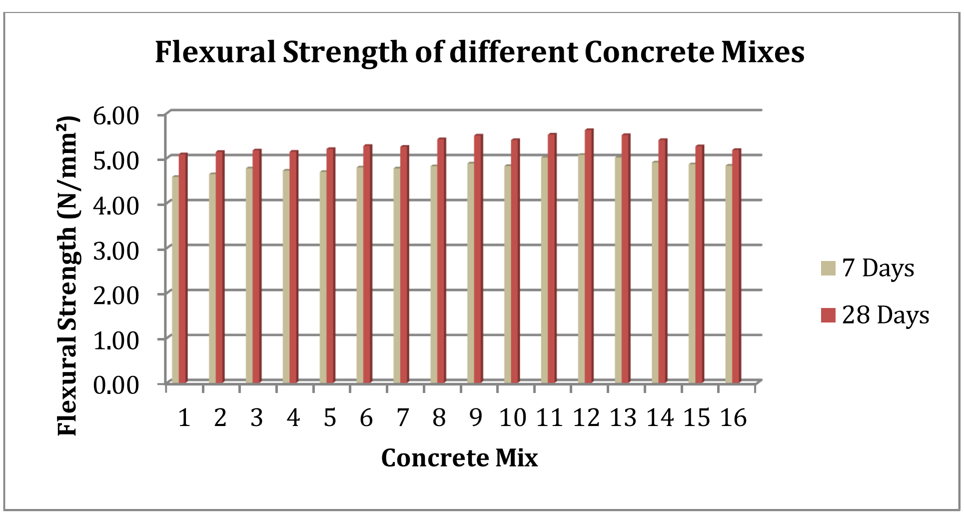

Fig. 3: Flexural strength of Concrete Mix Samples

4.4 Ultrasonic Pulse Velocity Test

The main objective of this test is check the concrete quality and also defects in concrete when electromagnetic waves pass through concrete. As the UPV value increases then it tends to increase the WFS content in concrete mixes with time. The cube samples were examined by UPV and from experimentation it shows that UPV12 gives the most suitable results.

Table No. 4: Result of ultrasonic Pulse Velocity of Concrete Mix Samples

Curing Days	7 Days		28 Days	
Concrete Mix	**Time Period**	**Velocity m/s**	**Time Period**	**Velocity m/s**
UPV1	32.9	4430	32.58	4408
UPV2	32.8	4445	32.48	4423
UPV3	32.6	4477	32.28	4455
UPV4	32.4	4491	32.08	4469
UPV5	32.1	4515	31.78	4493
UPV6	31.9	4522	31.58	4500
UPV7	31.8	4532	31.48	4510
UPV8	31.5	4541	31.18	4519
UPV9	31.2	4568	30.88	4546
UPV10	30.9	4572	30.58	4550
UPV11	30.5	4589	30.18	4567
UPV12	30.1	4598	29.78	4576
UPV13	29.9	4588	29.58	4572
UPV14	31	4570	30.68	4548
UPV15	30.9	4572	30.58	4550
UPV16	32.2	4519	31.88	4497

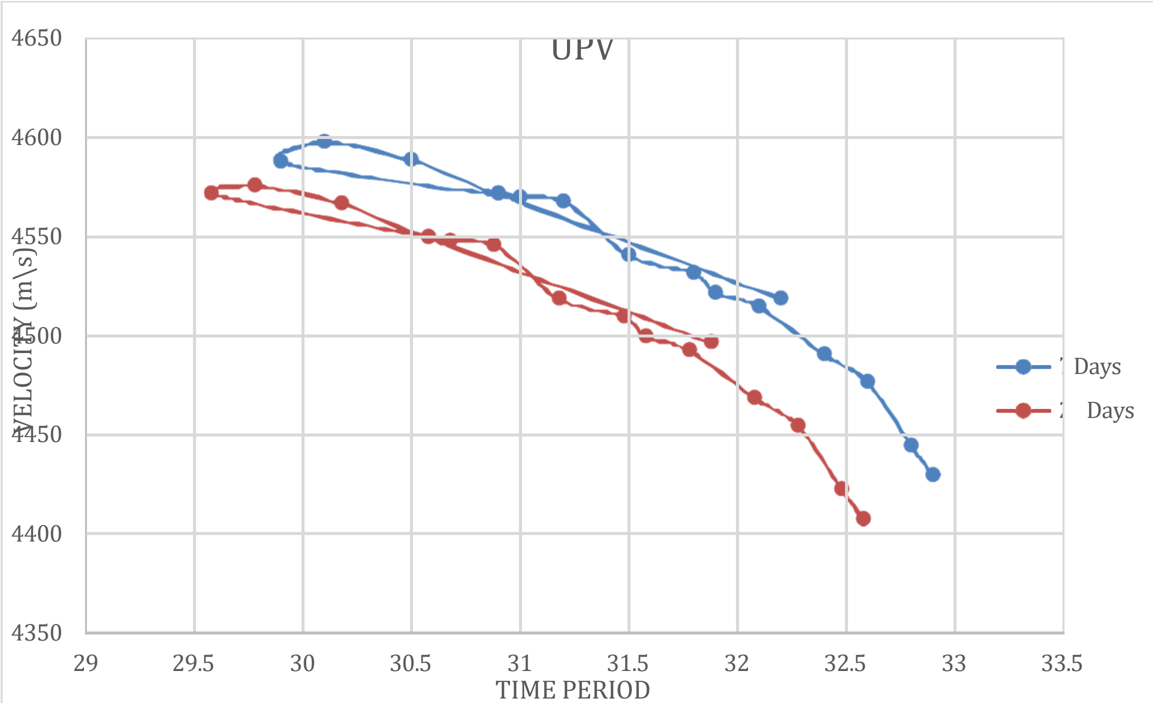

Fig. 4: Graph of ultrasonic Pulse Velocity of **Concrete Mix Samples**

5. Conclusions

This study's primary purpose was to illustrate how the Biomass ash and silica fume in the concrete. Compression was utilised to make concrete more compact in order to accomplish this purpose.

- Biomass ash and silica fume was utilised as a replacement at a replacement level from Some observations and recommendations are obtained from the research work:
- Both the split tensile strength test and the compressive strength test of the biomass ash and silica fume concrete compares favourably to standard concrete up to a 7 replacement of M12 and produces outstanding results. The concrete mix 7 shows that strength is 46.50 N/mm^2 in 28 days curing but in M12 concrete mix both the result of compressive strength gave much better result as compare to M7 at 7 days 40.73 N/mm^2 and 28 days 47.34 N/mm^2 at 7 and 28 days respectively.
- The cube samples were examined by UPV and from experimentation it shows that UPV12 gives the most suitable results.

References

- Anil Kumar, Nitin Kumar, Prashant Baredar & Ashish Shukla (2015) A review on biomass energy resources, potential, conversion and policy in India Renewable and Sustainable Energy Reviews 45 (2015) 530–539
- S Dhiman, R Garg, S Singla (2020) Experimental investigation on the strength of chipped rubber-based concrete IOP Conf. Ser.: Mater. Sci. Eng. **961** 012002
- ACI Committee 232, 2003, Use of Fly Ash in Concrete, ACI Manual of Concrete, 232.2R- 96, American Concrete Institute, Farmington Hills, Michigan, 34 pages
- E.R. Teixeira , A. Camões, F.G. Branco, J.B. Aguiar and R. Fangueiro (2019) Recycling of biomass and coal fly ash as cement replacement material and its effect on hydration and carbonation of concrete Waste Management 94 (2019) 39–48
- B.Chaudhary, S.Dhiman, R.Talwar, Syed Mohd Arif, V.Verma(2022) Experimental investigation of strength of concrete using recycled demolished construction materials as coarse aggregate 1194-1200
- F. O. Obi, B. O. Ugwuishiwu and J. N Nwakaire (2019) agricultural waste concept, generation, utilization and management Nigerian Journal of Technology (NIJOTECH)Vol. 35, No. 4, October 2016, pp. 957 – 964.
- Rishav Garg, Rajni Garg, Bhanu Chaudhary, Syed Mohd Arif (2021) Strength and microstructural analysis of nano-silica based cement composites in presence of silica fume Materials Today: Proceedings (Elsevier).
- Sourabh Dhiman, Syed Mohd Arif, Vineet Pandey, Sonia Rani (2021) Stability Aspects of Concrete Using Bagasse Ash, Marble Dust and Waste Concrete Aggregate International Journal of Mechanical Engineering Vol. 6 (Special Issue 4, November 2021).
- V. Pandey, S. Dhiman, S. M. Arif, V. Gandhi (2021), Optical Fiber in Translucent Concrete {Lightcrete}, International Journal of Mechanical Engineering Vol. 6 (Special Issue 4, November 2021).
- IS 456:2000, Code of practice Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi.

- IS 516:1959 (Reaffirmed 1999), Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi.
- IS: 8112:1989 Specification for ordinary Portland cement grade 43, Bureau of Indian Standards, New Delhi.
- Jeena, 2012, Properties of hardened RAC for structural purposes. Proceedings of Conference on Sustainable Construction, Dundee, Scotland, UK, 1998: 177-187
- J.M. Makavana, V.V. Agravat, P.R. Balas, P.J. Makwana and V.G. Vyas (2018) Engineering Properties of Various Agricultural Residue International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706Volume 7 Number 06 (2018)
- J. Cuenca, J. Rodríguez, M. Martín-Morales, Z. Sánchez-Roldán and M. Zamorano (2013) Effects of olive residue biomass fly ash as filler in self-compacting concrete Construction and Building Materials 40 (2013) 702–709
- J. Heinimo& M. Junginger (2009) "Production and trading of biomass for energy – An overview of the global status" biomass and bioenergy 33 (2009) 1310 – 1310.
- Kumar Harsh wardhan and Kanjan Upadhyay (2017) Effective Utilization of Agricultural Waste: Review Journal of Fundamentals of Renewable Energy and Applications DOI: 10.4172/2090-4541.1000237
- K. Ganesan, K. Rajagopal and K. Thangavel (2007) Evaluation of bagasse ash as supplementary cementitious material Cement & Concrete Composites 29 (2007) 515–524
- Loan T. T. Vo and Patrick Navard (2017) Treatments of plant biomass for cementitious building materials – A review Construction and Building Materials, Elsevier, 2016, 121, pp.161-176. 10.1016/j.conbuildmat.2016.05.125. hal-01354139
- Mohamed H., 2014, Influence of nano materials on flexural behavior and compressive strength of concrete, Housing and Building National Research Center (HBRC), Vol.12, pp. 212–225.
- Mukharjee B.B. & Barai S.V (2014), Influence of Micro Silica on the properties of recycled aggregate concrete, Construction and Building Materials Vol. 55 pp 29-37.
- M. Salvo, S. Rizzo, M. Caldirola, G. Novajra, F. Canonico, M. Bianchi & M. Ferraris (2015) Biomass ash as supplementary cementitious material (SCM)Advances in Applied Ceramics 114:sup1, S3-S10, DOI: 10.1179/1743676115Y.0000000043

- Priyanka and Musaib Mehraj Bhat (2015) Study the Effect of Fly Ash, Silica Fume and Recycled Aggregate on the Compressive Strength of Concrete IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 1, Feb-Mar, 2015
- Radonjanin V., Malesev M., Marinkovic S. & Malty A.E., 2013, Green recycled aggregate concrete,Construction and Building Materials Vol. 47 pp 1503-1511.
- Rahul Seth, Rohit Seth and ShrishBajpai (2015) Need of biomass energy in India Progress In Science and Engineering Research Journal ISSN 2347-6680 (E)
- RejiniRajamma, Richard J. Ball , Luis A.C. Tarelho, Geoff C. Allen, Joao A. Labrincha, Victor M. Ferreira, (2009) Characterisation and use of biomass fly ash in cement-based materials,Journal of Hazardous Materials172 (2009) 1049–1060
- Shanmugapuria T. & Uma R.N., 2013, Experimental investigation on Silica Fume as partial Replacement of Cement in High Performance Concrete, The International Journal of Engineering and Science, Vol. 2, Issue 5, pp 40-45.
- Shetty M.S., 2002, Concrete Technology, theory and practice, S. Chand and company ltd., New Delhi
- Shuangzhen Wang and Larry Baxter (2007) Comprehensive study of biomass fly ash in concrete: Strength, microscopy, kinetics and durability Fuel Processing Technology 88 (2007) 1165–1170
- Shuangzhen Wang, Amber Miller, Emilio Llamazos, Fernando Fonseca and Larry Baxter (2007) Biomass fly ash in concrete: Mixture proportioning and mechanical properties Fuel 87 (2008) 365–371
- Shuangzhen Wang, Emilio Llamazos, Larry Baxter and Fernando Fonseca (2007) Durability of biomass fly ash concrete: Freezing and thawing and rapid chloride permeability tests Fuel 87 (2008) 359–364
- Shuangzhen Wang, Larry Baxter and Fernando Fonseca (2007) Biomass fly ash in concrete: SEM, EDX and ESEM analysis Fuel 87 (2008) 372–379
- SpyridonAlatzas, KonstantinosMoustakas, DimitriosMalamis and StergiosVakalis (2019) Biomass Potential from AgriculturalWaste for Energetic Utilization in Greece

- Srishaila J.M., Uttakar A., Parasivamurthy P.&Jawali V., 2014, Influence of Fly Ash and Silica Fume on Behavior of Self Compacting Concrete, International Journal of Engineering Trends and Technology, Vol. 12, Issue 5, pp246-254.
- Sushil D. Shepal and R. M. Swamy (2016) Comparative Study of Replacement of Cement by Biomass and Silica Fume International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169 Volume: 4 Issue: 4
- Verma A., Chandak R. &Yadav R.K., 2012, Effect of Silica fume on the Strength of Concrete with OPC, Research Journal of Engineering Sciences, Vol. 1, Issue 3, pp 1-4