ISSN: 2633-4828 Vol. 5 No.4, December, 2023

International Journal of Applied Engineering & Technology

MICROSCOPIC ANALYSIS AND HARDENED PROPERTIES OF CONCRETE USING BIOMASS ASH-AS AN ADMIXTURE

Gurpreet Singh Sidhu
Department of Civil Engineering, Punjabi University, Patiala-Punjab, INDIA
gurpreet.sidhu69@gmail.com

ABSTRACT

In the construction business, "sustainability" means using second-hand materials to build new buildings and using less cement to lower carbon dioxide pollution and clean up the environment. As an alternative to cement, biomass ash was used in this study. After a thorough investigation that included both chemical and physical tests, the addition of a certain material to concrete at different amounts compared to the cement's weight was looked at. The material was partially replaced with cement at different levels 0%, 5%, 10%, 15%, and 20%. At three different times, 7, 28, and 56 days, the compressive and split tensile values were checked. When biomass ash was used in concrete, the strength of the concrete went up until it reached a maximum value of 15%. Strength went down as the amount of ash in the mixture went up. Sulphate attack on biomass ash concrete was also looked into in the study. Using lab-based repetition, how biomass affects the long-term strength of concrete in a variety of weather situations. In order to do this, the water will have different amounts of light, moderate, and high ratios of Sulphate Salt (0%, 2% and 4% specifically, Magnesium Sulphate). The Ultrasonic Pulse Velocity (UPV) test, which doesn't damage the material, showed a link between the length of time and the strength of the concrete. The scanning electron microscope (SEM) test showed that the cement mortar had the right amount of calcium-silicate-hydrate (C-S-H) gel and silica in it. This helps you understand what concrete is made of.

Keywords: *Cement, Biomass ash, Compressive strength, Mass loss, USPV*

1. INTRODUCTION

Cement is the primary component used in the production of concrete. The process of cement manufacture is associated with the release of significant quantities of carbon dioxide into the Earth's atmosphere. For each kilogramme of cement manufactured, there is a release of 0.9 kilogrammes of carbon dioxide. Consequently, extensive research and scholarly investigations have been conducted to identify an alternative to cement in order to promote the sustainability and environmental friendliness of concrete production, with a particular emphasis on minimising its ecological footprint. The pozzolanic quality of biomass ash derived from the burning of sugarcane and maize stalk renders it suitable for serving as a partial substitute for cement, hence enhancing the strength of cementitious materials. The accumulation of a substantial amount of biomass ash over an extended period of time is anticipated to be a significant challenge in terms of its disposal and potential environmental ramifications. The practise of either grinding or dumping or disposing of ash in open fields is often seen, resulting in significant negative impacts on soil fertility and permeability.

The production of power from biomass combustion has been concentrated in the previous decade to reduce pollutants and increase efficiency due to worries about CO2 emissions. The most popular way to dispose of biomass combustion ash is landfilling, which has serious economic and environmental consequences [1]. The construction sector around the world uses coal Biomass ash to make concrete. Many sub/products or wastes have been researched for use in building materials, including biomass ash. BFA is chemically and mineralogical distinct from CFA. Biomass ash in building materials carbonates similarly to coal ash. Biomass ash adds alkalinity to combinations, which may assist building materials and ash management [2]. Rice husk, straw, sugarcane bagasse, and cotton stalk engineering qualities. Rice husk and straw had bulk densities of 331.59 and 380.54 Kg/m^3. Sugarcane bagasse was 723.2kg/m3 and cotton stalk 206.14kg/m3. These engineering features assist design equipment, improve plant output, and create novel agricultural residue-based technologies [3]. Cabrera et al. [4] examined how BBA treatments affect fresh and hardened qualities (mechanical and durability) in self-compacting concrete. The research recommended self-compacting concretes with up to 30% BBA sand

and 60% crushed BBA filler. Few studies have examined BBA in lightweight concretes. Rosales et al. [5] report on making lightweight concretes using recycled aggregates and BBA, all of which had compressive strengths within Spanish norms. Due to the above and the global concern for sustainable development, new building materials, including prefabricated ones, have received the most attention. Thermal and acoustic insulation technology can save energy, clean the environment, and lower economic costs if low-density concretes made with BBA are used. New building technology and methods are evolving quickly [6]. The use of biomass ash in concrete production as a substitute for fly ash is a promising prospect due to its composition, which consists of silica, alumina, and several other minerals with pozzolanic properties [7]. Numerous studies have shown that the use of biomass ash in the production of concrete offers a valuable application for a waste material that would otherwise be considered as refuse. This practice contributes to the circularity of the biomass energy generation process. [8]. The generation of biomass energy presents an opportunity for biomass energy producers to gain additional income [9]. A study [10] revealed that the incorporation of biomass ash in combination with other supplementary cementitious materials (SCMs) resulted in enhanced properties of concrete and mitigated the potential occurrence of alkali-silica reaction (ASR). The research conducted by Alesandro et al. [11] sought to assess and compare the mechanical properties of concrete including biomass ash with those of concrete made with cement or fly ash. Nasibeh et. al [12] investigated that decrease in porosity found in concrete when biomass ash is added may be attributed to its pozzolanic activity. The findings of this study suggest that the use of biomass ash as a viable substitute for fly ash may enhance the mechanical and durability characteristics of concrete buildings, hence offering a sustainable solution. According to [13] It has been shown that the alkali-silica reaction (ASR), known for its capacity to cause concrete cracking and decrease durability, has an increasing pattern when cement is gradually replaced with biomass ash. The use of pozzolanic materials and alkali-resistant aggregates is crucial for the mitigation of the detrimental effects caused by alkali-silica reaction (ASR). The suitability of biomass waste for concrete manufacturing has raised concerns over potential ecological issues. [14] The inclusion of biomass ash in a cementitious matrix might provide both favorable and unfavorable impacts on the mechanical and physical properties of the substance. [15] The simplicity of pouring and handling new concrete is greatly influenced by its workability. Previous studies have established that the workability of recently combined concrete is influenced by various factors, including the type, quantity, and shape of biomass-derived ash. A number of factors influence the fresh properties of concrete containing biomass ash, including the proportion of water to cement, chemical admixtures, and mixing procedures [16]. In addition to the limitations associated with the manufacturing process, empirical evidence supports the utilization of biomass ash in the production of concrete, an endeavor that also yields favorable environmental results. The use of biomass ash as a substitute for fly ash increased the compressive strength of high-strength concrete, as reported in [17, 18].

2. EXPERIMENTAL PROGRAMME

2.1 Material Used

2.1.1 Cement: The cement used is a Grade 43 Ordinary Portland Cement. The cement samples were evaluated using the procedures outlined in the international standard (IS) 8112-2013. Table 2.1 details the cement's physical qualities as established by a battery of tests.

Table 2.1: Physical properties of cement

Sr. No	Characteristics	Experimentalvalue	Specified valueas per IS8112-2013 [19]
1	Fineness (Dry Sieving)	3.5%	<10%
2	Consistency of Cement	31.26%	_
3	Specific Gravity	3.14	3.15
4	Initial Setting time	157 minutes	>30 minutes
5	Final Setting time	562 minutes	<600 minutes

2.1.2 Biomass Ash

Ash produced from biomass is a waste product that is left over after the combustion or thermal conversion of biomass resources such as wood, agricultural leftovers, and energy crops. Biomass ash may be used as a soil amendment. It comprises inorganic residues that persist following the combustion or conversion of the organic constituents of biomass. The composition of biomass ash encompasses a range of inorganic compounds, including silica, potassium, sodium, calcium, and phosphorus. These constituents contribute to the reactivity of biomass ash, enabling its involvement in the hydration process when combined with water and cementitious materials. The utilisation of biomass ash as a mineral admixture is attributed to its elevated silica content, as indicated in Table.2.2 The ash specimens were obtained from the 'Sangrur' region.

Fig 2.1 Biomass Ash

The pozzolanic and cementitious properties of biomass ash enable it to chemically react and contribute to the strength and durability of concrete. It has been shown that replacing some of the cement in concrete with ash from biomass produces improvements in the material's workability, compressive strength, and durability. In addition to this, it may improve the resistance to chemical assaults and lower the heat required for hydration. The current availability of biomass in India is estimated at about 750 MMT per annum and surplus biomass availability at about 230 MMT per annum.

2.1.2.1 Physiochemical Properties of Biomass Ash

The analyzed biomass ash has a dark gray color characteristic for products. The samples had hygroscopic properties that cause the grains to stick together, forming aggregates.

Table 2.2 Composition of Biomass Ash (as provided by vendor)

Minerals	Percentage(%)
SiO_2	62%
K_2O	10-38%
CaO	3-30%.
Al_2O_3	1-5%.
Fe_2O_3	1-5%.
MgO	1-5%.
Na_2O_3	1-5%.

2.1.3 Fine Aggregates

As fine aggregates, river sand that was readily accessible in the local area was utilized. It complied with the grading zone-II requirements of BIS: 383-1970 [20]. It had a specific gravity of 2.61 and a refinement modulus of 2.47, respectively. The outcomes of sieve analysis are shown in Fig.2.2

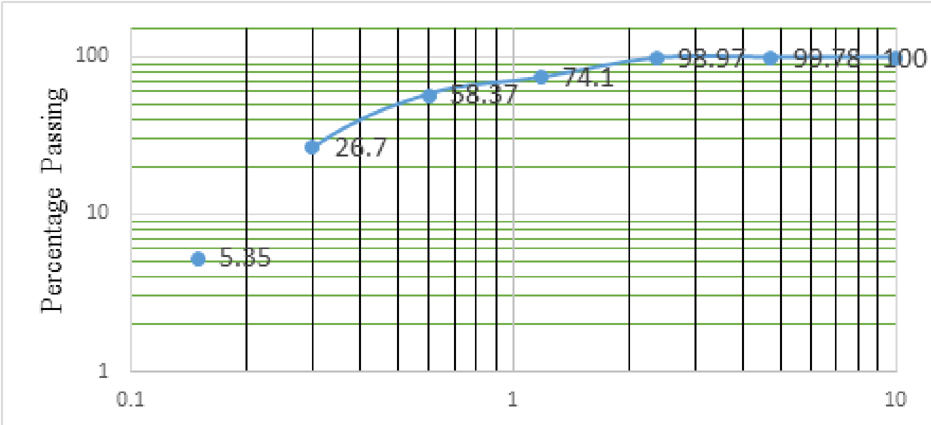


Fig.2.2 Grading Curve for fine Aggregates (Log Scale)

2.1.4 Coarse Aggregates

Coarse aggregates with a maximum size of 12 millimeters were sourced from the surrounding area. Both its specific gravity and its fineness modulus were measured to be 2.67 and 6.71

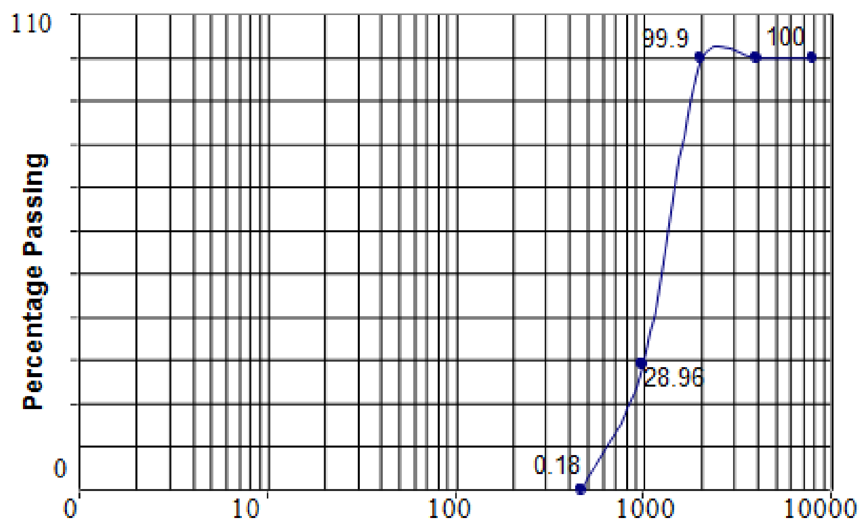


Fig 2.3 Grading Curve for Coarse Aggregates (Log Scale)

2.1.5 Concrete mix design

The M-25 grade of concrete refers to a concrete mix that has a compressive strength of 25 MPa (Mega Pascal) when cured for 28 days. To design M-25 concrete mix, (IS: 10262-1982 [21]) the materials and proportions are given table 2.3.

Table: 2.3 Mixture proportions

Constituents	Weight (0% biomass ash)	5% Biomass Ash	10% Biomass Ash	15% Biomass Ash	20% Biomass Ash
Cement(Kg/m^3)	390	370.5	351	331.5	312
Water (litre)	150.3	150.3	150.3	150.3	150.3
Fine aggregates(Kg/m^3)	647	647	647	647	647
Course Aggregates(Kg/m^3)	1150.60	1150.60	1150.60	1150.60	1150.60
Super Plasticizer	2.39ltr	2.39ltr	2.39ltr	2.39ltr	2.39ltr

3. RESULT AND DISCUSSIONS

3.1 Compressive Strength

The compressive strength test results for a concrete mix without biomass ash were recorded as per BIS: 516-1959[22] at various time intervals. At 7 days, the measured value was 25.44 MPa. Subsequently, at 28, 56, and 91 days, the measured values increased by approximately 41.41%, 47.38%, and 73.80%, respectively. At the 7-day mark, the compressive strength test of a mixture containing 5% biomass ash yielded a result value of 23.23 MPa. Subsequent measurements of the same mixture at 28, 56, and 91 days indicated an increase in the result values by approximately 42.7%, 28.36%, and 74.02%, respectively. The experimental results indicate that an increase in biomass content from 5% to 10% in the concrete mixture resulted in a noticeable effect on the compressive strength test values. Specifically, after 7 days, the compressive strength test value was recorded at 23.52 MPa. Furthermore, when the same mixture was tested after 28, 56, and 91 days, the results showed an increase in values by about 44.47%, 48.13%, and 72.27%, respectively. By increasing the biomass ash content from 10% to 15% in the same concrete mix, the compressive strength values at 28, 56, and 91 days showed a rise of approximately 41.05%, 55.69%, and 76%, respectively, compared to the 7-day compressive strength value of 24.13MPa for the same replacement level in the concrete mixture. The increase in biomass content from 15% to 20% in the concrete mixture resulted in noticeable changes in the compressive strength test results. After 7 days, the measured value of compressive strength was 22.76 MPa. Subsequently, at 28, 56, and 91 days, the recorded values exhibited decrease of approximately 44.47%, 48.13%, and 52.27%, respectively. However, the compressive values exhibited a decrease when 20% of the biomass was substituted with cement, as compared to the other groups of 0%, 5%, 10%, and 15%, across all ages.

The experimental findings demonstrated that the incorporation of biomass as a substitute for cement in concrete resulted in enhanced compressive strength across all time periods, up to a replacement level of 15%, as illustrated in Figure 4.10. However, as the percentage of replacement grows to 20%, there is a corresponding decrease in compressive strength. The presence of silica in biomass contributes to the improvement of compressive strength. The reaction between ash and calcium hydroxide results in the formation of calcium silicates and aluminates hydrates. These compounds fill the empty spaces within concrete, leading to an improvement in its microstructure. Consequently, the strength of the concrete is enhanced. However, as the replacement quantity reaches 20%, it begins to decrease, possibly due to a decrease in specific area and C-S-H gel.

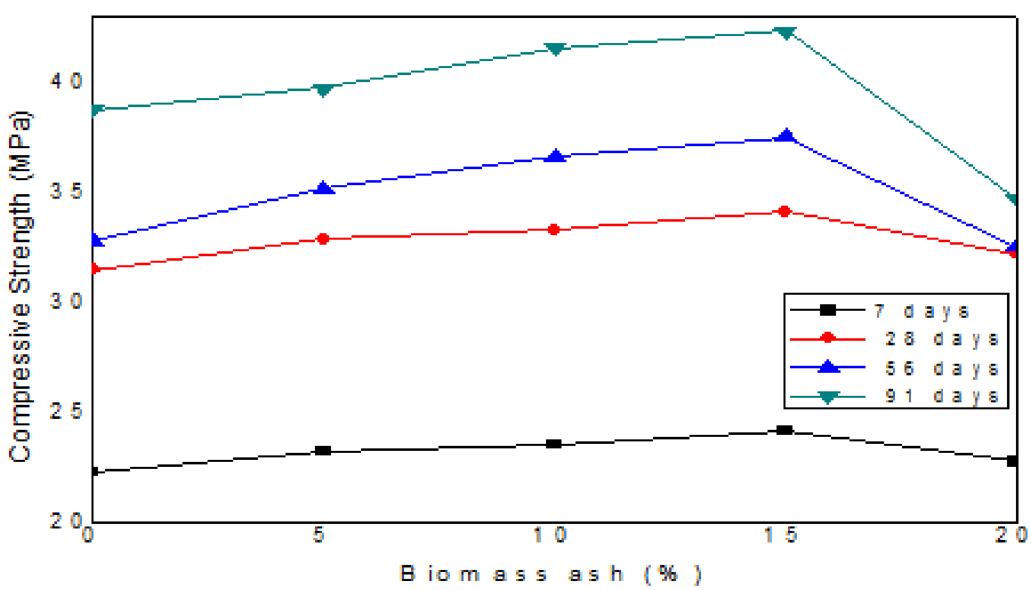
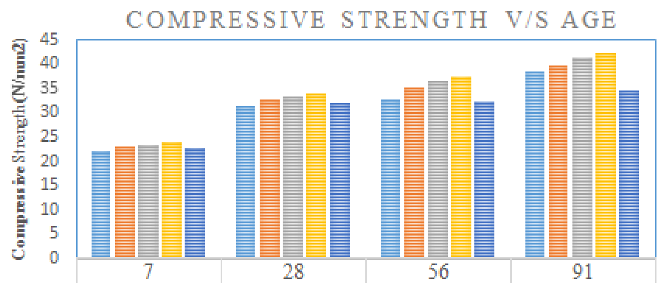


Fig.3.1 Effect of Biomass ash percentage on compressive Strength



	7	28	56	91
0% biomass ash	22.26	31.48	32.8	38.71
5% biomass ash	23.23	32.86	35.19	39.71
10% biomass ash	23.52	33.26	36.6	41.56
15% biomass ash	24.13	34.13	37.48	42.31
20% biomass ash	22.76	32.19	32.51	34.71

Fig. 3.2 Compressive strength verses age

3.2 Split Tensile Strength

The split tensile strength test results for a concrete mix without biomass ash were recorded as per IS: 516-1959[22] at various time intervals. At 28 days, the measured value was 2.51 MPa. Subsequently, at 56 days, the measured values increased by approximately 11.41%. At the 28-day mark, the split tensile strength test of a mixture containing 5% biomass ash yielded a result value of 2.63 MPa. Subsequent measurements of the same mixture at 56, days indicated an increase in the result values by approximately 9%. The experimental results indicate that an increase in biomass content from 5% to 10% in the concrete mixture resulted in a noticeable effect on the split tensile strength test values. Specifically, after 28 days, the split tensile strength test value was recorded at 2.66 MPa. Furthermore, when the same mixture was tested after 56 days, the results showed an increase in values by about 8%. By increasing the biomass ash content from 10% to 15% in the same concrete mix, the split tensile strength values at 56, days showed a rise of 9%, compared to the 28-day split tensile strength value of 2.73 MPa for the same replacement level in the concrete mixture. The increase in biomass content from 15% to 20% in the concrete mixture resulted in noticeable changes in the split tensile strength test results. After 28 days, the measured value of split tensile strength was 2.73 MPa. Subsequently, at 56 days, the recorded values exhibited an increase of approximately 4.4%, respectively. However, the split tensile strength values exhibited a decrease when 20% of the biomass was substituted with cement, as compared to the other groups of 0%, 5%, 10%, and 15%, across all ages.

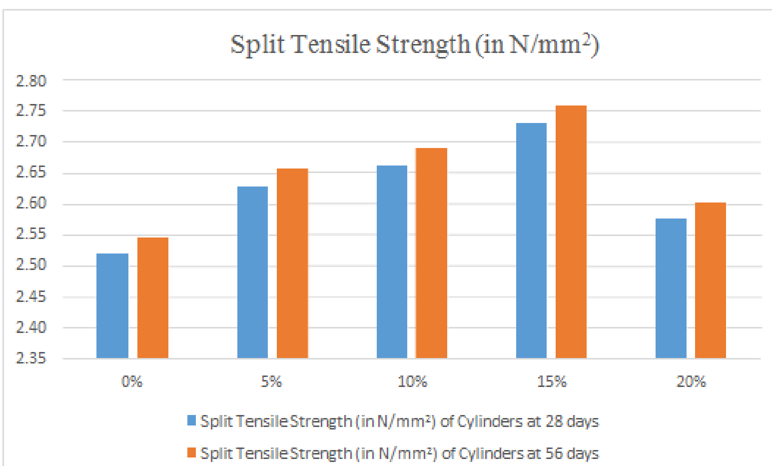


Fig. 3.3 Effect of biomass ash on split tensile strength

3.3 Compressive Strength Loss

After the immersion in Mg_2SO_4, concrete specimens were measured for mass loss, no spalling and cracks were observed in all the concrete specimens during the entire duration of test. Test conducted as per ASTM C 1012-10 [23]. Even after 91 days of immersion in 6% magnesium sulphate solution no loss in mass of all replacement levels of concrete specimens was observed. However, signs of white deposits were observed after 91 days of immersion period.

3.3.1 Change in Compressive Strength

The results of compressive strength after immersion in magnesium sulphate solution are displayed in Fig. 3.4 and the percentage loss in compressive strength after immersion in 2, and 4% magnesium sulphate solution presented in Fig.3.5. Result shows that as the biomass ash content increase in the concrete mixtures reduction in compressive strength also increases. But minor reduction in compressive strength was observed in all concrete mixture as compared with water cured mixtures, the reduction in compressive strength was not more than 5% after 28 days. Furthermore at 91 days curing age, 0% replacement of iron slag in concrete, the loss in compressive strength by immersing the concrete specimen in 4% magnesium sulphate solution was 4% as compared with the compressive strength of water cured specimens of same replacement, at 2 and 4%, replacement with cement. After 28 days immersion period in magnesium sulphate solution the percentage increase in compressive strength of all SCC mixtures was lower than that of water cured SCC mixture.

Table 3.1 Compressive strength before and after dipping in Mg_2SO4 Solution

Percentage of Biomass Ash	StrengthBefore immersion	Strength After immersing in solution of MgSO4 concrete		
		0%	2%	4%
0	25.44	26.71	24.80	24.16
5	26.55	27.87	26.01	25.48
10	26.88	28.224	26.34	25.80
15	27.58	28.90	27.02	26.47
20	26.01	27.31	25.48	24.96

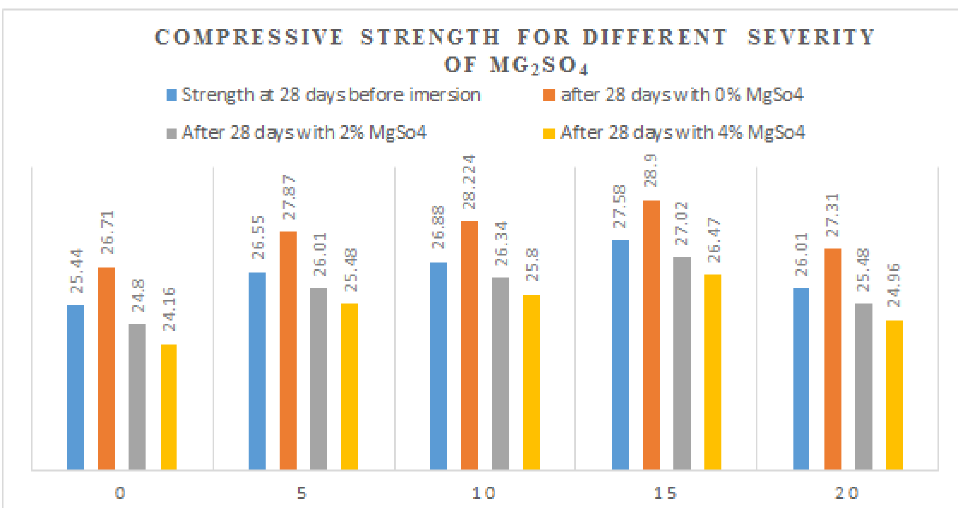


Fig. 3.4 Compressive Strength obtained for different severity of Mg_2SO4

3.4 Ultra-sonic Pulse Velocity

The pulse velocity results of concrete with and without biomass ash in Table 3.2 displayed in Fig 3.5 the results measured at 28 days curing age. Test conducted as per ASTM C 597-02 [24]. Concrete incorporating biomass ash shows similar movement in growth of UPV as in compressive strength. The pulse velocity results showed that as the biomass ash content increased the ultra-sonic pulse velocity also increased. All the test result values of UPV are greater than 3500 m/s. It depicts the excellent concrete quality. Lower value of velocity in concrete is 3528 with 0% replacement on curing age of 28 days and higher value of velocity in concrete is 3721 with 20% replacement of cement with biomass ash at the curing age of 28 days in between the values of UPV increased gradually.

Table 3.2 UPV results after 28 days of curing

S. NO.	% COMPOSITION	TIME	VELOCITY (m/s)
1	0 %	35.8	3528
2	5 %	35.3	3591
3	10 %	35.0	3623
4	15 %	34.9	3654
5	20 %	34.7	3721

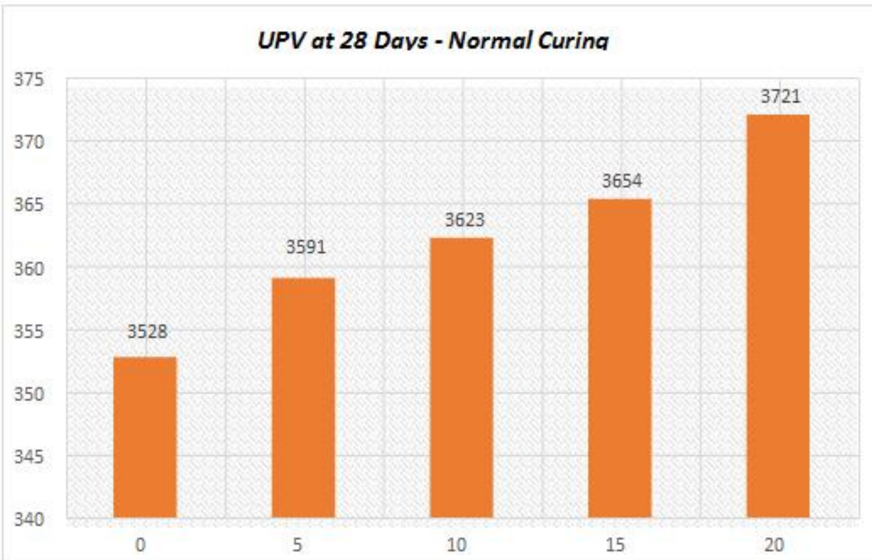


Fig.3.5 UPV at 28 days

Hence the quality of concrete falls in the Good Range and the quality increases for increase in the percentage of composition of Biomass Ash as a replacement of cement.

Table 3.3 Results after Additional 28 days of Chemical Action

S. No.	Composition	Velocity inNeutral conditions (0%)	Time	Velocity in Mild Conditions (2%)	Time	Velocity in Strong Conditions4%	Time
1	0 %	4211	30.4	3781	33.5	3642	34.8
2	5 %	4263	30.2	3792	33.4	3667	34.6
3	10 %	4294	29.9	3836	33.0	3714	34.1
4	15 %	4341	29.5	3877	32.7	3749	33.8
5	20 %	4368	29.0	3893	32.59	3801	33.3

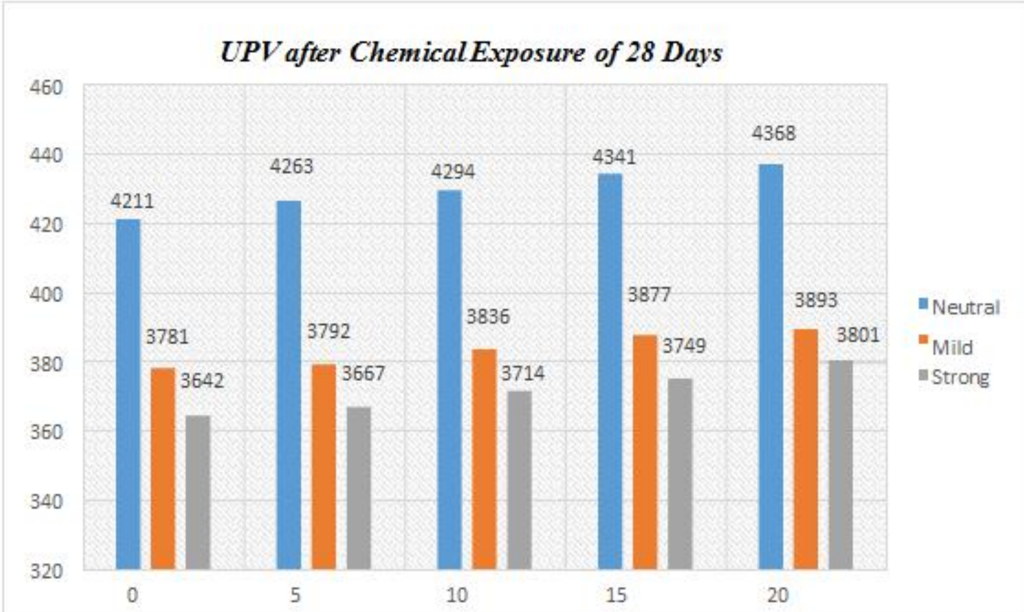
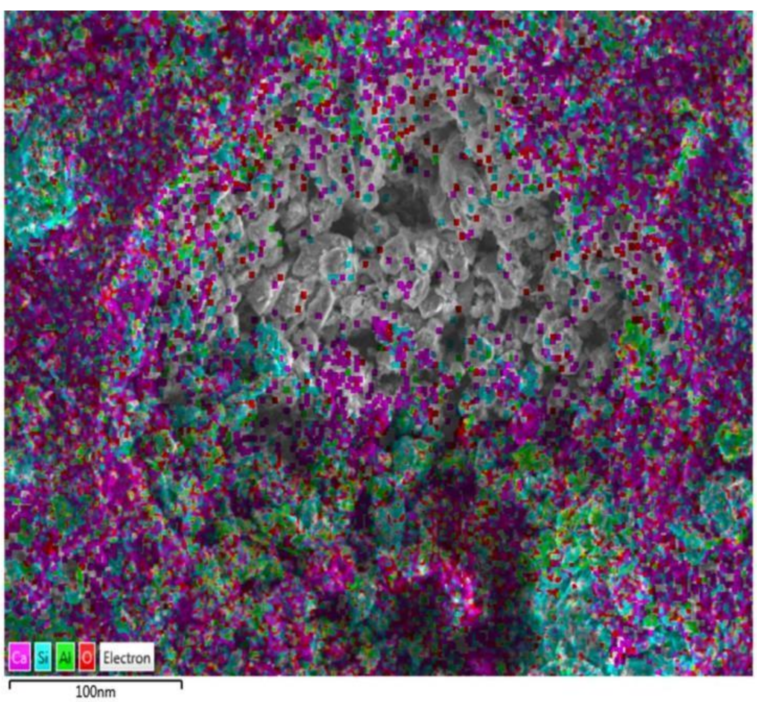
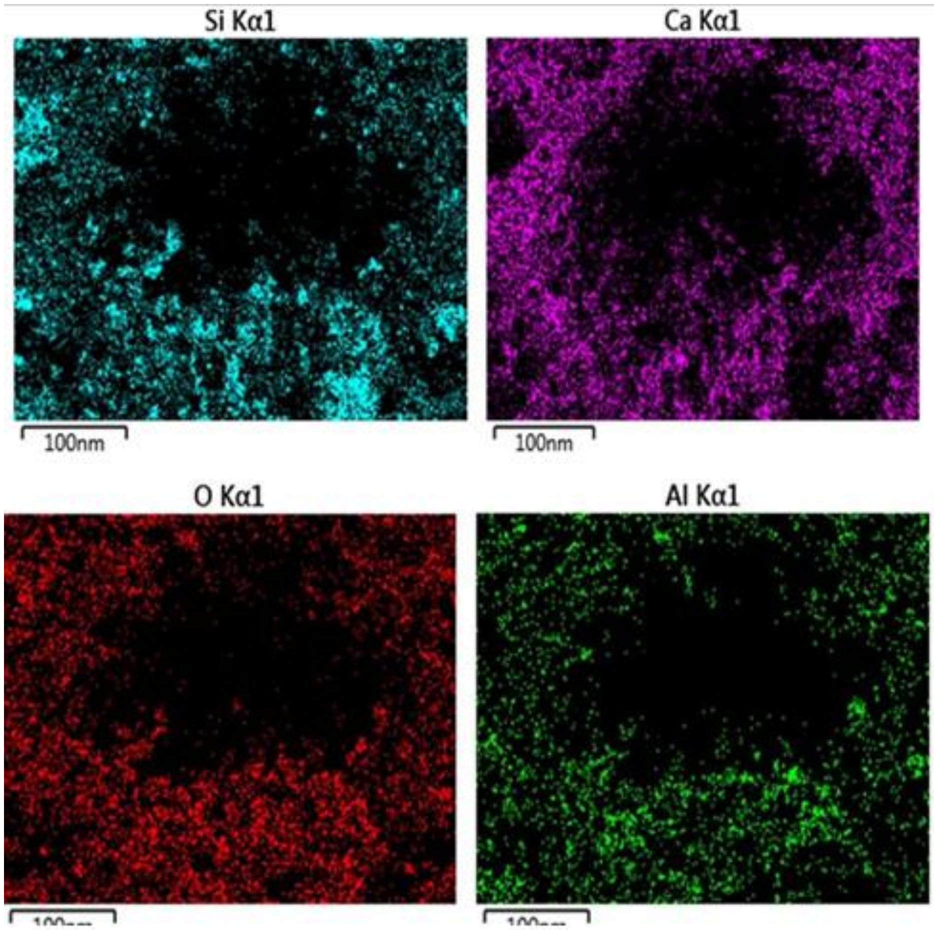


Fig. 3.6 UPV values for different compositions of Biomass Ash in replacement with Cement

4. SEM AND EDS ANALYSIS

In a SEM/EDS system, the signals generated include secondary and backscattered electrons, which are employed in image formation for morphological analysis. In addition, X-rays are created, which are used for the identification and quantification of compounds that are present in measurable amounts. When it comes to EDS, the detection limit is influenced by the conditions of the sample's surface; the smoother the surface, the lower the detection limit. EDS has the ability to detect both major and small elements, with a threshold of 10% of weight for significant elements and 1% of weight for tiny elements. SEM/EDS images shown in Fig. 4.1.





5. CONCLUSION

The purpose of the present investigation was to determine how the mechanical qualities of concrete changed when cement was replaced with increasing percentages of Biomass Ash (0%, 5%, 10%, 15%, and 20%). Eighty test specimens were used to measure how these replacements affected the concrete's compressive strength, split tensile strength, and durability. Based on the data collected, a conclusion has been drawn and incorporated in this investigation.

1. The substitution of cement content in the present study resulted in an augmentation of the compressive strength of cubic specimens. The strength of the material attained its maximum value over a period of 28 days, during which replacement batches were utilized with an optimal replacement ratio of 15% Biomass Ash. The utilization of Biomass Ash as a substitute for cement resulted in a progressive reduction in compressive strength.
2. Based on the findings of the conducted investigation, it was established that the specimens exhibited an optimal level of Split Tensile strength at a magnitude of 15%. The split tensile strength of the samples exhibited a drop in magnitude as the proportion of cement substituted by Biomass Ash saw an increase.
3. The investigation revealed that the inclusion of biomass ash resulted in enhanced durability of the specimens.
4. The stated research revealed that the utilization of UPV testing yielded a greater mean velocity. The incorporation of biomass ash into concrete offers a mutually beneficial outcome as it serves to both mitigate void formation and enhance the concrete's resistance to chemical degradation.

REFERENCES

1. Silva, R., de Brito, J., Lynn, C., & Dhir, R. (2019, January). Environmental impacts of the use of bottom ashes from municipal solid waste incineration: A review. Resources, Conservation and Recycling, 140, 23–35. https://doi.org/10.1016/j.resconrec.2018.09.011.

2. Teixeira, E., Camões, A., Branco, F., Aguiar, J., & Fangueiro, R. (2019, July). Recycling of biomass and coal fly ash as cement replacement material and its effect on hydration and carbonation of concrete. *Waste Management*, *94*, 39–48. https://doi.org/10.1016/j.wasman.2019.05.044.

3. Alatzas, S., Moustakas, K., Malamis, D., & Vakalis, S. (2019, March 21). Biomass Potential from Agricultural Waste for Energetic Utilization in Greece. *Energies*, *12*(6), 1095. https://doi.org/10.3390/en12061095.

4. Cabrera, M., Martinez-Echevarria, M. J., López-Alonso, M., Agrela, F., & Rosales, J. (2021, October 14). Self-Compacting Recycled Concrete Using Biomass Bottom Ash. *Materials*, *14*(20), 6084. https://doi.org/10.3390/ma14206084.

5. Rosales, J., Beltrán, M. G., Cabrera, M., Velasco, A., & Agrela, F. (2016, March 12). Feasible Use of Biomass Bottom Ash as Addition in the Manufacture of Lightweight Recycled Concrete. *Waste and Biomass Valorization*, *7*(4), 953–963. https://doi.org/10.1007/s12649-016-9522-4.

6. Rodrigues, C., & Freire, F. (2014, November). Integrated life-cycle assessment and thermal dynamic simulation of alternative scenarios for the roof retrofit of a house. *Building and Environment*, *81*, 204–215. https://doi.org/10.1016/j.buildenv.2014.07.001.

7. Amran, M., Debbarma, S., & Ozbakkaloglu, T. (2021, February). Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties. *Construction and Building Materials*, *270*, 121857. https://doi.org/10.1016/j.conbuildmat.2020.121857.

8. Maschowski, C., Kruspan, P., Arif, A. T., Garra, P., Trouvé, G., & Gieré, R. (2020, May 14). Use of biomass ash from different sources and processes in cement. *Journal of Sustainable Cement-Based Materials*, *9*(6), 350–370. https://doi.org/10.1080/21650373.2020.1764877.

9. Saidur, R., Abdelaziz, E., Demirbas, A., Hossain, M., & Mekhilef, S. (2011, June). A review on biomass as a fuel for boilers. *Renewable and Sustainable Energy Reviews*, *15*(5), 2262–2289. https://doi.org/10.1016/j.rser.2011.02.015.

10. Sakir, S., Raman, S. N., Safiuddin, M., Kaish, A. B. M. A., & Mutalib, A. A. (2020, May 9). Utilization of By-Products and Wastes as Supplementary Cementitious Materials in Structural Mortar for Sustainable Construction. *Sustainability*, *12*(9), 3888. https://doi.org/10.3390/su12093888.

11. Arrigoni, A., Panesar, D. K., Duhamel, M., Opher, T., Saxe, S., Posen, I. D., & MacLean, H. L. (2020, August). Life cycle greenhouse gas emissions of concrete containing supplementary cementitious materials: cut-off vs. substitution. *Journal of Cleaner Production*, *263*, 121465. https://doi.org/10.1016/j.jclepro.2020.121465.

12. Nasibeh, F.M., Reza, E.F., Nour, F.A. (2015) Mechanical properties of concrete containing biomass ash as cement substitute. Adv. Environ. Biol., 9 (4) pp. 177-180.

13. Esteves, T., Rajamma, R., Soares, D., Silva, A., Ferreira, V., & Labrincha, J. (2012, January). Use of biomass fly ash for mitigation of alkali-silica reaction of cement mortars. *Construction and Building Materials*, *26*(1), 687–693. https://doi.org/10.1016/j.conbuildmat.2011.06.075.

14. Jura, J., & Ulewicz, M. (2021, November 7). Assessment of the Possibility of Using Fly Ash from Biomass Combustion for Concrete. *Materials*, *14*(21), 6708. https://doi.org/10.3390/ma14216708.

15. Teixeira, E., Camões, A., Branco, F., & Matos, J. (2021, February 26). Effect of Biomass Fly Ash on Fresh and Hardened Properties of High Volume Fly Ash Mortars. *Crystals*, *11*(3), 233. https://doi.org/10.3390/cryst11030233.

16. Teixeira, E. R., Mateus, R., Camões, A. F., Bragança, L., & Branco, F. G. (2016, January). Comparative environmental life-cycle analysis of concretes using biomass and coal fly ashes as partial cement replacement material. *Journal of Cleaner Production*, *112*, 2221–2230. https://doi.org/10.1016/j.jclepro.2015.09.124.

17. Wang, S., & Baxter, L. (2007, December). Comprehensive study of biomass fly ash in concrete: Strength, microscopy, kinetics and durability. *Fuel Processing Technology*, *88*(11–12), 1165–1170. https://doi.org/10.1016/j.fuproc.2007.06.016.

18. Nagrockienė, D., & Daugėla, A. (2018, June). Investigation into the properties of concrete modified with biomass combustion fly ash. *Construction and Building Materials*, *174*, 369–375. https://doi.org/10.1016/j.conbuildmat.2018.04.125.

19. IS: 8112-1989: Specifications for ordinary Portland cement 43gd. Bureau of Indian Standards, New Delhi. 1989.

20. BIS: 383-1970, Indian standard specifications for coarse and fine aggregates from natural sources for concrete New Delhi, India: Bureau of Indian standards; 1970.

21. IS: 10262-1982: Recommended guide lines for concrete mix design. Bureau of IndianStandards, New Delhi. 1982.

22. IS: 516-1959 (reaffirmed 1999): Methods of tests for strength of concrete. Bureau of Indian Standards, New Delhi. 1999.

23. ASTM C 1012-10. Standard test methods for length change of hydraulic-cement mortars exposed to sulphate solution. West Conshohocken, USA: ASTM International.

24. ASTM C 597-02. Standard test methods for pulse velocity through concrete. Conshohocken, USA: ASTM International.