Chapter – 01

Introduction

1.1 GENERAL

Cement is one of the most commonly used construction materials. Its highly energy-intensive production process consumes about 45% of its energy from burning fuel and 55% from calcinations.

Globally, the cement industry produces about 5% of man-made carbon dioxide (CO_2) annually. In the United States, cement is responsible for nearly 1% of all CO_2 that is emitted. As is well known, the emission of CO_2 contributes to the greenhouse gas (GHG) effect, and, therefore, many countries are trying to reduce CO_2 emissions in order to mitigate the negative environmental consequences. Accordingly, any reduction in carbon emissions in the preparation of concrete will improve the material's sustainability and help the environment. One possible solution is the development of carbon sequestration in concrete and/or concrete admixtures. Such sequestering may reduce the carbon footprint of concrete and also improve its mechanical properties and durability. For one means of carbon sequestration, many studies show that bio-char has great potential to reduce GHG effects by sequestering carbonic soils. The estimated residence time of carbon in bio-char is in the range of hundreds to thousands of years, which is much longer than that of carbon in plant material, which takes place over decades. Therefore, this sequestration process using bio-char would reduce the release of CO_2 back into the atmosphere when the carbon is stored in the soil.

Recently, efforts have been made to find environmentally sound uses for high-carbon bio-char. To expand the practical applications of bio-char, the Canadian Bio-char Initiative encourages its use as an additive in several industrial areas, including the asphalt/concrete industry. However, it is a challenge to consume the high carbon content of bio-char in concrete. The carbon itself increases the water demand in the concrete and causes a reduction of compressive strength with an increase in replacement rate.

The overall research objective in this study is to provide quantitative information about bio-char so that it can be used as a carbon sequestration agent in concrete and/or as a self-curing agent. First, it is hypothesized that the high carbon content of bio-char can be captured in concrete without substantial negative side effects, such as reduction in compressive strength and durability. Second, it is hypothesized that the high water retention capacity of carbon in bio-char can help to reduce the evaporation of water in concrete and provide water for the hydration process. In this study, the chemical and material properties (e.g., chemical components, microstructures, concrete weight loss, compressive strength and mortar flow) of bio-char are examined using sample mortar mixes that have varied replacement rates of bio-char. Two different curing methods, air-cured and moisture-cured, are used for the compressive strength testing. The experimental results are compared with those of other mortar mixes that include fly ash as a cement substitute.

1.2 GREEN BUILDING & BIOCHAR

Green building (also known as green construction or sustainable building) refers to both a structure and the using of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition.

1.2.1 Worldwide Green Building Ingredient

The most important part of a Green Building is its design. An expert opinion must be sought while planning a building. And only based on this design we can determine the materials needed for building.

For an environment friendly building a few **important points** must be kept in mind:-

- Stick framing must be replaced with wall panels. This saves a lot of resources and also reduces wastage. It has been noticed that this cuts down the wood usage by 11-20%. Wood framing can also be eliminated totally. Prefabricated modular home components are found to be more durable and efficient as well as they make a better envelope for the building.

- Structurally insulated panels can also be used. They are made up of strand wood, which are a product got from trees which are small. Their harvesting too doesn't affect the environment much. Expanded polystyrene forms the core which provides a rigid insulation. This ensures that the structure is more environmental friendly. As a result the comfort level increases and the energy bills decreases.

- When selecting materials for building one must ensure that they are properly certified as environment friendly. Currently many certifications organizations have come up but often they turn out to be dishonest. So it is better if one trusts the consensus based certifiers.

- To minimize the use of artificial lighting sources there should be plenty of windows. The design of windows should ensure that the sunlight stays indoors for the maximum amount of time during the day. Houses in areas with high temperature summers should make use of tainted glass to keep the indoors cool.

1.2.2 Construction of Green Building by Biochar

Biochar, a highly porous material produced from plant waste, is mostly used in agriculture as a soil conditioner, in livestock farming as a feed supplement, and in metalworking as a reducing agent. It can also be used for cleaning “grey water”, as an absorber in sports clothing, in batteries and many other uses . The latest developments at the Ithaka Institute are now focusing on its use as a building material. As well as having excellent insulating properties, improving air quality, being able to soak up moisture and protect from radiation, biochar also allows buildings to be turned into carbon sinks. Every ton of biochar used in a building’s envelope means that the equivalent of more or less one ton of CO_2 is prevented from re-entering the atmosphere.

1.3 SCOPE OF THE PROJECT

Biochar is produced from plants, has no toxic effects and can be recycled at the end of its lifetime as a valuable soil conditioner. This means that whole cities could become carbon sinks and, at the end of several centuries, returned to nature in the form of compost. Instead of having to use special landfill sites for getting rid of contaminated building materials, we could be growing on the remains of demolished houses. Besides, Biochar is an ingredient that is eco-friendly. The structure from bio-char is also having greater positive influence in Environmental issue. If we can use bio-char as replacement for fine materials in building construction we may bring diversification in a good way.

Chapter – 02

Literature review

2.1 GENERAL

The history of biochar dates back 2,000 years to a civilization in the Amazon Basin where extensive regions of dark, highly fertile soil known as terra preta – Portuguese for "black earth" – have been discovered and analyzed, revealing high concentrations of charcoal and organic matter, such as plant and animal remains. Found only within inhabited areas, the presence of terra preta indicates that humans were deliberately responsible for its creation. Soil scientists theorize the ancient Amazonians used a "slash-and-char" process to develop this rich soil. With slash-and-char, plant material or crop remains were cut, ignited, and buried to smolder (rather than burn), which eventually produced char, now commonly referred to as "biochar" or "agrichar". This process isolated most of the carbon in the vegetation, creating a particularly hospitable amendment, which in turn nurtured beneficial micro-organisms that transformed the degraded soil to extremely rich and stable humus. For centuries the slash-and-char technique produced the fertile soil – often referred to as the "Secret of El Dorado" – that supported the agricultural needs of the Amazonians, which in turn, enabled their numbers to grow by the millions. From this ancient method modern scientists have developed the technology for producing biochar as a means to improve today's soil quality, store carbon, and generate renewable energy. Now it's a researchable branch of knowledge studies in engineering materials.

2.2 BIOCHAR

A solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment (Pyrolysis process). It is a 2000 year old practice to improve soil and it is found in soils around the world as a result of vegetation fires and historic soil management practices. Biochar was also used in the past in agriculture. Terra Preta soils in the Amazon are among the most prominent examples of human enriched soils.

Simply put, biochar is a highly adsorbent, specially-produced charcoal originally used as a soil amendment. Scientists theorize biochar was first used in the Amazon Basin thousands of years ago where extensive regions of dark, highly fertile soil known as terra preta were discovered, revealing high concentrations of biochar and organic matter.

Similar to charcoal, biochar is produced using the ancient practice of heating wood or other plant material (biomass) with little to no oxygen. However, unlike charcoal, which is often used for cooking, biochar is made under specific conditions with the intent to be applied to soil as a means to increase soil fertility and agricultural yields, and sequester carbon to reverse global warming. Other market uses of biochar are being discovered regularly as universities conduct extensive research into this versatile material and its cation exchange properties.

Biochar is thought to be the key component in a carbon-negative strategy to resolve several critical current ecological and energy challenges. Biochar is produced by pyrolysis, a process in which biomass is heated in an oxygen-deprived environment to break down into simpler substances. There are two types of pyrolysis: fast and slow. Fast pyrolysis uses moderate to high temperatures and rapid heating of wood chips while slow pyrolysis is characterized by gradual heating over a wide range of temperatures to produces its biochar. Biochar now uses slow pyrolysis to permit various wood sizes, moistures and nature's anomalies to be slowly processed into consistent, high quality biochar.

Fig 2.1: Biochar

2.3 BIOCHAR VS CHARCOAL

In order to be called biochar, it must be suitable (and therefore safe) for use in soil. Commercial charcoal is not going to necessarily be good for use in soil. Some of it may be. Some of it may not be. Charcoal is also chemically different from biochar. Biochar contains high fixed carbon content, minimal tars and a high surface area (giving lots of space for microorganisms to create their homes)—thus making it far more porous than charcoal.

2.4 IMPORTANT PROPERTIES OF BIOCHAR

- **Greater Surface Area:** The long pores provide significant surface area. As a matter of fact, 1 gram of BN biochar has a surface area of about 400 m^2.
- **Nutrients Receptacle**: Biochar has a cation exchange capacity that electrostatically attracts certain types of molecules including Nitrogen and Phosphorus nutrients in the soil, air and/or water. The molecules are lightly bonded to the biochar walls where roots can access them throughout the growing season. The biochar becomes a nutrient-rich, time-release capsule for plants and is a major reason why biochar is so effective enhancing plant growth.
- **Water Sequestrainer**: Biochar has been tested for water sequestration and found to hold 5.6 times its weight in water. And, because the pores are very long compared with their openings, there is very little evaporation. When roots do not consume the sequestered water, it is held for long periods of time.
- **Increase microbial growth in Soil:** To soil microbes, cleaned out biochar pores look like a concrete condominium. So they move in to set up family and community. Once embedded, they are protected from precipitation that would otherwise disperse them. With biochar, microbes flourish and help create living soil.

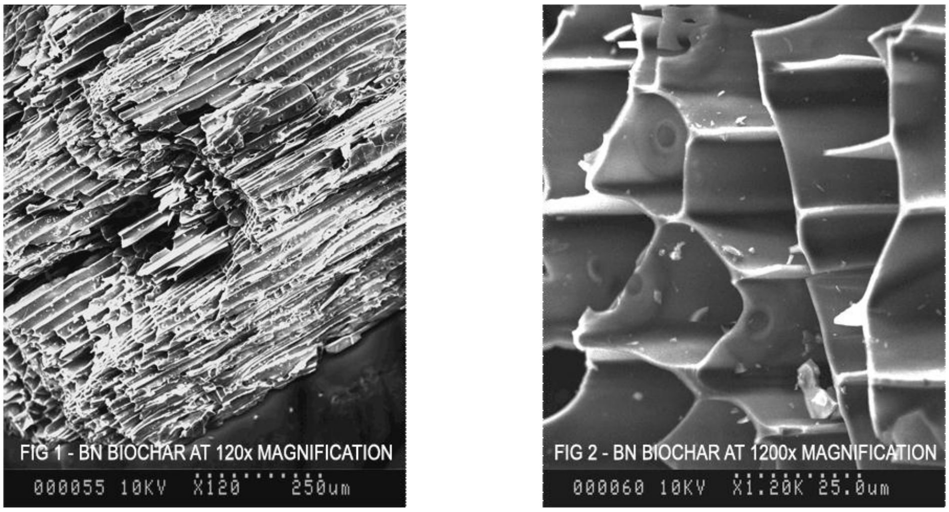


Fig 2.2: Microscopic view of biochar

- **Microstructure:** During the pyrolysis reaction of the biomass that results in bio-char, the yield rates ofbio-oil, bio-char, and syngas are affected by the type of feedstock and operating conditions, as seen in Fig 2.3. The processing temperature also affects the carbon content of bio-char, in that the temperature is inversely related to the yield of bio-char, increasing from 56% to 93% between 300 and 800°C. Any further increase in temperature or reaction time decreases the bio-char yield without increasing its carbon content (this is due to an increase in ash). The typical microstructure of bio-char is a highly micro-porous cellular/irregular structure, which explains its high specific surface area. The macro-pore structure (mm scale) of bio-char produced from biomass inherits its architecture from the feedstock and is an important factor for its adsorption. In concrete mixtures, this porous structure and high carbon content in bio-char demands much water, which affects the workability of concrete.

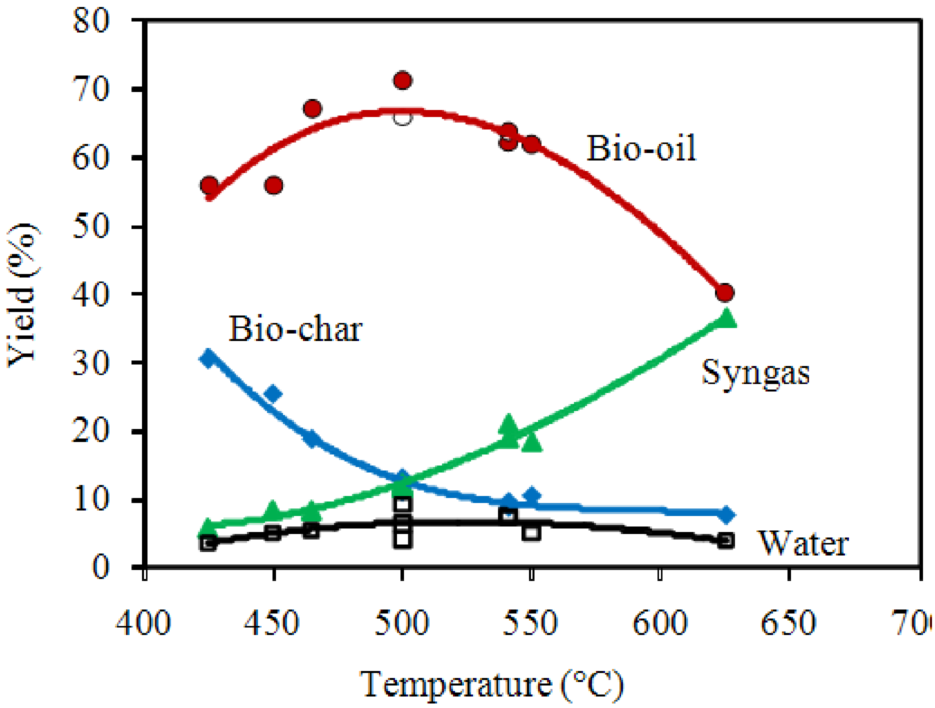


Fig 2.3: Relative proportion of products from fast pyrolysis of biomass

- **Self-curing:** The absorbed water in bio-char, however, does not bond chemically with carbon so that the absorbed water would be released during the hydration procedure, which may aid the hydration process during the early age of the concrete. Furthermore, this water retention capacity of bio-char provides good curing conditions for concrete and helps to develop the concrete microstructure and pore structure such that it also improves the concrete's durability and material properties. The water retention capacity of bio-char also reduces water evaporation from the concrete, which reduces both the plastic shrinkage and drying shrinkage of the concrete. This concept is similar to that of a self-curing agent in concrete.

2.5 CHEMICAL COMPOSITION OF BIOCHAR

The typical chemical components of bio-char, as obtained from switchgrass, hardwood, rice husk ash (RHA) and coal fly ash with high lime content (Class F) and low lime content (Class C), are compared in Table 2.1.

Table 2.1: Chemical compositions (% by mass)

Element	Switch-grass F.P. char	Hardwood char	Rice Husk ash	Fly Ash Class F	Fly Ash Class C
Al_2O_3	0.49	0.6	0.4	25.8	16.7
CaO	3.65	22.37	0.9	8.7	24.3
Cl	0.47	0.03	-	-	-
Fe_2O_3	0.76	2.36	0.5	6.9	5.8
$Na_2O + K_2O$	6.07	1.41	1.8	0.6	1.3
MgO	1.55	0.48	-	1.8	4.6
MnO	0.15	0.83	-	-	-
P_2O_5	3.86	0.2	-	-	-
SiO_2	43.62	5.67	82.6	54.9	39.9
SO_3	0.99	0.27	0.1	0.6	1.3
Other	0.25	0.51	-	-	-
Total	61.86	34.73	86.3	99.3	93.9

The chemical components of bio-char indicate a possible application as a supplementary cementitious material. In the case of switch grass char, the amount of silica (SiO_2) is 43.63%, which is close to that of Class F fly ash. The major acidic oxides (SiO_2 + Al_2O_3 + Fe_2O_3) are close to 50%, which is the minimum requirement for pozzolanic activity in accordance with ASTM C618, as shown in Table 2.2. While the amount of silica in hardwood char is below for the pozzolanic activity. It may be inappropriate for the cement substitute.

The magnesium oxide content is 1.55% and 0.48% in the switch-grass and hardwood char, respectively. These percentages satisfy the required value of 5% maximum.

The LOI of bio-char obtained from switch-grass ranges from 5% to 35%. These values are more than the 10% maximum as required for pozzolans, which means that the bio-char contains carbon that reduces the pozzolanic activity of the char. The carbon itself is not pozzolanic, and its presence serves as filler to the mixture. Cordeiro and et al. have confirmed that RHA with high LOI could be used successfully as a supplementary cementitious material in concrete due to its high content (over 80%) of silica.

Table 2.2: Chemical requirements of coal, fly ash, raw or calcined natural pozzalon for use in concrete (ASTM C618-08a)

Component	Class N	Class F	Class C
$SiO_2 + Al_2O_3 + Fe_2O_3$, min, (%)	70	70	50
SO_3 , max, (%)	4	5	5
Moisture content, max, (%)	3	3	3
Loss of ignition, (LOI), max, (%)	1	6	6

Here, in our research purpose, we use Rice Husk to produce biochar as a replacement of cement, as it is close to switch-grass which is recommended regarding the above context.

2.6 ADVANTAGES & DISADVANTAGES OF BIOCHAR ADDITION IN CONCRETE

- **Water Retention Capacity:** Mortar mixes that include bio-char exhibit better water retention than mixes that do not contain bio-char.
- **Workability:** Uses of bio-char in mortar mixes decreases flow of mixes. Thus, also decrease workability.
- **Compressive Strength:** By using bio-char within a limit compressive strength can be increased.
- **Fire Resistance**: Researchers claim that biochar mixed concrete are more fire resistant than normal concrete.
- **Temperature & Humidity:** The structure which is built by bio-char contains moisture. For this reason the pore of the divider/wall of structure is fill-up by moisture, which control temperature & humidity of inner side.
- **Carbon Sequester:** Biochar is referred to as “carbon-negative” because it has the potential to sequester more carbon than is produced. During pyrolysis, approximately 50% of the biomass’ carbon content is held by the biochar, compared to 10-20% that remains in biomass after 5-10 years of natural decomposition. When biochar is added to soil, the carbon is sequestered for centuries, thereby reducing atmospheric carbon dioxide. Biochar also improves soil fertility, thereby enhancing plant growth which absorbs more carbon dioxide from the atmosphere.
- **Reduction in Greenhouse Gas Emission:** Biochar also retains nitrogen, thereby reducing emissions of another alarming greenhouse gas, nitrous oxide. Research indicates that biochar-amended soils can provide anywhere from 50-80% reduction in nitrous oxide emissions, which is significant considering that the nitrous oxide released from certain fertilizers is 310 times more potent than an equal amount of carbon dioxide. Turning agricultural and forestry waste into biochar also reduces methane generated by natural decomposition.

2.7 APPLICATION OF BIOCHAR

2.7.1 Present Application

- **Biochar in soil for agricultural purpose:** Adding biochar to soil has environmental and agricultural potential due to its long-term carbon sequestration capacity and its ability to improve crop productivity. Recent studies have revealed that soil-applied biochar flourish the systemic resistance of plants to several prominent foliar pathogens. Biochar enhances soils. By converting agricultural waste into a powerful soil enhancer that holds carbon and makes soils more fertile, we can aid food security, discourage deforestation and preserve cropland diversity. Research is now confirming benefits that include:-
  - Reduced leaching of nitrogen into ground water
  - Possible reduced emissions of nitrous oxide
  - Increased cation-exchange capacity resulting in improved soil fertility
  - Moderating of soil acidity
  - Increased water retention
  - Increased number of beneficial soil microbes

  Biochar can improve almost any soil. Areas with low rainfall or nutrient-poor soils will most likely see the largest impact from addition of biochar.

- **To increase water holding capacity of soil :** In recent years global population is increasing day by day and increased agricultural requirements comes an increasing need for freshwater. Currently, it is estimated that approximately 75% of fresh water consumption is for the growth of agricultural crops, and only 10% to 30% of this water is actually made available to plants. It is widely accepted that farming practices which rely heavily on chemical fertilizers and unsustainable land management practices have led in many regions to infertile sandy soils with reduced water holding capacity and insufficient amounts of organic matter. Combined with increasing global population, the need to better manage fresh water use, particularly agricultural usage, is paramount. The use of biochar as a soil refitment has been suggested as a way to increase water holding capacity, but only limited quantitative studies exist in terms of the effectiveness of biochar in increasing a soil's water holding capacity. High percentage mixtures of biochar increase water holding capacity dramatically. These results suggest the use of biochar has potential to mitigate drought and increase crop yields in loamy sand soil.

2.7.2 Our Aimed Application

- **Bio-char as a Building Material:** Biochar based building material offers the possibility of carbon negative construction in addition to a slew of other unique and promising properties. The first building using this material was built in 2013 at the **Ithaka Institute in Switzerland** and is currently undergoing extensive performance testing. Already though, the building has proven to be highly insulated with great humidity control. Two of Biochar’s key properties are:-
  1. Low thermal conductivity
  2. Ability to absorb water up to 5 times its weight
  3. Biochar-clay plasters adsorb smells and toxins, a welcome property in kitchens and for smokers.

Fig 2.4: Biochar-Clay plaster used in Ithaka Institute

These properties mean that biochar is just the right material for insulating buildings and regulating humidity. Through the use of biochar-based insulation material, houses can become very long-term carbon sinks, while at the same time providing healthier indoor climate. And should such a house be demolished at a later date, the biochar-clay or biochar-lime plaster can be directly used as a compost supplement, thus continuing the carbon cycle in a natural way.

Green building materials with Biochar:

1. **Biochar-Clay plaster:** Positive effects of biochar plaster -
   - ✓ Humidity regulation
   - ✓ Insulation
   - ✓ Noise protection
   - ✓ Deodorant
   - ✓ Aesthetic
   - ✓ Anti-bacterial, fungicide
   - ✓ Binding of toxins (volatile organic compounds)
   - ✓ Protection against electromagnetic radiation
   - ✓ Less electrostatic charging
   - ✓ Conservation of wood
   - ✓ Less dust (mites!)
   - ✓ Air-cleaning

2. **Biochar-Mud plaster for living quarters:**
   Biochar-mud plaster can also be applied to walls made of plasterboard, as well as being used in more massive walls or for plastering over a wall heating system. The latter aspect is of particular interest, as wall heating systems provide very high levels of comfort, with the biochar-clay plaster acting as thermal storage, slowly radiating it's warmth into the room. It is well suited for timber-framed walls as the biochar–clay excels in wood conservation.

Fig 2.5: Biochar wall (white-painted) does not need to be black

3. **Biochar-Clay plaster for wine cellars:**
The walls of an old Valais wine cellar were sprayed with a 10 cm thick layer of clay and biochar. This massive wall coating provides not only good thermal insulation and consequently lower temperature fluctuation, but is also a great humidity regulator. At higher humidity levels, the walls quickly adsorb moisture, returning it to the room just as quickly when humidity levels drop. While too high a level of humidity promotes the development of harmful microbes, too low a level is also not desirable, as it leads to particulate pollution, electrostatic charging of the air and the evaporation of wine in wooden barrels. It creates an ideal environment for wine making.

Fig 2.6: Biochar-Clay plaster in wine cellar

4. **Biochar-Brick and Concrete:**
There are many advantages of using the Biochar as a component in Green Buildings for clean indoor air. Biochar can remain for up to 1000 years and more in the soils. Biochar found in earth walls of over 100 years old, is still intact. Biochar can be mixed in different proportions with sand / cement / earth / other suitable material to produce bricks / panels / blocks. The percentage Biochar in different products can be decided based on the purpose and product properties. Biochar use makes the building walls light and insulate.

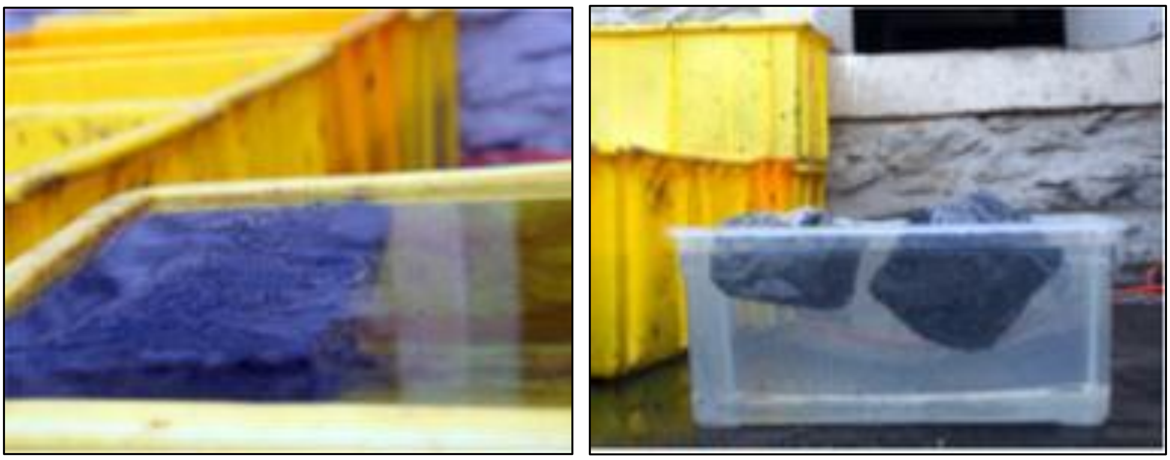


Fig 2.7: Biochar-Bricks are so light that they swim

Fig 2.8: Normal Brick & Biochar-Brick

Uses of Biochar-Brick:

- Around plants and path ways
- In construction of buildings, especially inside walls and higher walls
- Even when the building is demolished, the biochar would benefit the soil.
- Ideal for bed room to reduce obnoxious smell.

Three types of Biochar-Brick:

- Cement: 3 kgs
  Rice husk
  biochar:6 kgs
- Sand: 14 kgs
  Rice husk
  biochar:2.5 kgs
  Cement: 2 kgs
- Sand : 14 kgs
  Rice husk
  biochar:1 kg
  Cement: 1 kg

Dimensions of each brick: 11.5 x 7.5 x 6 inches
Note: The rice husk bio-char is saturated with water.

2.7.3 Furure Possible Application

- We know that bio-char can be turned into fine particle & Fine particle can contain more moisture than large particle. For concrete curing purpose we need water for duration. This biochar can hold water for long period. So, in future it may be a possible application to use it in curing.

- In this research we concentered on bio-char mortar to apply as plaster. But it’s a greater opportunity to use bio-char in concrete, especially in column, beam, and pier. Here bio-char use in pier will be a marvelous task as pier remains under water & bio-char mold is more effective in compressive strength in water. The more we hold bio-char specimen in water, the more it will gain strength.

Chapter – 03

Methodology

3.1 GENERAL

Cement is one of the most commonly used construction materials. In United States, cement is responsible for nearly 1% of all CO_2 that is emitted. As is well known, the emission of CO_2 contributes to greenhouse gas (GHG) effect, and therefore, many countries are trying to reduce CO_2 emissions in order to mitigate the negative environmental consequences. One possible solution is development of carbon sequestration in concrete and /or concrete admixtures. Therefore, this sequestration process using biochar would reduce the release of CO_2 back into the atmosphere when the carbon is stored in the soil. Biochar can be used as a carbon sequestration agent in concrete and/or as a self-curing agent.

3.2 MANUFACTURING PROCESS OF BIOCHAR

3.2.1 Available Method

3.2.1.1 Carbon-Zero Experimental Biochar Kiln

I. A simple closed retort kiln is constructed using an insulated firebrick enclosure designed for a 200 liter dry-goods steel barrel with a clamp-on cover as a retort. Operation of the kiln is relatively simple. Insert the barrel / retort into the fire brick enclosure. Fill it with dry wood or other dry biomass. Insert the temperature probes into the barrel so you can monitor the progress of the reaction. Cover it and place the afterburner on top, ready to go. Place a few sticks of wood under the retort and set them alight.

Fig 3.1: Carbon-zero experimental biochar kiln

II. It can take as little as 15 minutes to bring temperatures up above 300°C to initiate pyrolysis if the feedstock is bone dry, and as much as 2 hours or more if it is somewhat moist. At some point, the heat given off by the thermal reaction occurring inside the retort will be enough to sustain the process, and you can let the flames die out underneath the barrel. Again, this is highly dependent on the moisture content of the feedstock. Use the temperature probes to guide you. If you see the temperature rapidly falling below 320°C or so, add more wood to the fire under the barrel. If you see the temperature holds above 320°C, likely in a range between 360° and 440°C, then the reaction has become self-sustaining and you don't need more wood.

III. Once temperatures in the retort approach the pyrolysis zone, a significant amount of smoke will begin to emanate from the hole in the center of the cover. Light the afterburner and keep the flame maintained. When the afterburner flame goes out on its own and very little smoke remains, the batch is done.

IV. Carefully remove the barrel if you are going to immediately run another batch. Keep your nose and face away in case the char lights on fire if you remove the cover. 2 people and some sturdy heat resistant gloves may be necessary. A bit of engineering resourcefulness and some handles that catch to the outside of the barrel on some latch or hook welded to the outside would be better. And either quench and/or cover the barrel so the char doesn't burst into flames.

Note: A word of warning. It is possible to get burned doing this if you are not careful, so think things through carefully and make sure you are prepared for each step before proceeding to make bio-char in this, or in fact any way.

Advantages:

- ✓ We can control to a significant degree the temperature of the pyrolysis reaction because of the closed retort.
- ✓ The firebrick enclosure retains and refracts a significant amount of heat, enabling the use of much less wood to drive the reaction.

3.2.1.2 A Two-Barrel Charcoal Retort

I. Two metal barrels, the larger about 20 cm (8 in) wider and 10 cm (4 in) higher than the smaller vessel. In the larger one you make air intakes some centimeters (about 1 in) from the bottom that allows an ample amount of air intake. The smaller vessel, you do nothing with.

II. Fill the smaller vessel with biomass, preferably dry to make the charring procedure more efficient. Use chips, dry grass, bamboo or Miscanthus stalks, twigs, sawdust or what you have. Even some hard bones are good to put in. Put the material in as tight as possible.

Fig 3.2: Two metal barrels

Fig 3.3: Fill the smaller vessel with biomass

III. Fill the vessel level with the top. It will be placed upside down.

IV. Put the filled vessel on a pair of bricks to make the next step easier.

V. Put the larger drum upside down on top of the smaller vessel, so the bottom of the drum fits close to the top of the biomass filled vessel.

VI. Hold the inner vessel tight to the bottom of the larger when turning it back so the content doesn't spill out. When you have done that, the smaller vessel stands upside down in the larger. No lids, no fastening. (Although it could be fine with some cover, just to keep the material inside the vessel when turning).

Fig 3.4: Vessel placed on a pair of bricks

Fig 3.5: Barrel placing

VII. Put dry firewood in the space between the two vessels (and some on top). Light it. Replenish the fire Wood, so it burns at least 30-40 minutes.

Fig 3.6: Burn the wood placed in the outer barrel

VIII. After 30-40 minutes, the pyrolysis of the biomass starts. The gases will emerge from the vessel through the chink between the vessel and the barrel and immediately take fire and heat the vessel more, so more gases emerge, and so on. It is easy to see when this happens. To be sure that all the pyrolysis gases take fire, be sure that the air inlets really gives an excess of air, and the passage between the vessel and the jar is long enough (if it takes 1 second, you are on the safe side). Otherwise, the fire will smoke and powerful greenhouse gases will emerge into the atmosphere.

IX. After about half an hour, the fire will stop burning rather abruptly. At that time, there is (hopefully) only charcoal left in the vessel. Let it cool at least an hour. If you take hot charcoal into the air, it may catch fire.

X. When the vessel has cooled down, turn everything back again.

Fig 3.7: The fire itself has disappeared

Fig 3.8: Biochar is ready

3.2.1.3 Open Pit Method

In the beginning years of Hawaii Bio-char Products (pre-cursor to Pacific Bio-char) there were no fancy machines, only wood and sweat, lots of sweat. With a large supply of clean dry wood from local sawmills to play with, a technique that proved to be a very efficient way to transform wood into bio-char. Many different approaches were attempted, but the winning technique was the Open Pit Bio-char Burn. This technique is very similar to the Japanese cone kiln design that has become popular.

The concept is rather simple, but the details are important. It all began on flat ground. It grew into a pit to gain greater air control. Wood burns twice, once from wood to char, then from char to ash. The second part can only happen with oxygen. On flat ground the char produced during burning is hard to protect from oxygen entering from the sides. In a pit, the char is covered with more wood as it is produced.

Fig 3.9: Dig a pit, place wood and burn

I. First, a fire is started in the bottom of a pit, then dry wood is then added as fast as the fire will allow – you must always push the fire near to the point of smothering it, yet without actually smothering it. It is important to always keep a clean burning fire – no smoke. If it becomes a bit smoky, back off, let the fire catch up. If it is raging, add more wood to choke it out a bit. In this way you are constantly covering the char that has been made with fresh layers of wood, which become char, which are soon covered with fresh layers of wood, which become char, and so on. When you near the top of the pit or the end of your wood supply, you finish with small diameter wood. This chars quickly.

II. Let the flames die down a bit, then voila – a large bed of red hot glowing coals. By this point, if you have done it right, the entire pit has turned to char. You can either hose it down immediately, or cover it with soil to snuff it out, then uncover it a few days later and hose it down. Look to the pictures in the next page for a visual reference.

Fig 3.10: Wood has turned into char

3.2.1.4 Smoke Free Biochar Retort

Equipment:

- The bottom of the burner is made out of an old barbecue with holes drilled around base & top.
- The drum measures 9'' high by 11'' in diameter.
- The Bio-char is made in a barrel with clip on lid.
- The barrel measures 19'' high by 13'' in diameter.

Fig 3.11: Specified barrel for smoke free retort

Steps:

I. A hole has been cut in both ends to take a chimney. The chimney is made from stainless steel tube with holes drilled around one end. The holes allow the gases to escape and to be burnt.

Fig 3.12: Chimney

II. The chimney is put through the base of the barrel with the holes at the top. For this demonstration a variety of materials have been used to make bio-char as an illustration of what can be charred.

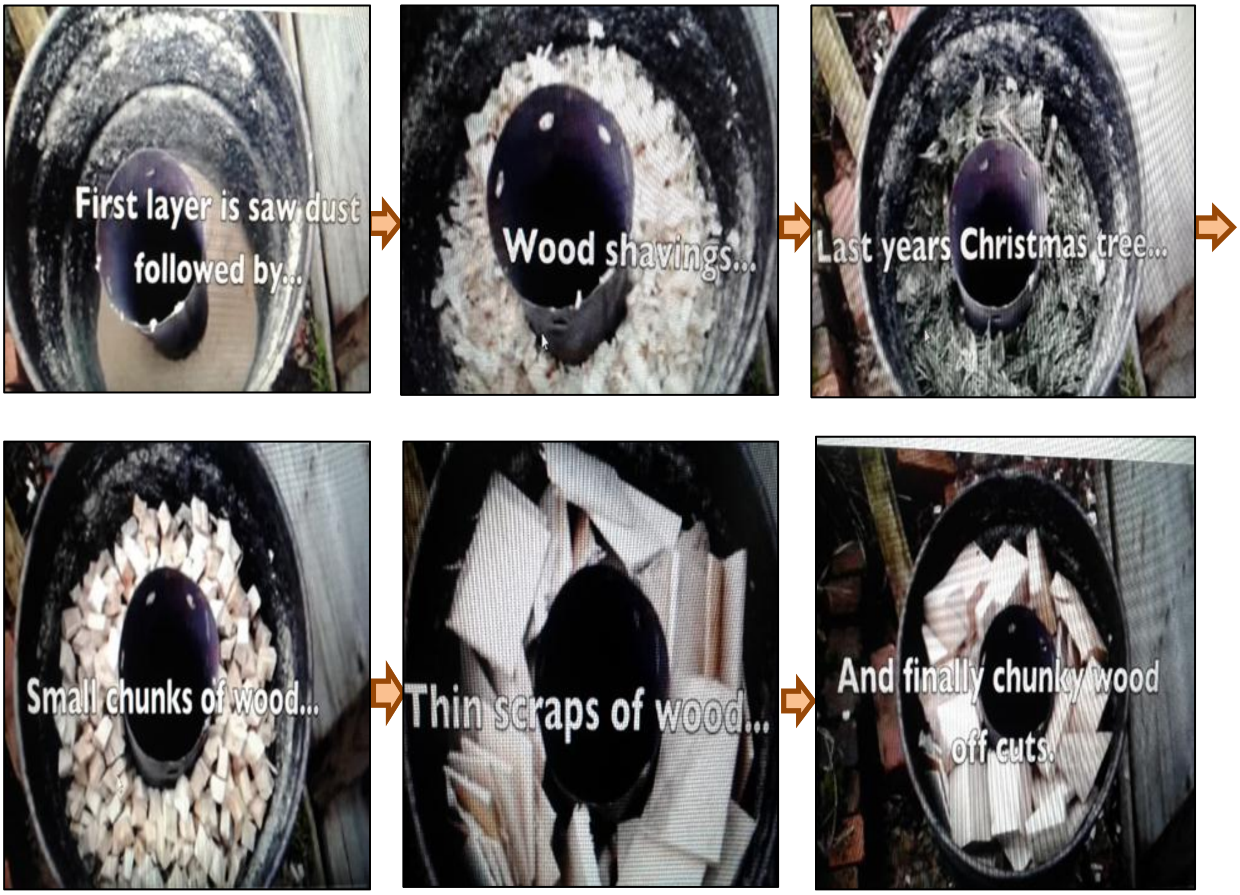


Fig 3.13: Different biomass placed between the gap

III. Then the lid is put on and the barrel scaled, ready to be fired up. Firing the Bio-char burner. A fire is started in the small drum.

IV. The scaled barrel is then put upside down on top of the small drum. (Holes in the chimney to the bottom).

Fig 3.14: Light the fire at the bottom and smoke will appear initially

V. At first there is a fair amount of smoke until it heats up. As the large barrel heats up the wood starts to gasify and large flames start come out of the chimney.

VI. Now there is virtually no smoke being given off. If it is windy a small chimney with holes around the top is used to help keep the smoke to a minimum fuel can be added either from the hatch in the small drum or down the chimney.

Fig 3.15: Smoke gone and large flame appear

VII. Keep slowly adding the fuel to maintain a constant temperature.

VIII. You will see flames coming out of the holes at the bottom of the chimney. These are the gasses being burnt off from the wood in the barrel.

IX. When the flames stop coming out of the holes all the wood has finished charring. When all the contents have been turned to bio-char the barrel needs to be scaled to prevent the bio-char from spontaneous combustion.

X. The base of the barrel is buried in a shallow hole and the top scaled with more soil & left to cool.

Fig 3.16: Top of the barrel filled with soil to prevent spontaneous combustion

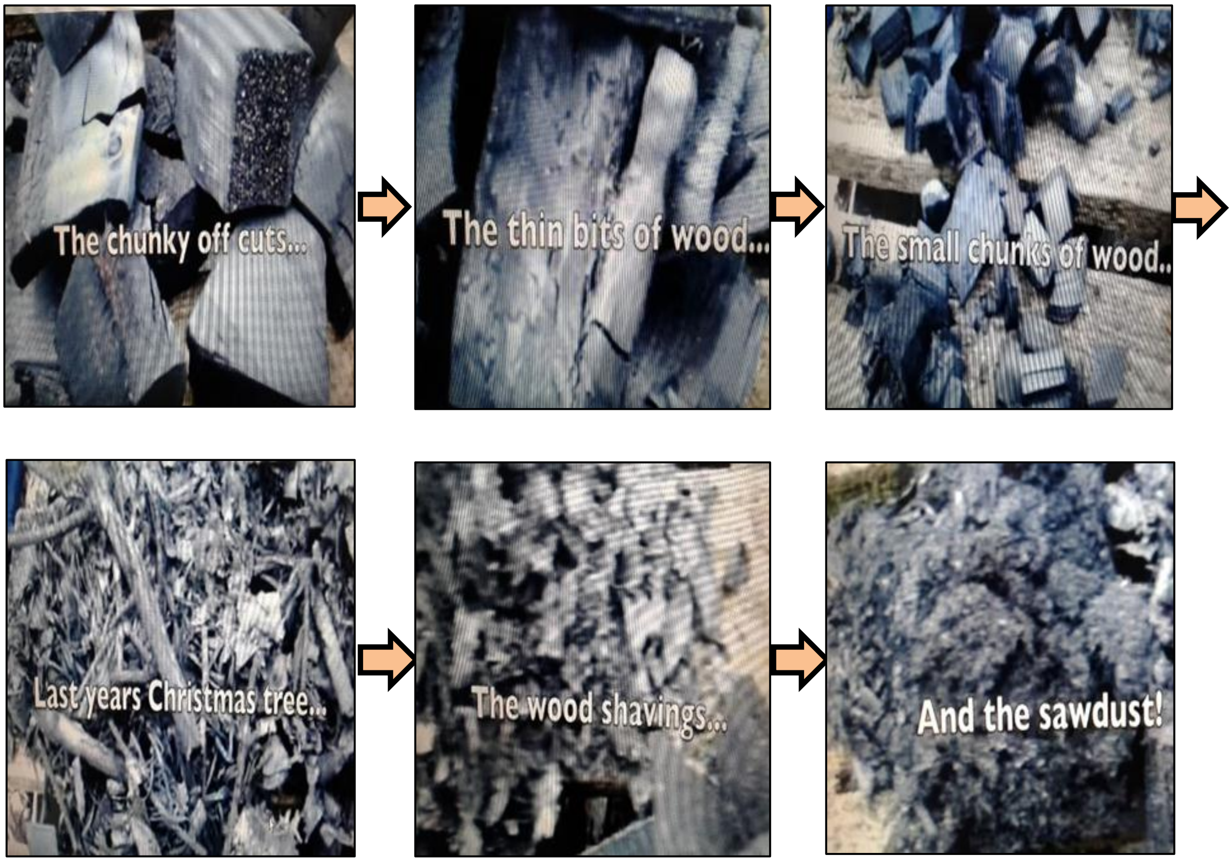


Fig 3.17: Different biochar got from different biomass

3.2.1.5 Rice Hull Biochar

I. Pick a fairly level spot that can be scorched and has access to water.

Fig 3.18: A barrel, rice hull and hood

II. The mechanics of it are simple. The fire under the hood pushes the hot air & smoke up the chimney. Air is pulled down through the rice hulls to the hood. Meanwhile, the hulls in contact with the hood begin to char, consuming the oxygen. As the burn zone works its way out, the inner layer has no more oxygen, & can't burn to ash. Thus biochar is produced.

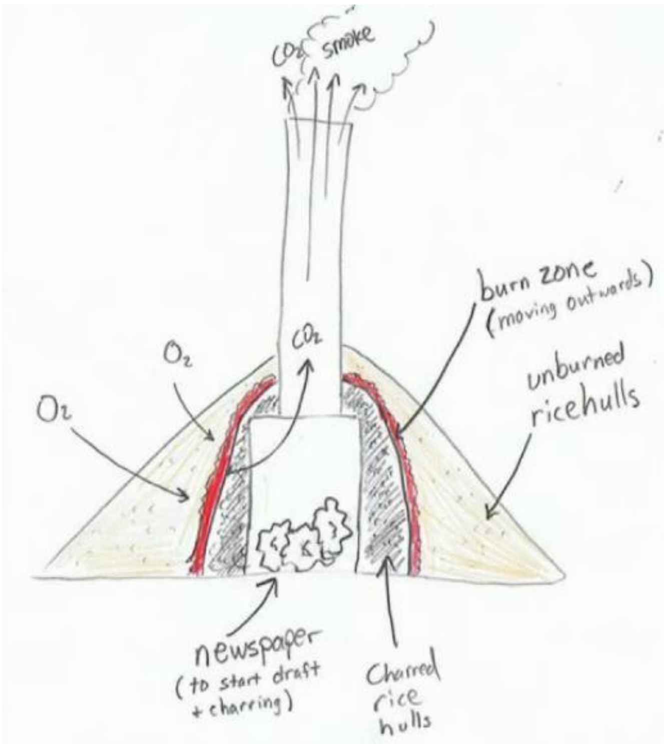


Fig 3.19: A neat sketch describing the working principle

III. Put the tinder (card-board is fine) in the bottom of the barrel & light it.

IV. Drop the biochar hood over the burning tinder.

Fig 3.20: Place tinder and then hood over it

V. Pour some rice hulls around the hood. Try not to put them into the middle.

VI. Then put on the chimney. The draft caused by the addition of the chimney will really get the cardboard burning furiously.

VII. Add more rice hulls as much as you can, sloping up towards the chimney. They will lose a lot of volume by the end.

Fig 3.21: Pour rice hull around the hood & add a chimney

VIII. Now it really starts smoking. This is still the beginning, it gets much smokier later. Charring around the chimney.

Fig 3.22: Chimney is heated and charring the hull around

IX. About an hour later here still lots of smoke, but most hulls are charred.

Fig 3.23: Finally all rice hull is charred

X. Time to pull the hood out & put out the embers with water.

3.2.2 Our Chosen Method

Open Pit Method

Aluminum pot Method

(Absence of oxygen inside the pot)

3.2.2.1 Open Pit Method

We first try to make biochar by open pit method. We dug a gently sloping hole to prevent the oxygen burning. Put the material into the hole, fire them up and wait till the grey gas starts to emit. Then we put a wetted sack onto it and cover the hole by soil, wait to cool down.

Fig 3.24: Dig a hole and light fire

Fig 3.25: Separate biochar from the fully burnt

3.2.2.2 Aluminum Pot Method

Then we try another method. We simply put the dry biomass (coconut fiber, wood chips, wood blocks, rice husk) in an aluminium pot and cover the pot with a lid to prevent the oxygen going inside the pot and put the pot on oven. First the white smoke created that is actually the moisture evaporating from the biomass and after about 10 minutes the grey smoke starts to emit. The grey smoke creates when the carbon in the biomass is burnt. So we stop heating the pot when the grey smoke starts to emit. We wait to cool down the biomass and the pot with the lid on it. When it has cooled down, we grind the biochar into fine particle.

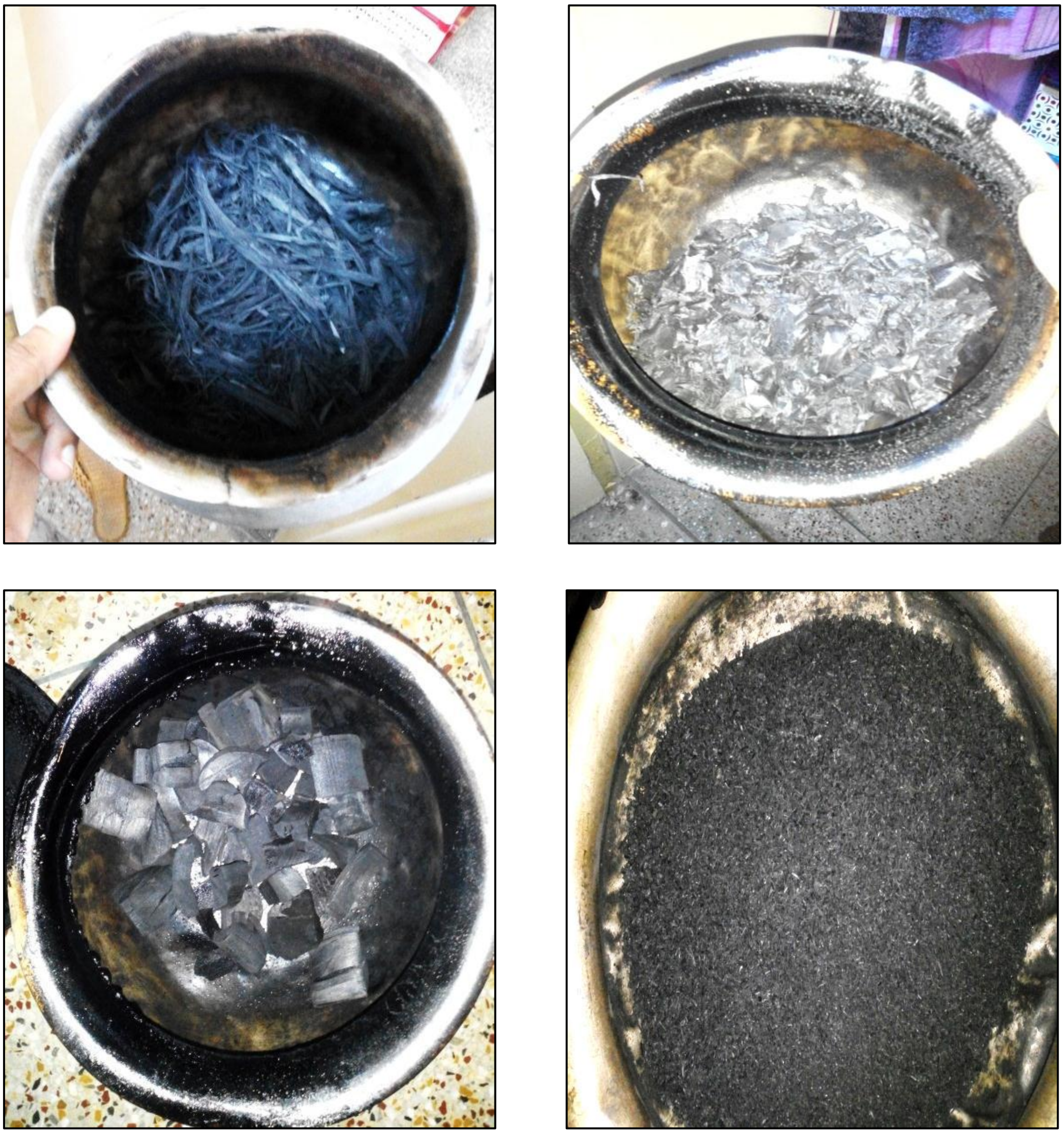


Fig 3.26: Biochar made from coconut fiber, wood chips, wood blocks and rice husk

3.3 WATER HOLDING CAPACITY TEST OF BIOCHAR

Tested materials:

- Biochar of Coconut Fiber
- Biochar of Wood Chips
- Mixture of Biochar(coconut fiber) & natural coconut fiber
- Only natural coconut fiber

3.3.1 Testing

<u>Equipment</u>: Funnel, Measuring Cylinder, Beaker, Filter Paper.

<u>Procedure</u>:

I. We measure 15g of each material (dry) and 50mL of water for each material testing.

Fig 3.27: Measure the materials

II. Place a filter paper on the funnel and put the funnel over a measuring cylinder.

III. Pour 50mL of water into the material filled funnel and wait till the last drop of water falls about 1hr ago.

Fig 3.28: Pour water and wait

IV. Measure the water deposited in the measuring cylinder and calculate the water holding capacity of each material by volume basis.

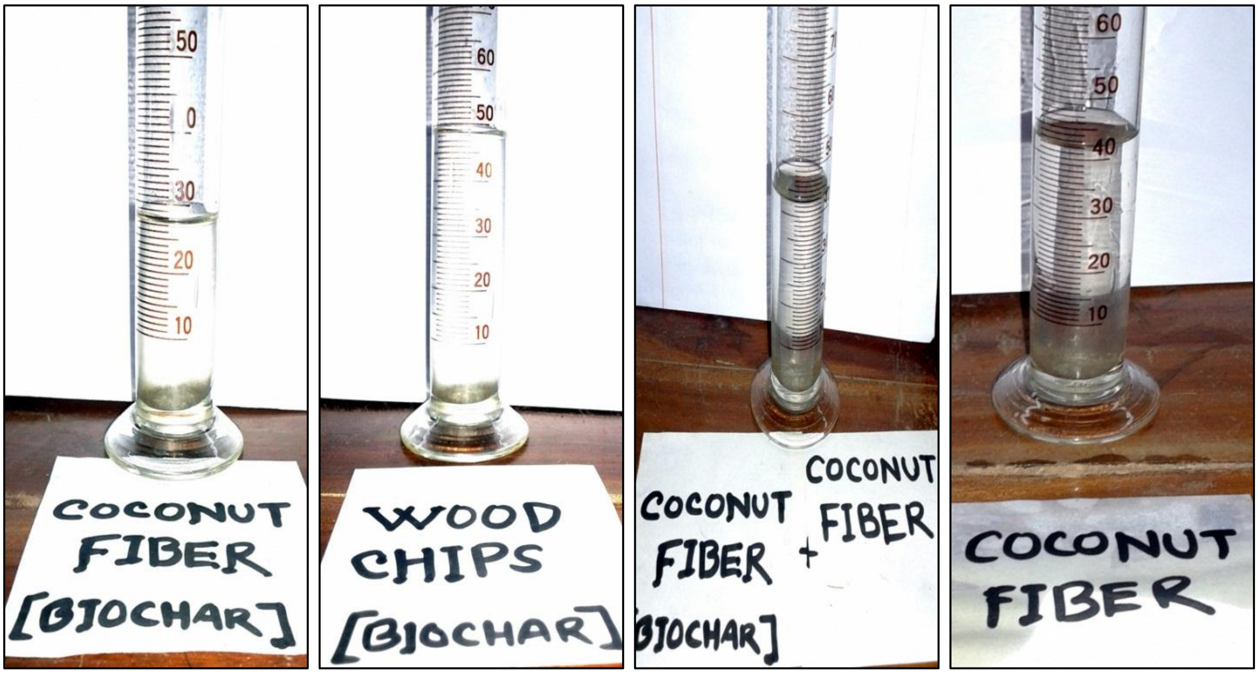


Fig 3.29: Measure the water deposited

Result:

Table 3.1: Determination of water holding capacity of different materials

Materials	Water Deposited in the Measuring Cylinder (mL)	Water Retained by the material (mL)	Water Holding Capacity (% of total water Volume)
Coconut Fiber (Biochar)	29	(50-29)=21	42
Wood Chips (Biochar)	49	(50-49)=01	2
Mix Coconut Fiber (Biochar + Natural) (50% + 50%)	42	(50-42)=08	16
Coconut Fiber (Only Natural)	43	(50-43)=07	14

3.3.2 Result Summary

First we have tested the water holding capacity of biochar from three different types of material (Coconut, Wood Chips & Wood Blocks). Among the three biochars, we took the biochar having the most water holding capacity (Biochar of Coconut Fiber=42%) and mixed it with the natural coconut fiber and tested the mixture. Comparing the result with the natural coconut fiber, we found actually there is no difference if we use the mixture or the only natural coconut fiber. Here we have prepared the mixture by 1:1 ratio. If we increase the biochar content of the mixture, there may be an increase in the water holding capacity of the mixture.

3.4 DETERMINATION OF MECHANICAL PROPERTIES OF BIOCHAR MIXED MORTAR

In this study, mechanical properties (e.g. compressive strength, concrete weight loss, mortar flow) of biochar mixed mortar are examined using sample mixes varying the replacement rate of biochar.

3.4.1 Replacement of Mortar Ingredients by Biochar

Mortar is a mixture of cement, sand & water. We can replace cement or sand by biochar in mortar. Here we use biochar in mortar as **a replacement of cement**. In these mechanical tests, we have used biochar made from **rice husk** because it may have a cementious property.

3.4.2 Procedure of Different Mechanical Properties Test

Here we have mainly focused on three properties. They are examined by:-

- Compressive Strength Test
- Water retention/ Weight Loss Test
- Flow Test

3.4.2.1 Compressive Strength Test

This test method conforms to the ASTM standard requirements of specification C109. Mortar is a mixture of cement and sand in a specified ratio on which the strength of the mortar depends. If the mortar is weak then also its compressive strength is very low but if the mortar is a strong one then its compressive strength is also very high. Mortar is generally used for brick masonry and plastering.

Apparatus:

- Cube Mold
- Measuring Jar
- Mixing Pan
- Tamping Rod
- Trowel
- Testing Machine (UTM - Universal Testing Machine)

Materials:

- Fine aggregate (Sand)
- Cementing material (Cement & Biochar)
- Clean water

Sample Making Procedure:

1. At first wash the sand to remove debris from sand. Then oven dry the sand for 24hrs. Then sieve the sand.

Fig 3.30: Sieve the sand

2. Measure all the materials needed as per requirement to prepare a mixture of cement and sand having ratio of 1:2.75 (**According to ASTM standard C109**). That is one part of cement and 2.75 parts of graded standard sand by weight. We used 250g cement & 687.5g sand for making mortar samples without biochar. For 5% biochar mixed sample, we used 237.5g cement and 12.5g biochar **(as a replacement of cement)**. For 10% biochar mixed sample, we used 25g biochar and 225g cement. The amount to sand is 687.5g for all samples.

Fig 3.31: Measure the materials

3. We make a homogeneous mixture of dry ingredients by automatic mixing machine, and then add 135 mL water at a water/cement ratio of 0.54 to make a paste. The amount of water added is same for all samples.

Fig 3.32: Thoroughly mix the materials by automatic mixing machine

4. Place a layer of mortar about 1 in. (approximately one half of the depth of the mold) in all of the cube compartments. Lubricate the surface area of each mold compartment before placing the mortar.

Fig 3.33: Lubricate mold and place & compact the sample

5. Tamp the mortar in each cube compartment 32 times in about 10 sec in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen.

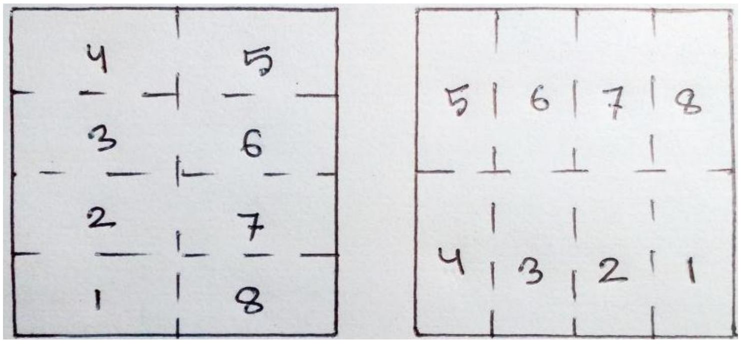


Fig 3.34: Tamping pattern

6. When the tamping of the first layer in all of the cube compartment is completed, fill the compartment with the remaining mortar & then tamp as specified for the first layer.
7. On completion of the tamping, the tops of all cubes should extend slightly above the top of the molds. Bring in the mortar that has been forced out onto the tops of the molds with a trowel & smooth off the cubes by drawing the flat side of the trowel one across the top of the each cube at right angles to the length of the mold.

Fig 3.35: Level the mixture with trowel

8. Immediately upon completion of molding, place the test specimens in the moist closet or moist room.

Fig 3.36: Casting & molding is complete

9. Keep all the test specimens, immediately after molding, in the molds on the base plates in the moist room from 20 to 24 hrs. With their upper surfaces exposed to the moist air but protected from crippling water.
10. After 24hrs we remove the mortar from mold and mark them on their top surface depending on their material proportion and curing condition.

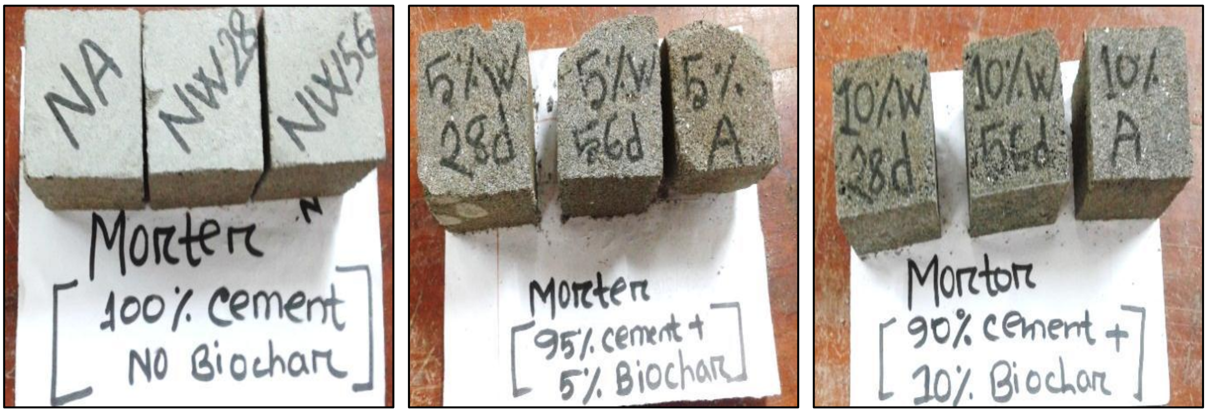


Fig 3.37: Mark the samples

11. Then we place some samples for air curing and some for water curing for specified period.

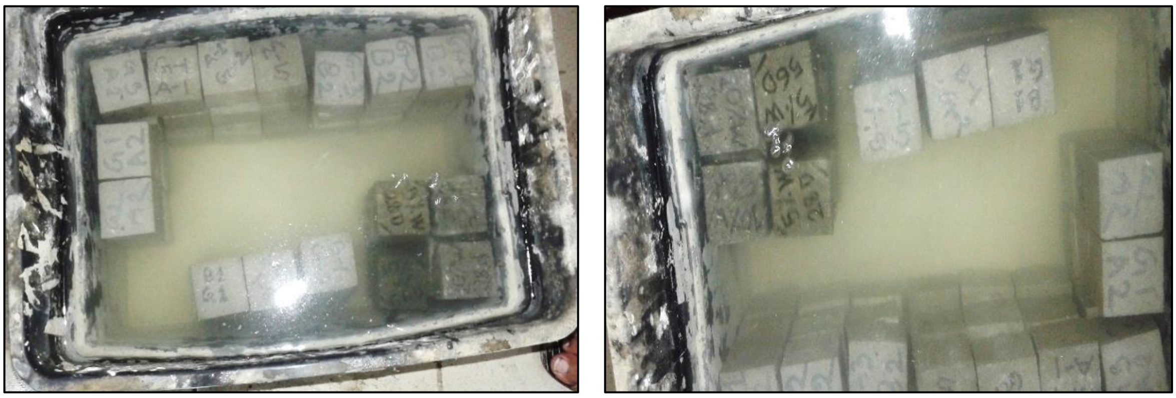


Fig 3.38: Samples are placed for water curing

Sample Testing Procedure:

1. All the test specimens for a given test age should be broken under compressive force within the permissible time tolerance.

Table 3.2: Permissible time tolerance

Test Age	Permissible Tolerance
24 hrs.	±1/2 hrs.
3 days	±1 hrs.
7 days	±3 hrs.
28 days	±12 hrs.

2. For water cured sample, the samples are taken out from water and allowed to dry for 24hrs before testing.
3. Measure the size of each sample before testing. Place the sample in UTM machine and apply loading.
4. Record the load at which the sample fails.

Fig 3.39: UTM machine, load applying and recording

Fig 3.40: Different cracking pattern

<u>Summary of Compressive Strength Test:</u>

Sieving

Measuring

Mixing

Lubricating

Placing & Tamping

Summary of Compressive Strength Test (Continued…..):

Leveling

Casting & Molding

Marking

Curing

Testing

Fig 3.41: Flow chart of compressive strength test

3.4.2.2 Water Retention / Weight Loss Test

Procedure:

1. To examine the water retention rate the weight loss was measured by filling containers made from PVC pipe with 4 in (100 mm) inside diameter & 5 in (125mm) height.
2. The bottom of the cylinder is sealed by slip-in connector which was glued to the pipe.

Fig 3.42: Make cylindrical mold

3. Measure all the materials needed as per requirement to prepare a mixture of cement and sand having ratio of 1:2.75. That is one part of cement and 2.75 parts of graded standard sand by weight. We used 580g cement & 1595g sand for making mortar samples without biochar. For 5% biochar mixed sample, we used 551g cement and 29g biochar **(as a replacement of cement)**. For 10% biochar mixed sample, we used 58g biochar and 522g cement. The amount to sand is 1595g for all samples.

Fig 3.43: Measure the materials

4. We make a homogeneous mixture of dry ingredients by manually, and then add 320 mL water at a water/cement ratio of 0.55 to make a paste. The amount of water added is same for all samples.

Fig 3.44: Mix the ingredients with water

5. The concrete was placed into the cylinder in a uniform fashion. Due to the 5 in height of the cylinder the, concrete was put into the cylinder in three layers. First the cylinder was filled roughly halfway, then the concrete mix was tamped with a tamping rod 25 times per layer.

Fig 3.45: Sample Placing & Tamping

6. The cylinder then was filled to the top, tamped down, filled again to the top, & then smoothed with a trowel.
7. Once all the mixes were made, the initial weights were recorded immediately after mixing.

Fig 3.46: Sample is ready to measure weight

8. Then the weights were recorded in the following intervals: 1 hr, 2 hrs, 3 hrs, 5 hrs, 1 day, 3 days, 7 days, 10 days, 14 days, 20 days, 31 days, 39 days, and 49 days.

Summary of Weight Loss / Water Retention Test:

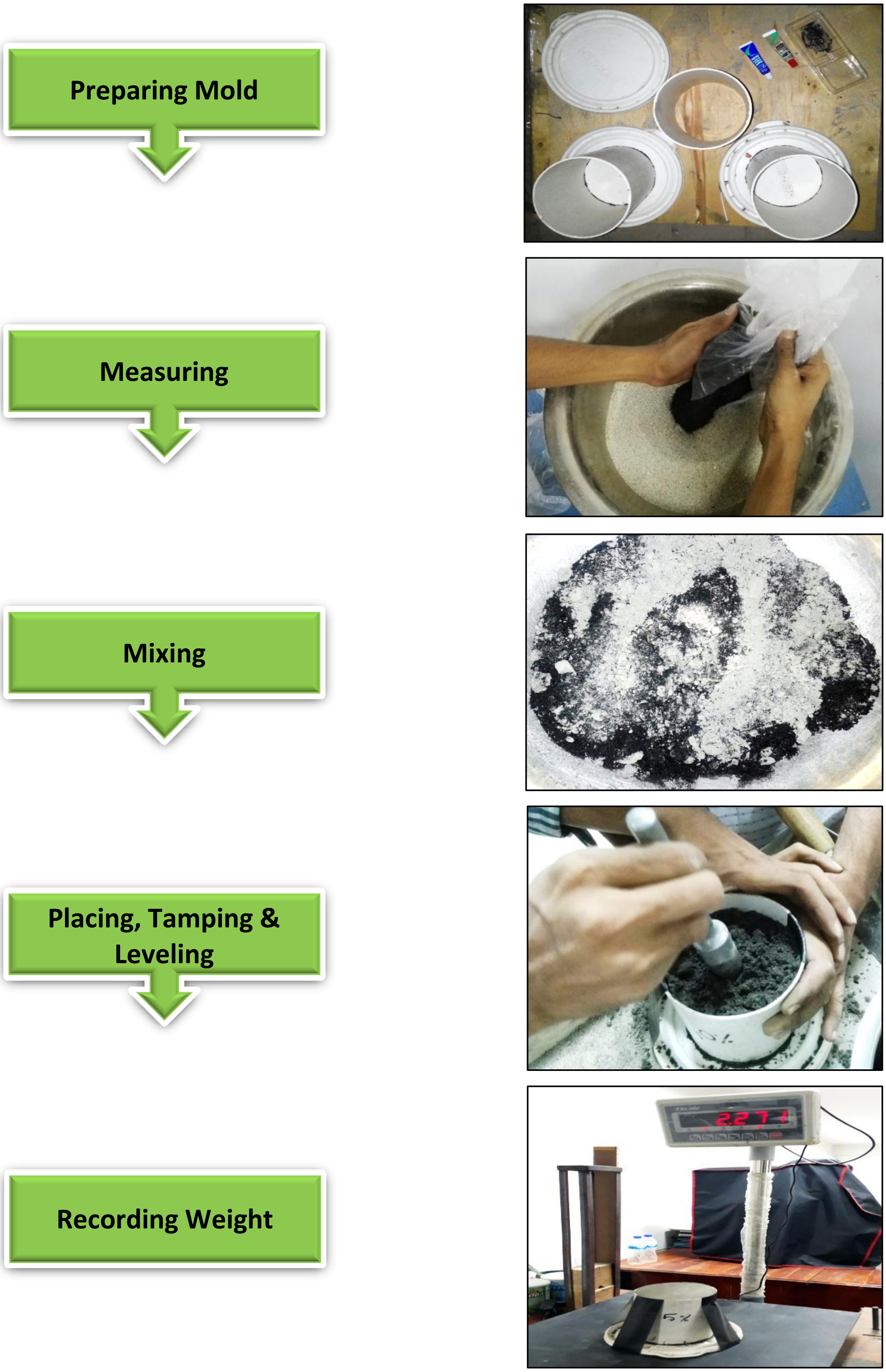


Fig 3.47: Flow chart of weight loss test

3.4.2.3 Flow / Workability Test

Procedure:

1. A mold of 4 cm height, 6 cm top dia, 7 cm bottom dia is used for flow test.

2. Measure all the materials needed as per requirement to prepare a mixture of cement and sand having ratio of 1:2.75. That is one part of cement and 2.75 parts of graded standard sand by weight. We used 87g cement & 240g sand for making mortar samples without biochar. For 5% biochar mixed sample, we used 82.65g cement and 4.35g biochar **(as a replacement of cement)**. For 10% biochar mixed sample, we used 8.7g biochar and 78.3g cement. The amount to sand is 240g for all samples.

Fig 3.48: Mold for flow test

3. We make a homogeneous mixture of dry ingredients by automatic mixing machine, and then add 130 mL water at a water/cement ratio of 1.5 to make a paste. The amount of water added is same for all samples. Here, we intentionally used water/cement ratio of 1.5 because we had no shake table for conducting standard flow test. Mortar had to be spread by gravity. That's why we have used higher water/cement ratio.

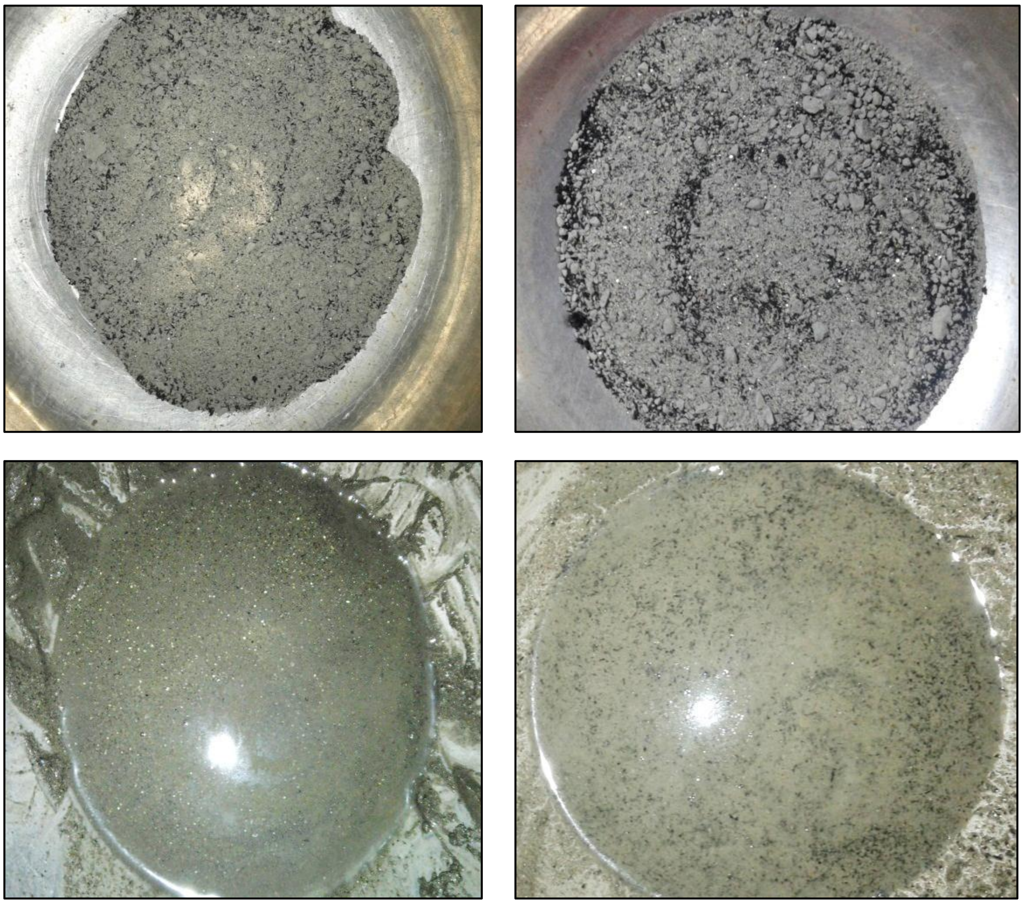


Fig 3.49: Mix the measured materials

4. Put the mold on a smooth surface and spread a plastic sheet over it. Pour the sample into the mold upto top level & after few seconds we remove the mold to allow the mortar to spread.

Fig 3.50: First molding & then demolding

5. Sample is spread by gravity & then we measure the largest diameter and record it.

Fig 3.51: Measure the sample diameter after spreading

Summary of Flow / Workability Test:

Fig 3.52: Flow chart of flow/workability test

3.5 DEVIATION FROM STANDARD PROCEDURE

Table 3.3: Deviation from standard procedure

Test Name	Standard Procedure	Followed Procedure
Compressive Strength Test	According to ASTM C109 the water/cement ratio is 0.485 for all Portland cement.	We didn't soak the sand for 24hrs before casting and used the oven dry sand. That's why we increased the w/c ratio a little bit (0.54) for better workability.
	If the cross-sectional area of a specimen varies more than 15% from nominal, use the actual area for the calculation of the compressive strength.	Here we used the actual area of the specimen for the calculation.
Water Retention or Weight Loss Test	According to standard, the water/cement ratio is 0.485 for all Portland cement.	We used water/cement ratio of 0.54 for better workability.
	According to literature review, the weights are recorded in the following intervals: 1hr, 3hrs, 6hrs, 1 day, 2 days, 3 days, 7 days, 10 days, 15 days, 20 days and 28 days.	In our test, the weights were recorded in the following intervals: 1hr, 2hrs, 3hrs, 5hrs, 1 day, 3 days, 7 days, 10 days, 14 days, 20 days, 31 days, 39 days and 49 days.
Flow Test	According to ASTM C1437 this test requires a specially designed table (Shake Table) in which the mortar sample is dropped for 25 times.	But due to unavailability, we couldn't use the required table and allowed mortar to flow by gravity.
	According to standard, the flow test is conducted twice for each mortar mix, and the average values are computed.	Here we measured the diameter at different positions and record the largest diameter.

Chapter – 04

Results & Discussion

4.1 COMPRESSIVE STRENGTH TEST

4.1.1 Sample Preparation

Table 4.1: Mortar mix design for compressive strength test

Age	Sample ID	Method of Curing	Biochar Addition	Cement (g)	Biochar Content (g)	Sand (g)	W/C Ratio
For 28 Days Testing	NW28D	**Water**	no	250	0	687.5	0.54 (Added Water = 135 mL)
	5%W28D		5%	237.5	12.5		
	10%W28D		10%	225	25		
For 28 Days Testing	NA28D	**Air**	no	250	0		
	5%A		5%	237.5	12.5		
	10%A		10%	225	25		
For 56 Days Testing	NW56D	**Water**	no	250	0		
	5%W56D		5%	237.5	12.5		
	10%W56D		10%	225	25		

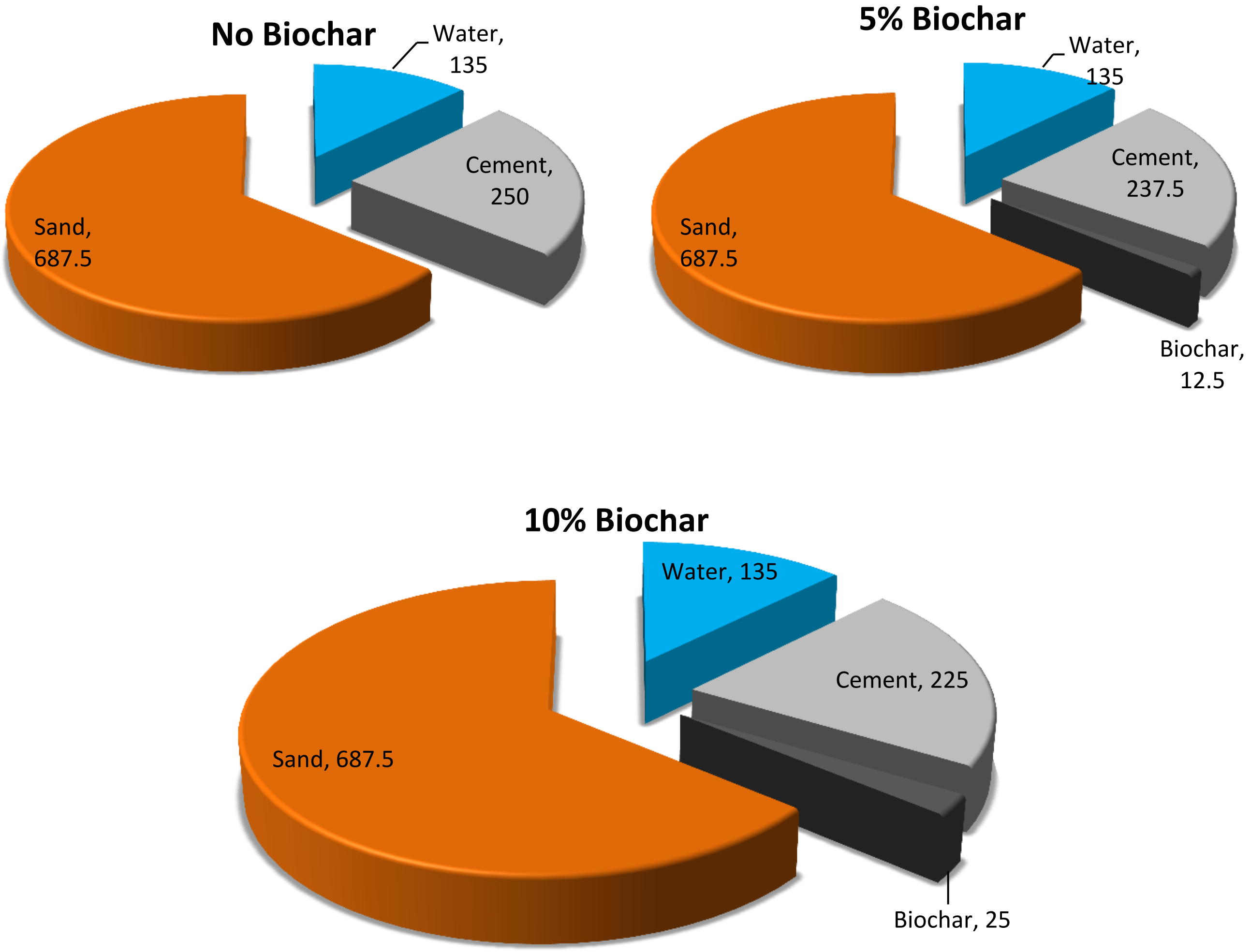


Fig 4.1: Different mortar mix for strength test shown by Pie-chart

Table 4.2: Mixing & final picture of mortar cube

Biochar Addition	Mixing Picture	Final Picture
No		
5%		
10%		

4.1.2 Sample Testing

Table 4.3: Crushing load of different sample tested on UTM machine

Age	Sample ID	Method of Curing	Biochar Addition	Area (in^2)	Crushing Load (N)
For 28 Days Testing	NW28D	**Water**	no	1.96 × 2	10582
	5%W28D		5%	1.937 × 2	9273.4
	10%W28D		10%	1.968 × 1.968	5372.9
For 28 Days Testing	NA28D	**Air**	no	1.937 × 1.937	7139.9
	5%A28D		5%	1.937 × 2	7102.5
	10%A28D		10%	1.937 × 2	3835.2
For 56 Days Testing	NW56D	**Water**	no	1.968 × 1.937	10473
	5%W56D		5%	1.968 × 1.968	9783.8
	10%W56D		10%	1.968 × 1.937	6400.4

4.1.3 Analysis & Result

Table 4.4: Determination of compressive strength

Sample ID	Area (in^2)	Area (in^2)	Crushing Load (N)	Crushing Load (lb) (1N=0.2248lb)	Compressive Strength (psi)
NW28D	1.96 × 2	3.92	10582	2378.92823	606.8694462
5%W28D	1.937 × 2	3.874	9273.4	2084.74325	538.1371314
10%W28D	1.968 × 1.968	3.873024	5372.9	1207.87597	311.86896
NA28D	1.937 × 1.937	3.751969	7139.9	1605.11337	427.805605
5%A28D	1.937 × 2	3.874	7102.5	1596.70551	412.1593995
10%A28D	1.937 × 2	3.874	3835.2	862.187256	222.5573712
NW56D	1.968 × 1.937	3.812016	10473	2354.42405	617.6322592
5%W56D	1.968 × 1.968	3.873024	9783.8	2199.48573	567.8988127
10%W56D	1.968 × 1.937	3.812016	6400.4	1438.86716	377.4556967

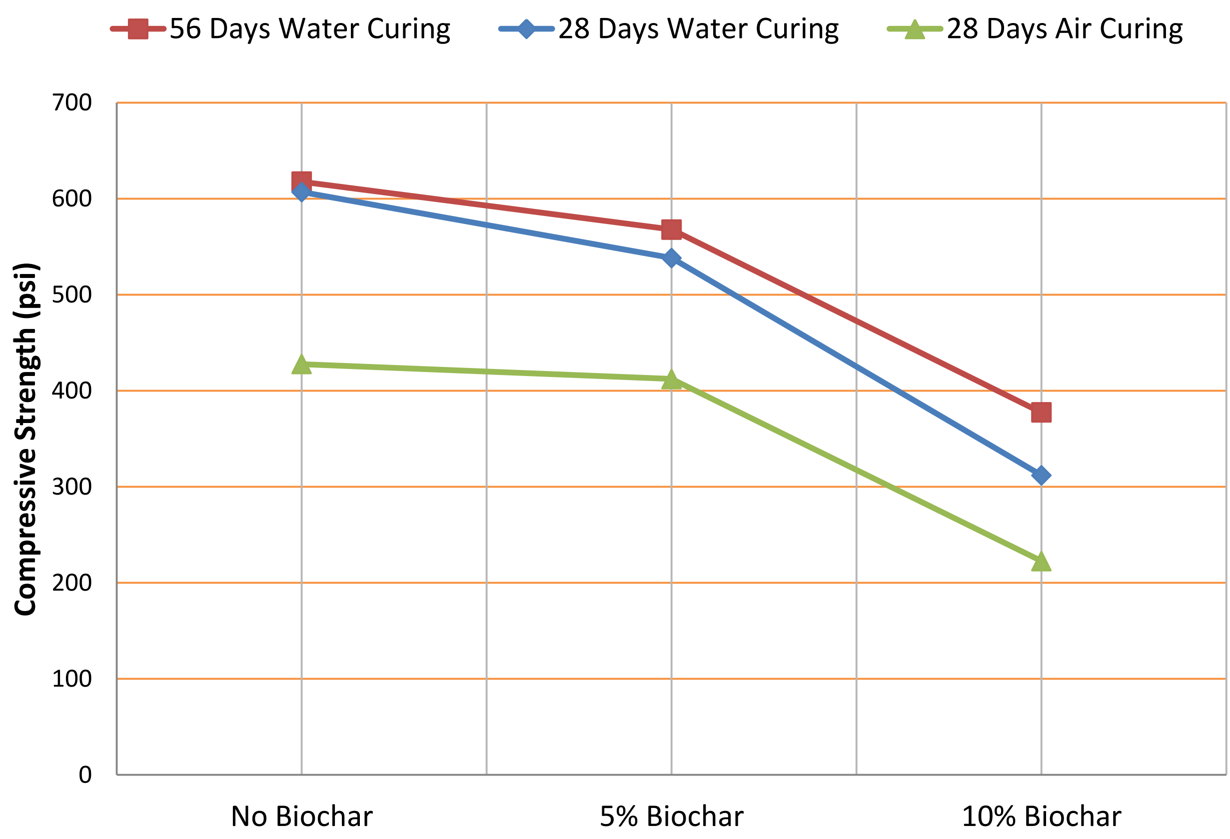


Fig 4.2: Development of compressive strength

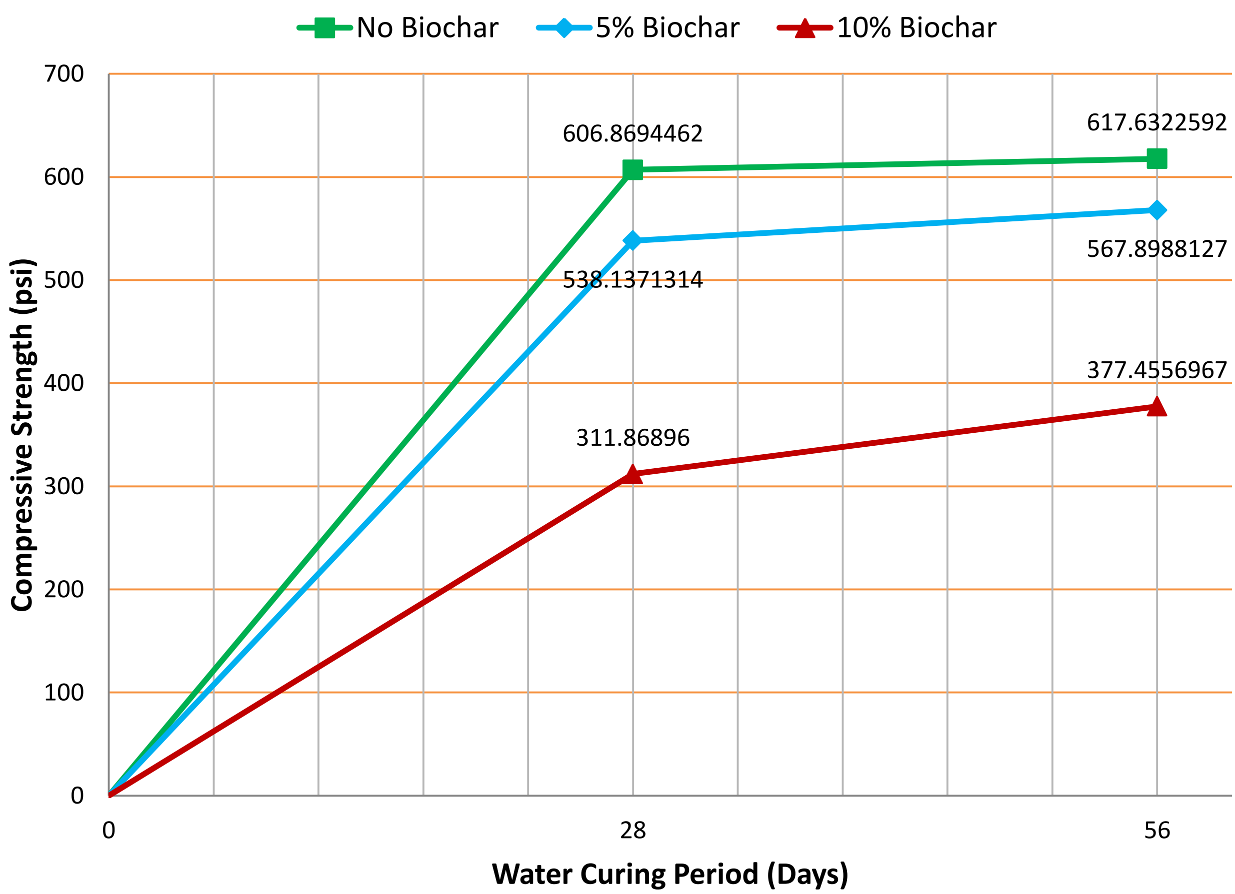
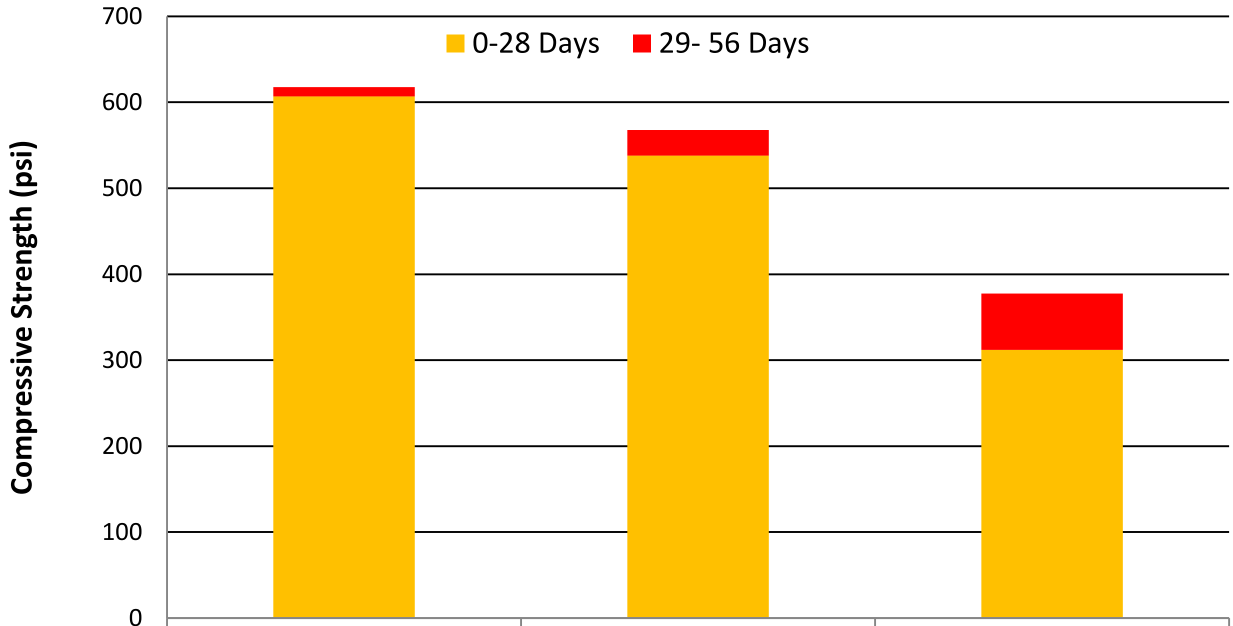


Fig 4.3: Compressive strength development due to water curing for more than 28 days



	No Biochar	5% Biochar	10% Biochar
29- 56 Days	10.76281305	29.76168133	65.58673675
0-28 Days	606.8694462	538.1371314	311.86896

Fig 4.4: Compressive strength development due to water curing for more than 28 days shown by Pie-chart

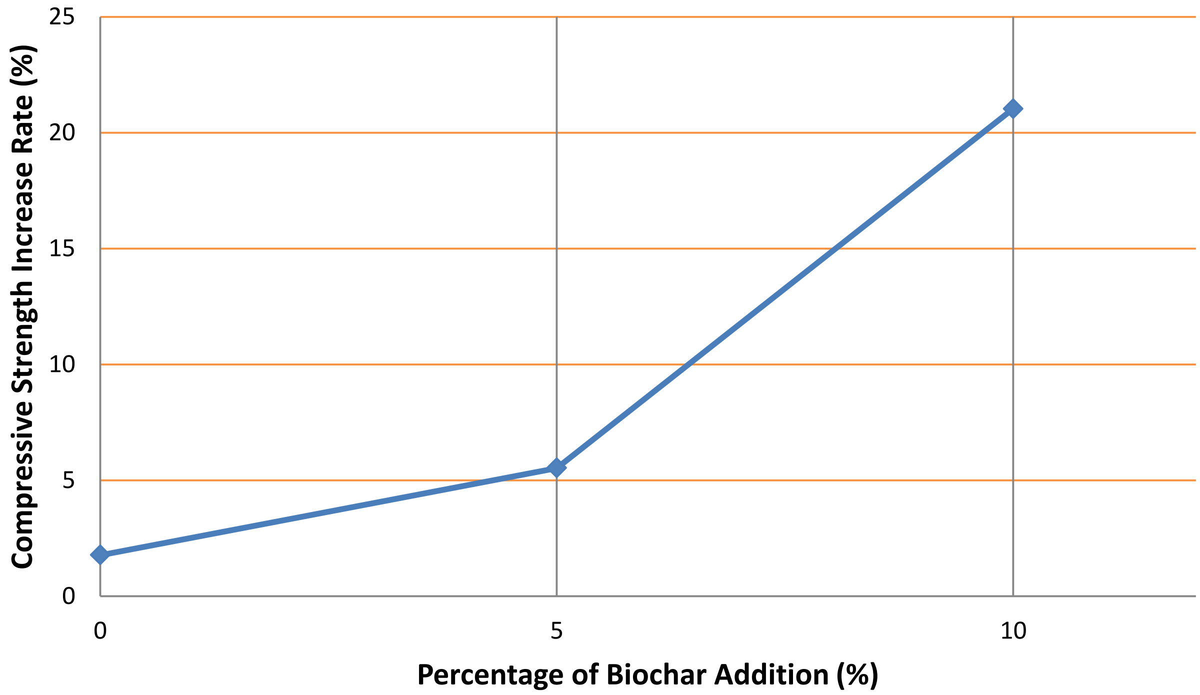


Fig 4.5: Compressive strength increase between 28 to 56 days due to water curing

From **Fig 4.3-4.5**, we can conclude that –

- Normal concrete gains 99% of its total strength in 28 days
- Due to addition of biochar into concrete, it continues to gain strength even after 28 days.
- For normal concrete the rate of gain of compressive strength is much slower after 28 days. Whereas for biochar mixed concrete, the rate is much higher.

4.2 WATER RETENTION / WEIGHT LOSS TEST

4.2.1 Sample Preparation

Table 4.5: Mortar mix design for weight loss test

Sample ID	Biochar Addition	Cement (g)	Biochar Content (g)	Sand (g)	W/C Ratio
N	no	580	0	1595	0.552 (Added water=320mL)
5%	5%	551	29		
10%	10%	522	58		

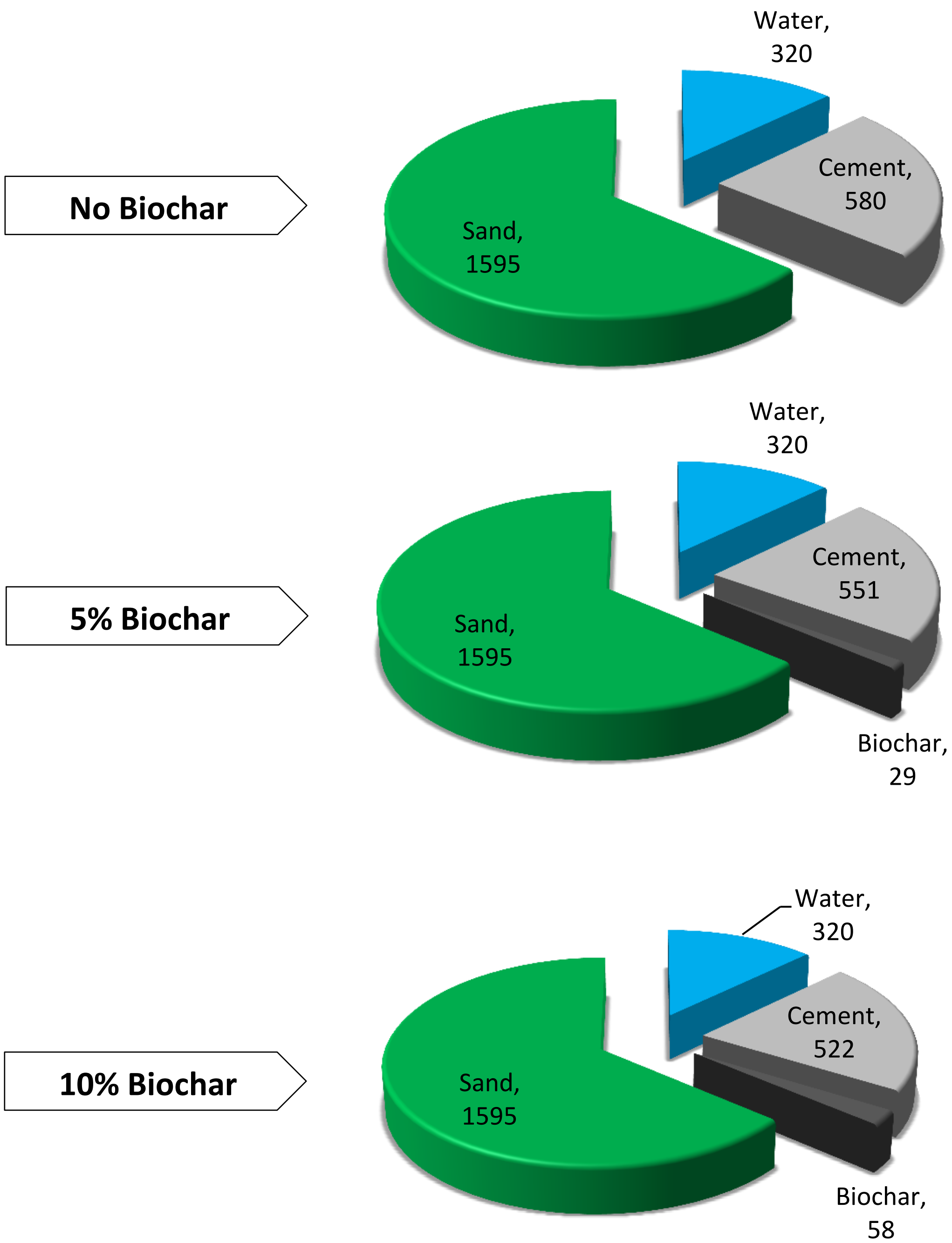


Fig 4.6: Different mortar mix for weight loss test shown by Pie-chart

4.2.2 Sample Testing

Table 4.6: Weight measured at different time intervals

Time (hr)		0	1	2	3	5	24	72	168	240	336	480	744	936	1176
Weight (g)	No Biochar	2536	2534	2532	2531	2530	2516	2496	2481	2476	2472	2469	2463	2459	2457
	5% Biochar	2369	2366	2364	2363	2362	2349	2331	2312	2303	2302	2296	2291	2285	2282
	10% Biochar	2258	2255	2253	2253	2251	2238	2220	2203	2194	2191	2185	2181	2174	2171

4.2.3 Analysis & Result

Table 4.7: Percentage of weight loss with respect to initial weight

Time (hr)	Weight (g)			Weight Loss (g)			Percent of Weight Loss (%)		
	No Biochar	5% Biochar	10% Biochar	No Biochar	5% Biochar	10% Biochar	No Biochar	5% Biochar	10% Biochar
0	2536	2369	2258	0	0	0	0.000	0.000	0.000
1	2534	2366	2255	2	3	3	0.079	0.127	0.133
2	2532	2364	2253	4	5	5	0.158	0.211	0.221
3	2531	2363	2253	5	6	5	0.197	0.253	0.221
5	2530	2362	2251	6	7	7	0.237	0.295	0.310
24	2516	2349	2238	20	20	20	0.789	0.844	0.886
72	2496	2331	2220	40	38	38	1.577	1.604	1.683
168	2481	2312	2203	55	57	55	2.169	2.406	2.436
240	2476	2303	2194	60	66	64	2.366	2.786	2.834
336	2472	2302	2191	64	67	67	2.524	2.828	2.967
480	2469	2296	2185	67	73	73	2.642	3.081	3.233
744	2463	2291	2181	73	78	77	2.879	3.293	3.410
936	2459	2285	2174	77	84	84	3.036	3.546	3.720
1176	2457	2282	2171	79	87	87	3.115	3.672	3.853

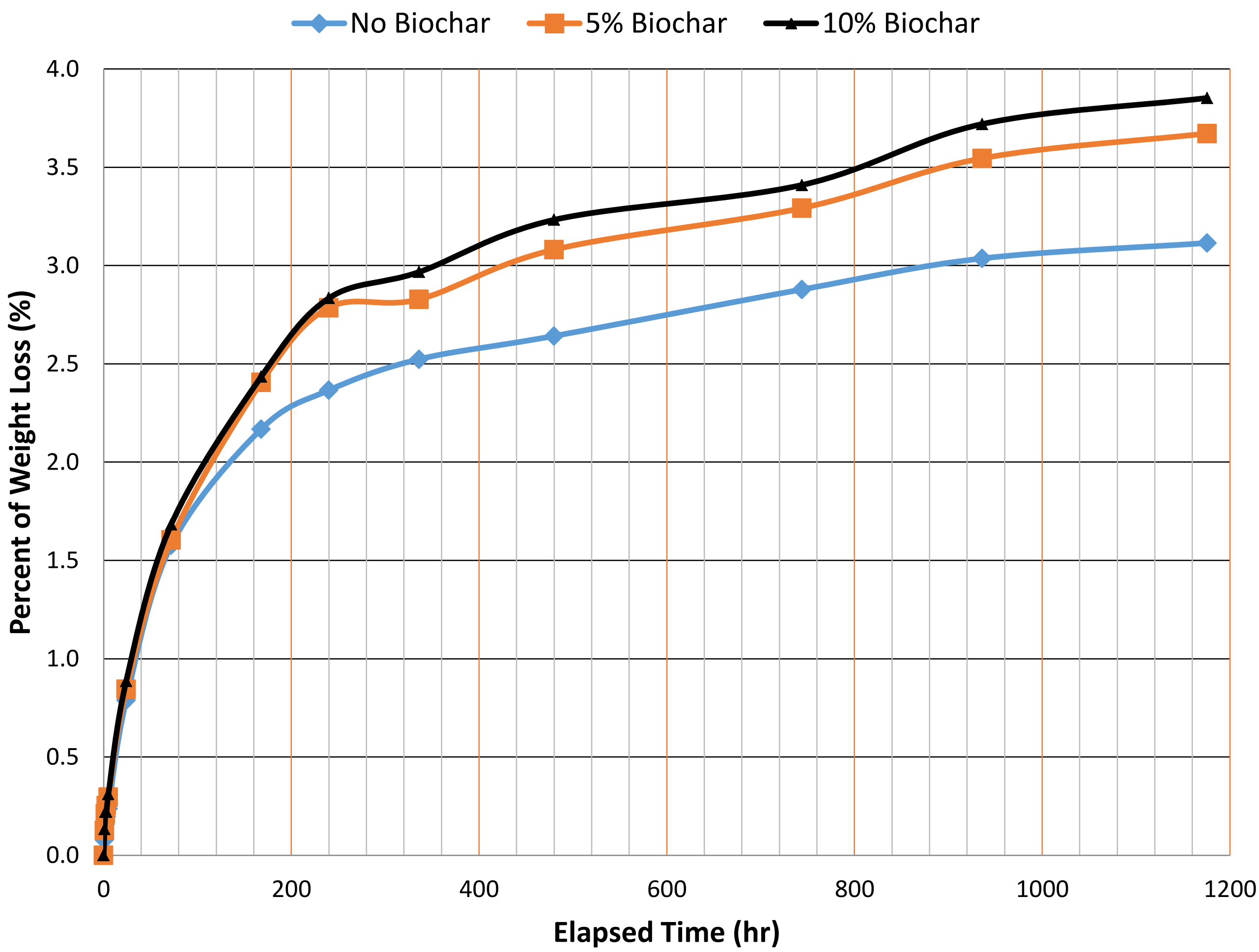


Fig 4.7: Percentage of weight loss with time

4.3 WORKABILITY / FLOW TEST

4.3.1 Sample Preparation

Table 4.8: Mortar mix design for flow test

Biochar Addition	Cement (g)	Biochar Content (g)	Sand (g)	W/C Ratio
no	87	0	240	1.5 (Added water = 130 mL)
5%	82.65	4.35		
10%	78.3	8.7		

***As we didn't have Shake table for conducting flow test, we had to allow the mortar to flow by gravity. So, we added water at a w/c ratio of 1.5.

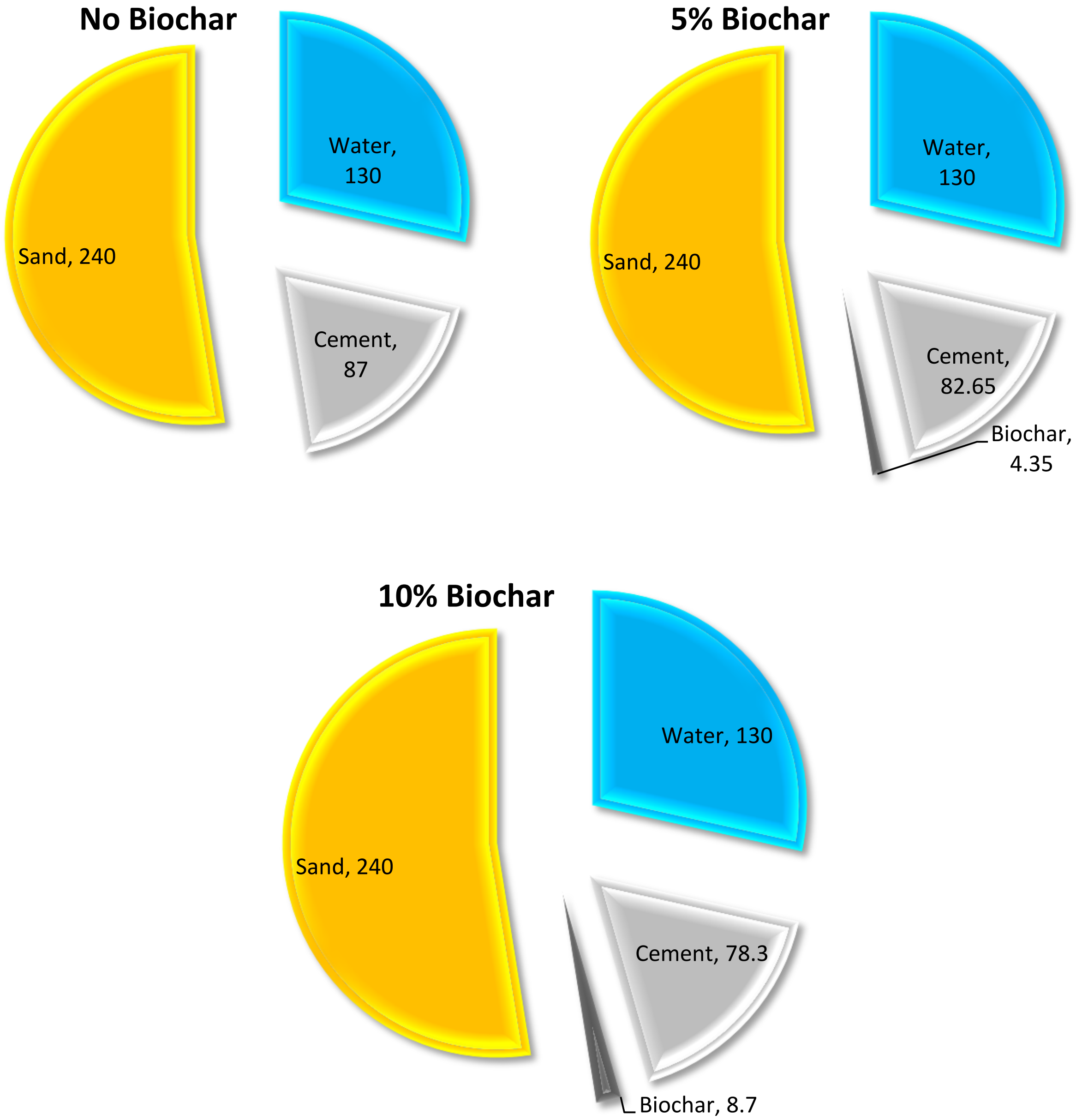


Fig 4.8: Different mortar mix for flow test shown by Pie-chart

4.3.2 Sample Testing

Table 4.9: Data obtained from flow test

Biochar Addition	Diameter After Flow (inch)	Mold Dimension	
no	6.9	Top Diameter	6cm / 2.362in
5%	6.7	Bottom Diameter	7cm / 2.756in
10%	6.5	Depth	4cm / 1.575in

Fig 4.9: Mold for flow test

4.3.3 Analysis & Result

Table 4.10: Determination of flow rate

Biochar Addition	Initial Average Diameter (cm)	Initial Average Diameter (inch)	Diameter After Flow (inch)	Difference in Diameter (inch)	Flow Rate (%)
no	$\frac{6+7}{2} = 6.5$	2.56	6.9	4.34	169.53
5%			6.7	4.14	161.72
10%			6.5	3.94	153.91

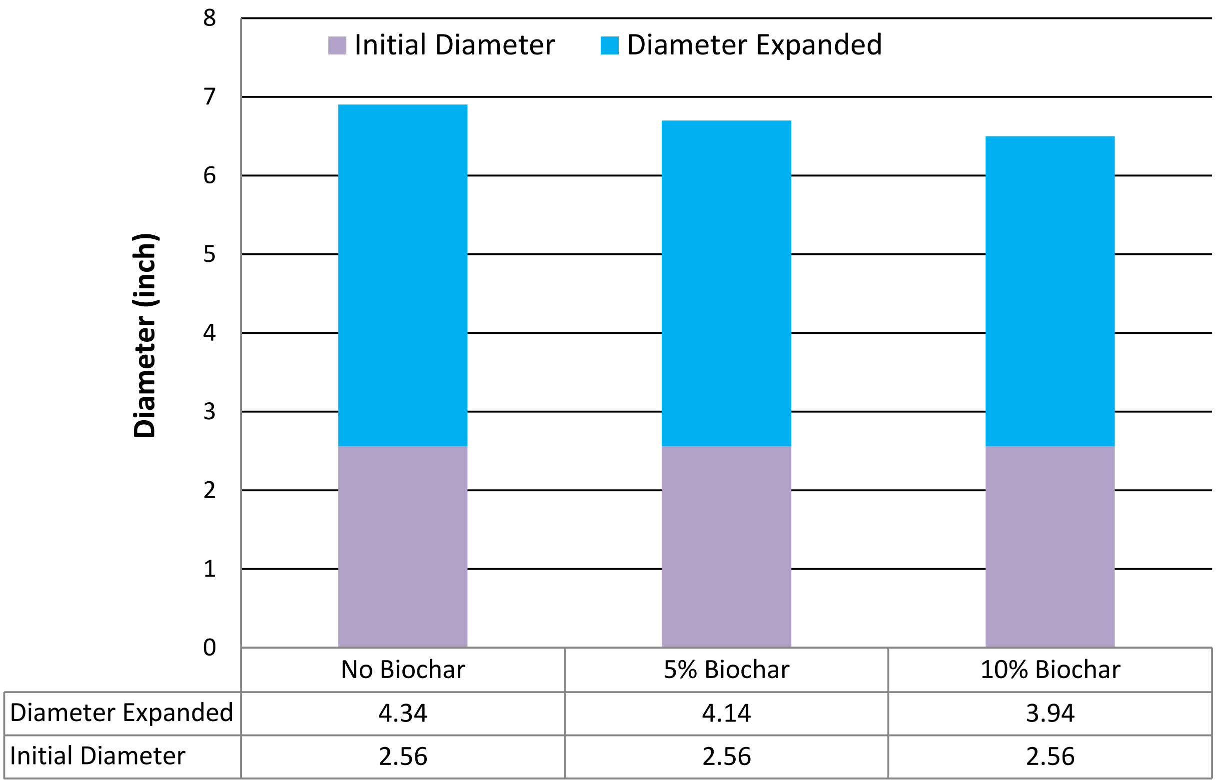


Fig 4.10: Variation of workability due to biochar addition shown by Bar-chart

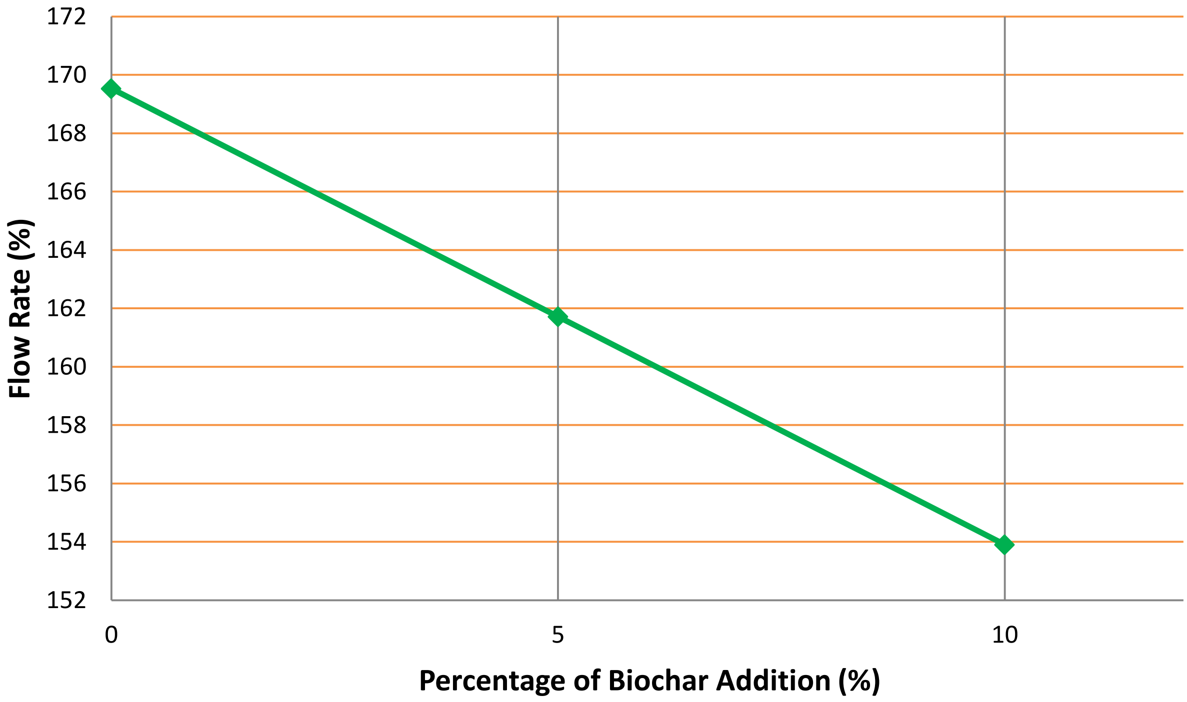


Fig 4.11: Variation of flow rate due to biochar addition

4.4 OVERVIEW

Table 4.11: Result summary

Test	Findings
Compressive Test	◊ Carbon emission from cement industry can be reduced by reducing the use of cement. Biochar can be used as a replacement of cement in concrete upto 5% without significantly reducing the concrete strength. Thus the concrete can be a source for carbon sequestration. ◊ The more the biochar-mixed concrete is water cured, the more the possibility that it gains the strength equal to normal concrete. ◊ For biochar replaced mixes, we found that concrete continues to gain strength at a moderate rate even after 28 days curing, whereas the increase rate for normal mixes is very low after that period. The reason is – biochar has a high water holding capacity and it holds the water that is added during casting. ◊ If it is not possible to perform continuous water curing, the strength will not be such lowered for biochar-mixed concrete than that for normal concrete.
Weight Loss Test	◊ According to our literature review, the weight loss over time due to moisture evaporation is less for the mortar mixes that include biochar than that for the conventional mix. As biochar holds the water, the weight loss should be less for biochar-mixed concrete. But we found the opposite one. The reason may be – we conducted a very small ranged test.
Flow Test	◊ A negative effect of biochar addition is that – the more the replacement rate is, the less the workability of the mixture is. ◊ For 5% biochar replacement, this problem is not that much effective.

Chapter – 05

Conclusion, Limitation & Recommendation

5.1 CONCLUSION

- Hazardous greenhouse gas emission from cement industry which is responsible for global warming can be reduced by using Biochar as a replacement of cement in concrete upto a few percent without significantly reducing its strength.
- Concrete can be used for long term storage of carbon in the form of Biochar.
- Biochar can be used as a self-curing agent in concrete due to its high water holding capacity.
- For conventional mixes of concrete, the increase rate of strength is significantly reduced after 28 days. But we have found for Biochar mixed mixtures, even after 28 days the increase rate is much better.
- A negative side of Biochar addition is that – the more the biochar is used as a replacement of cement/sand, the more the workability is reduced.

5.2 LIMITATION

- We had no sophisticated equipment for making biochar. But we have succeeded to make it by home-made technology.
- As we didn't have any technology for determining chemical composition of biochar, we faced difficulties in selecting biomass materials among which have cementious property.
- For conducting compressive strength test of mortar, we have used UTM machine instead of the specified machine which is standardized for testing mortar cube due to unavailability.
- Due to incautious demolding procedure, some sample cubes for strength test were not in perfect shape.
- The molds we made for weight loss test were not such durable and uniform.
- We couldn't follow the standard procedure for flow test due to lack of equipment.
- Due to time constraints, we couldn't check the capacity of biochar mixed sample against fire and the effect on temperature & humidity.
- Due to some limitation we had to conduct our research on a small scale. Results would be more significant if we could test more samples and average their results.

5.3 RECOMMENDATION

- The biochar we used are produced from rice husk. We have assumed that it has a cementitous property. One should try with varying materials for better result.
- More sophisticated equipment should be used for making biochar.
- Here we have done our analysis based on a few specimens. But is better to analyze with more specimens which will provide more significant, accurate and dependable results.
- We couldn't follow the standard follow test. For more authentic result, one must follow the standard code for flow test.
- For further research, one should concentrate on evaluating other mechanical properties of biochar mixed concrete such as fire proofing capacity, temperature & humidity control.

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