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A LABORATORY WORK WITH BIOMASS: A CEMENT REPLACEMENT MATERIAL IN CONCRETE MIX

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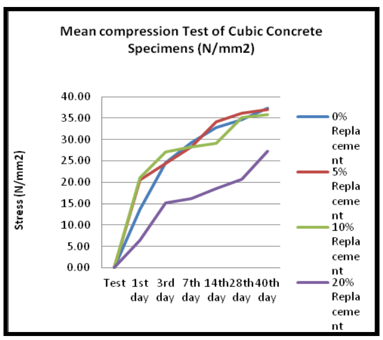
Graphical abstract



Abstract

The cement production facing the current environmental issue like CO_2 emission and scarcity of raw materials, burning of higher amount fossil fuel for production and rapidly increasing demand for cement and concrete can be of a greater problem in the near future. On the other hand there is an ongoing issue of biomass waste management, so there is great opportunity for biomass ash to be used as a cement replacement material as many ongoing researches suggest. This can help to cut down the production of cement and with waste management. The pozzolanic characteristic of several biomass ash can be advantageous, and if the required strength of concrete can be achieved with a certain amount of replacement of cement with biomass ash, then this can be used widely if allowed by structural codes. This report explores the scope of biomass as a cement replacement material in several percentages (5%, 10%, 20%) and shows an effective result with 5 to 10% replacement as the cement with this percentage showed almost same engineering and durability properties like the traditional mix.

Keywords: Biomass, pozzolanic material, cement replacement material, concrete, biomass ash

Abstrak

Industri Pengeluaran simen menghadapi masalah alam sekitar seperti pengeluaran CO_2 dan kekurangan bahan mentah, pembakaran bahan bakar dengan jumlah yang banyak dan peningkatan permintaan terhadap simen akan memberi masalah pada masa hadapan. Di samping itu, terdapat isu berterusan mengenai pengurusan sisa biomass, jadi kajian ini adalah bertujuan untuk mengatasi masalah ini dengan menggunakan sisa abu biomass sebagai bahan pengganti simen. Ini boleh membantu untuk mengurangkan pengeluaran simen dan dengan pengurusan bahan sisa. Ciri pozzolanik daripada beberapa abu biomas boleh digunakan, dan jika kekuatan yang diperlukan konkrit boleh dicapai dengan jumlah tertentu penggantian simen dengan abu biomass, maka ini boleh digunakan secara meluas pada struktur-struktur tertentu. Kajian ini mengkaji bahan biomass sebagai bahan pengganti simen dalam beberapa peratus (5%, 10%, 20%) dan keputusan mendapati bahawa di antara 5% hingga 10% penggantioan kepada simen menunjukkan cirri-ciri kejuruterran dan ketahan yang hamper sama dengan bancuhan tradisional.

Kata kunci: Gentian keluli, konkrit berbusa, konkrit ringan, mampatan, lenturan

1.0 INTRODUCTION

Generally each year 1m^3 of concrete is being produced by a person if the current total use of concrete and population worldwide is considered and the production of Portland cement used contributes to the emission of 5- 8 % of the total CO_2, the major compound responsible for climate change [1]. Concrete is made when cement, coarse and fine aggregate, water and admixture and mixed properly. The mixture is said to be good if it can achieve a good strength and durability. The quality of concrete can be controlled and one way can be using pozzolanic material. According to ASTM 618-94a, pozzolan is siliceous or siliceous or aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture , chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Pozzolanic material like fly ash, silica fume and ground granulated blast furnace slag is very commonly in use. Besides, pozzolanic materials can be obtained from natural byproduct waste and can be good for environmental conservation. These by products can be used as cement replacement materials which replace a certain amount of cement in concrete mix and many researches are being done on biomass ash for using it as a cement replacement material [2].

Generally, Biomass ash is produced by burning biological products like wood, plants, energy crops, wastes etc. Among energy crops there are biofuel, fast growing trees, grasses and among wastes the ash can be produced from agricultural waste, paper industry waste etc. Biomass ash usually consists of organic and inorganic substances which contain various intimately associated solid and fluid phases with different contents and origin. The phases in biomass originate from natural (authigenic and detrital) and anthropogenic (technogenic) processes during presyngenesis, syngenesis, epigenesis and post-epigenesis of biomass according to the main formation process and place, time and mechanism of phase formation. The main structural organic components in biomass are cellulose, hemicellulose and lignin and these matrices contain in addition various major, minor or accessory organic and inorganic phases.

The structural components in biomass are of six types and the most common orders include: cellulose > hemicellulose > lignin; cellulose > lignin > hemicellulose; and hemicellulose > lignin > cellulose. Hemicellulose are abundant in annual and fast-growing plants or plant parts and this constituent plays a role of conducting and concentrating tissue for mineralized solutions abundant in sulphates, chlorides, nitrates and silicic acid in plants. Cellulose, lignin and extractives show associations with different non-mobile and mobile elements in biomass.

The biomass ash produced in thermal power stations are either used for landfills or goes through recycling in agricultural fields or just disposed. But as the disposal cost of biomass is in rise and also in its volume, so a sustainable way has to be established so that such ash can be managed and recycled to be used in some alternative fields [3]. But if recycled in environment the filter fly ash might create problem so in some European guideline they are to be treated or disposed as industrial waste [4]. However, there are possibilities in using the biomass ash in construction material as a part of lightweight aggregate or in cement blends and mortars [5]. The combustion of characteristics of biomass ashes depend on its source like herbaceous material, wood or bark etc, on combustion technology or from where the ash has been collected like the bottom ash or fly ash [3,4,6].

According to a research done on different biomass fly ashes to see their behavior towards the fact that they can be used as cement replacement material the followings could be observed: Fly ash F1 from thermal power plant had levels of SiO2, Al2O3 and Fe2O3 which showed the possibility of having pozzolanic characteristics whereas, fly ash F2 from co-generation plant consisted of higher quantity of CaO (25%). Besides, in cement based mortar with 10 % fly ash the basic strength could be maintained. But when 20% of fly ash was used the mechanical strength was reduced to 75%. The fly ashes experimented contained a good level of chloride and sulphate and it was suggested that the removal of these chemical elements could help to improve the performance of biomass fly ashes selected. It has been also mentioned that up to 20 % of cement replacement could be possible with fly ash in cement based mortar to obtain an acceptable mechanical strength but an increase in replacement % lead to a deterioration in strength and the study clearly exhibited that a control on carbon, sulphate and chloride in fly ash can make it a good cement replacement material [7].

Different researches have also been carried out to incorporate fine wood waste fly ash as a cement replacement material and the results shown that this ash can be used as a replacement material for making concrete of acceptable structural grade, durability and strength [8]. Unlike coal ash biomass ash does not consist of any toxic metal. The biomass contents are of several types which depend on types of soil, harvesting etc. But in general the major constituents are Ca, K, Na, Si and P and some of them among these act as important nutrients for the ashes. Moreover, some biomass ashes are of high silica content like in rice husk, some have high alkali content (wood). The elemental composition of biomass depends on the inorganic constituents of the parent biomass, on the crystallinity and the mineralogy depends on the combustion technique used [9].

As biomass is the byproduct form burning renewable energy sources, agricultural residues and agro industrial wastes. e.g. Palm oil fuel ash (POFA) is found from the burning of palm oil fibers, shells, and empty fruit bunches in a palm oil mill power plant, rice husk–bark ash from burning of rice husk and eucalyptus bark in a biomass power plant. The crushing of these biomass ashes have shown better pozzolanic properties which also contribute to better strength development and can also be used as partial replacement of Portland cement. The use of pozzolans as cement replacement material can have effect on the overall strength of the concrete depending on the chemical and physical effects. Basically, the chemical effects are related to thenormal hydration of Portland cement compounds and water, and the pozzolanic reaction between pozzolanic material, Ca(OH)2 and water whereas, the mechanical effect is linked with the packing characteristics of mixtures and depends on the particle size of the pozzolan [10].

It has been noticed from many studies that management of biomass waste can be done if they are used in construction product making, especially in concrete and cement manufacture. But at the same time there are some constraints like codes, e.g. the codes like ASTM C618, EN -450 and EN 197-1 allow the use of ashes as a concrete additive but do not allow as replacement.

The following lab report is based on lab work that was done to test the engineering and durability properties of three concrete mixes with replacement of cement by 5, 10, 20 % of biomass ash and the results were compared with the test results of specimen made from normal concrete mix. The experiment was designed to observe up to which percent of cement replacement by biomass would be acceptable to achieve a certain mentioned strength.

2.0 EXPERIMENTAL PROGGRAMME

The mix design is based on to achieve the optimum proportion of cement, water, coarse and fine aggregate to produce a stated property of concrete. In this laboratory work the required target strength for the concrete was of grade 30 for the normal concrete for the first mix and the three other mixes were with replacement of 5, 10 and 20 percent of cement with biomass ash. Table 1 shows the mix design.

Table 1 Mix design

% of replacement	Water (kg)	Cement (kg)	Fine agg. (kg)	Coarse agg. (kg)	Biomass (kg)
0%	21	37.5	48.5	131	0
5%	21	35.6	48.5	131	1.87
10%	21	33.8	48.5	131	3.75
20%	21	30	48.5	131	7.5

The traditional and DoE (The Department of the Environment's Design of Normal Concrete Mixes), among the two mix design methods DoE was used to determine the mix design. The following data were used to determine the water cement ratio and the determine proportions of other materials to make the concrete mixes.

Slump: 40
Density: 2.65
Coarse Aggregate: Crushed 20 mm (Maximum)
Fine Aggregate: Zone 04

The proportion of materials for four different mixes are as the following and have been in calculated for 0.1 kg/m^3

3.0 MIXING PROCEDURE

The four concrete mixes with 0, 5, 10 & 20 % replacement of cement with biomass were done .The contents were weighed to obtain the required amount and then dried to get rid of any moisture content. Then they were mixed together gradually in the mixer and slump tests were carried out to check the workability of the mixture, unless the mixture obtained the required result for the slump test the mixture was adjusted in the mixer. As the, mixture was ready it was poured into the moulds. The moulds were tightened and brushed with grease before the mixtures were put. The mixtures were put in three pours, after each pour the moulds were shaken in vibrator to that the air bubbles were removed and the mixtures were compacted into the moulds properly. For each batch of concrete mixer 20 cubes and 12 prisms were used. After each mix was prepared they were kept for 24 hours to get hardened and then demoulde and put into water tank for curing. During the curing process the specimen were taken out from the tank and tested on the required test dates.

4.0 TESTING

The tests were done on the cubes and prisms during the curing phase on the 1st, 3rd, 7th, 14th, 28th and 40th day of age. The following tests were done to determine the engineering and durability properties of the samples.

To determine the engineering properties the density test was done the cubes and prism following the BS 1881: Part 114: 1983 which is the method for determining the density of hardened concrete. The weight of the concrete blocks was taken in air and the water weight was recorded by submerging the blocks in water. The following formula was used to calculate the density.

The compression and flexural test were done following the BS 1881: Parts 119: 1983 and BS 1881: Part 118: 1983 respectively. For the compression test cube samples of dimension 100mm X 100mm X 100 mm was selected and for the flexural test prism of dimension 100 mm X 100 mm X 500 mm were used. To determine the compressive strength three cubes of the same batch were used for each test day and the average was taken to get an accurate value and for the flexural test the average for two prisms were recorded every time.

The last test to determine the engineering property is the pundit to know the density the elastic properties of each batch of the mixes. The portable ultrasonic non-destructive indicating test (PUNDIT) is accordance with BS 1881: Part 203: 1986.

To determine the durability properties the following tests were done: Carbonation, water absorption, permeability, shrinkage and expansion.

A pH indicator would be sprayed on the freshly exposed surface of concrete prisms. The indicator will turn colorless eventually after few days if sprayed on carbonated concrete. The indicator changes to pink if sprayed on the surface to be checked are not carbonated.

For the water absorption and permeability test cylinders with diameter 75 mm and 50 mm are extracted from prisms. The water absorption test done in accordance with BS 1881: part 122: 1983. As the cylinders for this tests were extracted from the prism they are put in oven to dry out the moisture and then the specimens were weighed (air weight) in a balance and were put in water for 30 minute, then the weight (water weight) were taken again after they absorbed water. The absorption was calculated by the following formula: 100(water weight- air weight)/ air weight.

The permeability test was done using the 50 mm cylinders. They were dried in oven for 3 days before they were tested in Leeds cell permeameter.

The expansion and shrinkage tests were done with prisms of dimension 100 mm X 100 mm X 500 mm. The specimen was marked at two points with a gap of 205mm between them and demec disks were put at the points. With the strain gauge recorded the distance between the points after the specimen was taken out from the mould. One specimen was put in water and the other was kept in air from the same batch to determine the wet shrinkage and dry shrinkage respectively. The distances between the points were recorded on each test day.

5.0 RESULTS AND DISCUSSION

In this section discussions are made on different test results done to observe the entering and durability properties of four concrete mixes, one with the normal concrete mix and the other with replacement of cement with biomass ash proportions. The results are to be compared and major comparison is to be between the concrete with 0% cement replacement with 5,10 and 20 % of cement.

5.1 Density

The density of hardened concrete is the indicator of densities of the initial ingredients; mix proportion, initial and final water content, air content, degree of consolidation and hydration, volume changes etc. This test was carried out to compare the density of different sample of four different concrete batches on 1st, 3rd, 7th, 14th, 28th and 40th days of their testing.

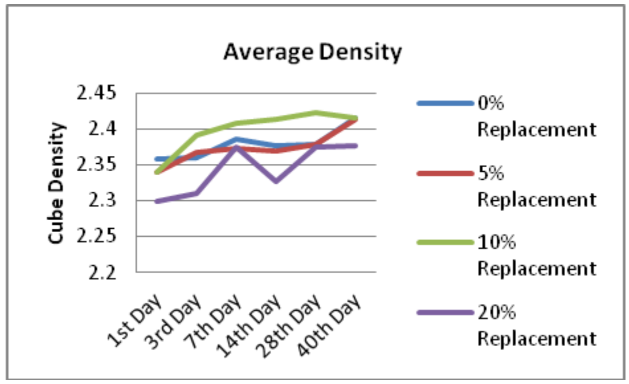


Figure 1 Four set of test results done with cube specimens to test the density

From Figure 1, it can be noticed the initial density for the concrete samples with biomass contents exhibited higher density than the concrete with 0 % replacement of cement. Whereas the sample with 10% biomass with highest density on 28th day of curing, but one the 40th day the density of sample with 0, 5 and 10 % replacement reached almost the same density. In contrast, the sample with 20% biomass showed lower density almost during all testing days.

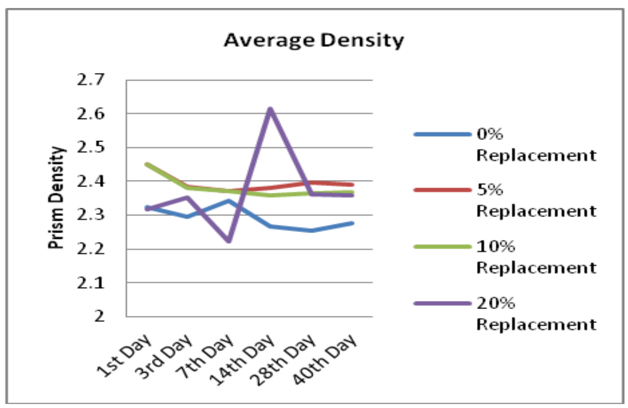


Figure 2 Four set of test results done with prism specimens to test the density

Figure 2 shows four set of test results done with prism specimens to test the density. For the prism samples the density was higher during all test days for 5 and 10% replacement than the normal concrete samples. The samples with 20% replacement showed uneven result and reached a pick of on the 14th day of curing. Overall, it can be noticed that samples, both cube and prism with showed a higher value density with 5 and 10% of replacement than the normal concrete.

5.2 Compressive Strength

Compressive & Tensile strength tests are two major strength tests conducted on concrete. Strength usually gives an Overall Picture of the quality of concrete because it is directly related to the structure of cement-paste.

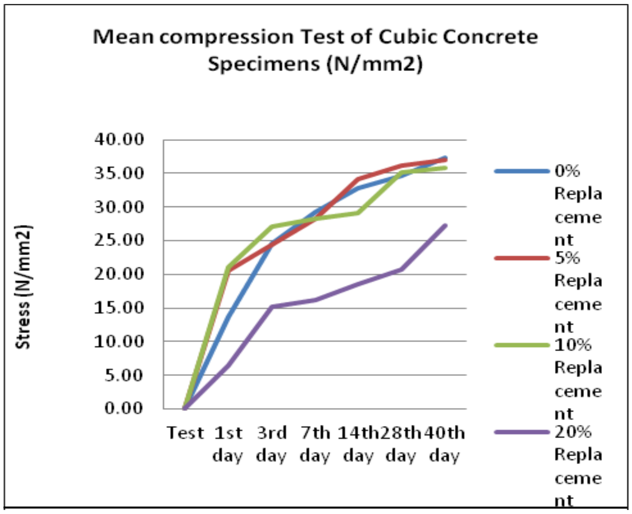


Figure 3 Compressive strength of four batches of concrete during their curing phase

Figure 3 showed the compressive strength went up with the number of days passing and the curing helped the samples from being dried up and aided the strengthening process. On the 28th day the sample with 5 % replacement of cement with biomass achieved the highest strength of around 36 N/mm^2 but on the 40th day the normal concrete and this sample reached the same strength. In the case of 10 % replacement of cement the sample reached the highest strength during the 3rd day of curing if compared with other samples but after that the strengthen process got steady, picked up on 28th day again and reached almost the same value like 0 and 5 % replacement on the 40th day.

However, the samples with 20 % replacement had a lower compressive strength all thought out its 40 days of curing and was noticeably lower on the 28th day when compared to other samples. So, up to 10 % replacement of cement with biomass ash could give a result almost same like 0% replacement or even higher for 5 % replacement on the 28th day, but for 20% replacement it was difficult to reach the strength which other samples have achieved.

5.3 Flexural

Flexural test was performed to observe the ability to resist deformation by the beams made of four quantities of cement contents for different batches for concrete. Two samples were tested on every test days for different batches of concrete and the average was counted. The following graph was plotted with the obtained values.

It can be seen from Figure 4 that unlike for the compressive strength with 5 % replacement which showed better performance when compared with other three mixes, the flexural strength is better in normal concrete on overall. But the highest strength was reached by the 10% replacement sample on the 28th day. The sample with 5 % replacement showed a lower strength even on the 28th day of curing and like for the compressive strength the values were lower again for the 20 % replacement. However, it managed to gain strength of almost the same value like for 0 and 10% replacement on the 40th day and even went higher than the sample with 5 % replacement.

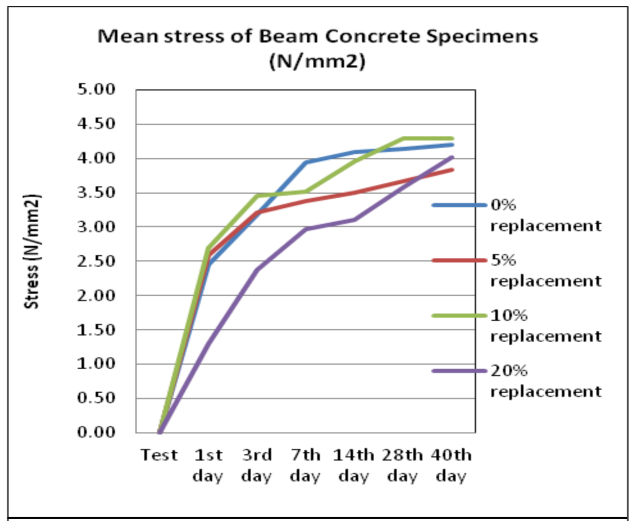


Figure 4 Flexural test on four batches of concrete during their curing phase

If comparing the compressive and flexural strength the results are different with different batches and do not follow the same trend of strength gaining for the different batches.

5.4 Pundit

The basic principle of this method of testing is that the velocity of an ultrasonic pulse through concrete is related to its density and elastic properties. This test is for the measurement of concrete uniformity and for checking of the presence or absence of voids, cracks and other imperfections. A sound wave is sent into the material being tested by a transducer and the time the sound wave takes to travel in the material depends on the characteristic and thickness of the concrete. If there is no defect in the material, the sound wave is reflected by the other side of material. In this case, the total travel time corresponds to the thickness of material. However, when the sound wave hits any flaw inside the material, the travel time is reduced accordingly.

From Figure 5, the PUNDIT test results shown the velocity of the pulse increased gradually as the age of the concrete samples increased. For the cube samples the 10 % replacement shows the highest value for the mentioned test, whereas from the 28th day onward the normal and 20 % replacement cement concrete possess the same velocity.

From Figure 6, for the prisms with the 5% cement replacing biomass had the highest speed of sound wave passing through the samples all throughout the testing phase. In contrast, samples with 20 % replacement of cement had the slowest speed of sound waves passing through them. The values for the normal concrete and concrete with 10% replacement lied in between the 5 % and 20 % replacement material concrete.

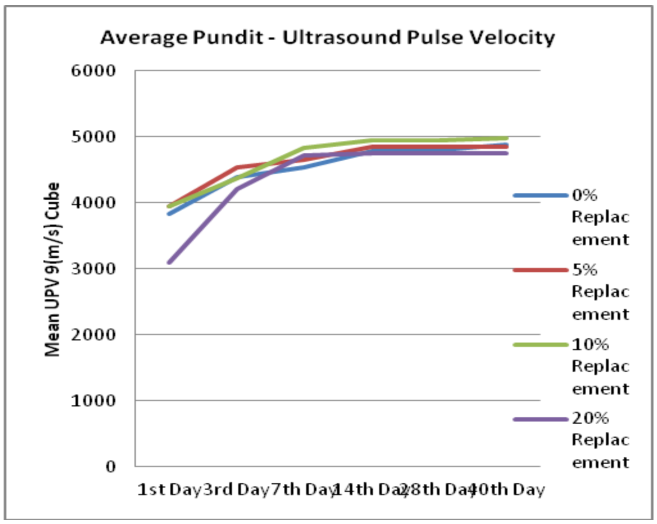


Figure 5 Pundit test results on four batches of concrete during their curing phase

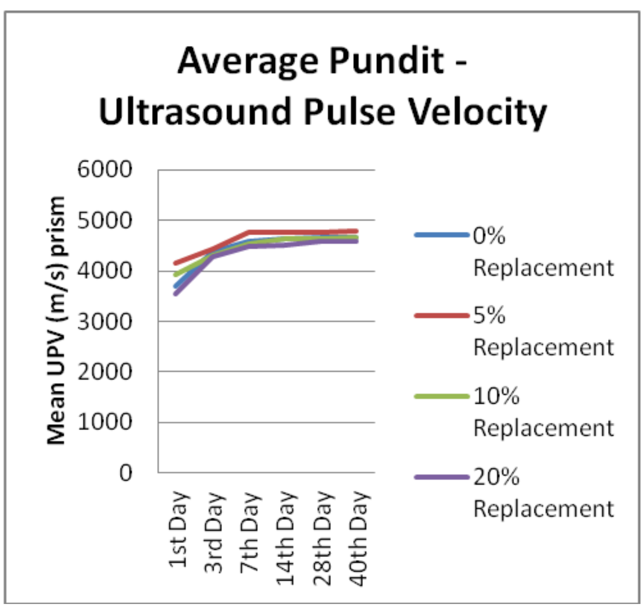


Figure 6 PUNDIT test (prism) results on four batches of concrete during their curing phase

5.5 Water Absorption

From Figure 7, it can be seen that the samples went through changes in volume changes during the plastic phase. The pattern showed by the concrete samples with cement replacement material showed exactly the opposite result to that of the concrete with no cement replacement material. The samples with 20 % replacement material absorbed the highest percentage of water due to the presence of highest amount of biomass ash compared to other mixes compared. The normal concrete absorbs the highest amount of water on the 7th day then goes through reduction in absorption ability as the samples goes forward through the 40 day long testing duration.

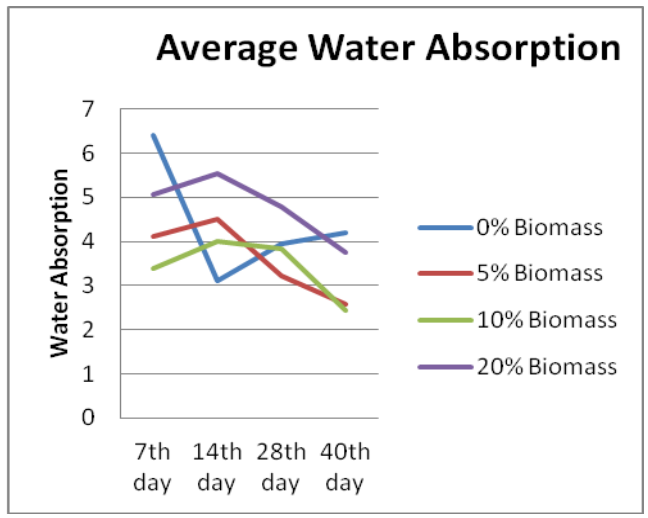


Figure 7 Water absorption rates of the samples

5.0 CONCLUSION

From the above test results for this lab work where four concrete mixes were made and the tests done on them on six several days within the period of 40 curing days it can be concluded:

- The replacement factor of 20% for the given biomass as a replacement material for cement could not perform effectively to achieve a good strength and properties when compared with other percentage of replacement.
- The 5 % and 10 % replacement specimen showed better performance in different tests but not one being consistently the most efficient in all property assessment tests.
- The 5 and 10 % cement replacement biomass ash in concrete mix showed almost the same result as normal concrete mix or ever better on 28th days so consideration can be given to such replacement in practical uses with necessary adjustments.

Acknowledgement

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