A STUDY ON THE STRENGTH OF CONCRETE BY PARTIAL CEMENT REPLACEMENT WITH SAWDUST ASH

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ABSTRACT

This study is based on the use of sawdust ash as a partial replacement material for cement in concrete for property modifications. In the concrete mixes, cement was replaced by sawdust ash at 5%, 10%, and 15% by weight, and the effects on replacement were observed. The use of sawdust ash allows the reuse of sawdust as a waste product in the construction process. Due to the lightweight of the sawdust ash in comparison to cement, the concrete ultimately becomes lighter in weight. The grade of concrete designed here was M25 and concrete cubes measuring 150mm×150mm×150mm, beams of sizes 100mm×100mm×500mm and cylinder 150 mm in diameter and 300 mm in height were cast and their compressive, flexural strength, and split tensile strength are evaluated respectively after 7 and 28 days.

INTRODUCTION

The construction industry is in constant demand due to the ever-growing population and its infrastructural demand. Adequate and affordable building materials are in need for the construction of infrastructure to meet both domestic and commercial demands. The conventional building materials have been increasing exponentially over time and in turn making the construction projects unbearably expensive, at the same time the majority of the world's population continues to subside below the poverty line. Due to this, there has been a search demand for alternate building materials for the construction purposes of infrastructure in both urban and rural areas without a compromise to their normal functions.

In the construction world, one material is dominantly used above all others, and that is concrete. Concrete according to Neville (1983) is a composite material that consists of a binding medium within which are embedded particles or fragments of aggregate. According to an article by Jonathan Watts et al (2015); concrete is the most widely used substance on the planet, after water. Its worldwide production and use exceed that of steel by the tenth factor in tons and by more than the thirtieth factor in volume. The average consumption of concrete is over 10 billion tons a year. This is more than 10 times the consumption by weight of steel.

Cement is widely noted as the most valuable and expensive constituent of concrete. According to a report by Statista Research Department (2021); in 2019, India was the world's second-largest producer of cement, and its consumption at the time stood around 328 million metric tons. Cement essentially binds the ingredients together, water gives the concrete viscosity to be molded and react with the ingredients, and the aggregates are what add bulk to the concrete, but are not involved in the chemical processes. The cement according to Neville (1983) is composed primarily of silica and lime, which forms the essential cementing compounds, tricalcium (C_3S) and dicalcium silicate (C_2S). According to S.A Sumaila et al (1999); N. Ambika (2015) any alteration in the silica content will invariably affect the strength characteristics of cement which are expected when alternate cementitious materials are used to partially replace cement in concrete.

It could be asserted that both the raw material shortness and the expensive industrial manufacturing processes undergone to produce cement may have accounted for its high cost. If this continuous increase in the cost of building materials is left unchecked, it might over time negatively impact the construction objectives of communities and the country at large. In the bid to solve this insurgence, many kinds of research have and are continuously being conducted on the possibility of using locally available materials to partially replace cement in concrete. Due to this as well as taking into account the current global initiatives to reduce carbon emissions, waste production and recycling of reusable products, there has been some research made to facilitate this particular initiative.

N. Bouzoubaâ et al (2001); CANMET undertook a research project trying to develop blended types of cement which incorporate high volumes of ASTM Class F fly ash. The main objective of this research was the need to reduce carbon dioxide emissions during the production of cement clinker, to reduce the consumption of raw materials such as limestone and clay, and to contribute to an overall cleaner environment by recycling waste materials. This in the end proved that more materials with pozzolanic properties can be used as partial replacements to cement in the concrete mixes. Some of these materials which can act as cement replacements may be calcined diatomaceous earth, rice husk ash, pulverized burnt clay, sawdust ash, etc. These materials which can act as cement replacement materials are known as pozzolanas. According to the Methods of Test for Pozzolanic Materials (IS:1727-1967) and American

Society for Testing Materials (ASTM) C 618 – 12a, pozzolana is a siliceous or siliceous aluminous material that contains little or no cementitious value, but in finely divided form and presence of moisture or water, chemically reacts with calcium hydroxide at ordinary temperature to form compound possessing cementitious properties. Commonly met pozzolanas include fly ash, calcined diatomaceous earth, rice husk ash, pulverized burnt clay, sawdust ash, etc.

According to H. Green (2006); sawdust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or any other carpentry tools; it is composed of fine particles of wood. It is also the byproduct of certain animals, birds, and insects that live in wood, such as the woodpecker and carpenter ant.

Sawdust is very common due to the availability of sawmills in almost every township in the country. Sawdust is one of the major underutilized by-products from sawmilling operations, generation of wood wastes in a sawmill is unavoidable hence a great effort is made from the utilization of such waste. Sawdust ash can be used as lightweight concrete that has already received attention over the past years. The implementation of waste sawdust can not only decrease environmental damage but also can save the concrete materials.

The sawdust used for this study was collected from sawmills. The Sample was carefully collected to avoid mixing the sawdust with sand. The collected sample was burnt into ash by open burning in a metal container. The sawdust ash (SDA) was ground after cooling using mortar and pestle. The yield calculation was done and tests were carried out to determine the physical and chemical properties of the Saw Dust Ash. The Saw Dust Ash particles passing through the sieve of aperture 90µm were used for this study. Conducted a particular study on the utilization of materials that can fulfill the expectations of the construction industry in different areas.

Different types of concretes are prepared by partially substituting the cementitious phases with sawdust ash, the outcome concrete can be molded to its application with varying strength, density, or chemical and thermal resistance properties of the material. The concrete solidifies and hardens through a chemical process called hydration. The water reacts with the cement, which bonds the other components together, creating a robust stone-like material. In this study, cement has been replaced by sawdust ash accordingly in the range of 0%, 05%, 10%, and 15% by weight of cement for M25 mix with a 0.40 water-cement ratio.

➢ The objective of the current study:

- To explore and assess the possibility of using waste sawdust in concrete in terms of its strength.
- To assess the compressive strength of the concrete mix.
- To assess the flexural strength of the concrete mix.

To assess the split tensile strength of the concrete mix.

MATERIAL AND METHODS

Cement

Ordinary Portland Cement (OPC) of 53 grades conforming to ISI standards has been procured and various tests have been conducted per IS:12269-2013.
The following data was obtained from the conducted tests:

Table 1: Table of results of tests for OPC

S No.	Test conducted for Ordinary Portland Cement	Test Results
1	Specific gravity	3.13
2	Initial setting time	35 Mins.
3	Final setting time	590 Mins.
4	Fineness	95%
5	Consistency	33%
6	Soundness	3 mm

Sawdust Ash

The sawdust used in this study has been collected from local mills**,** on an open steel container and grounded and sieved on a 300 µm sieve to obtain the sawdust ash.
The specific gravity obtained after testing = 1.8.

Figure 1: **Sawdust Ash**

Fine Aggregate

Natural river sand conforming to Zone-III of Table 4 of IS:383-1970 has been obtained.

The following data was obtained from the conducted tests:

Table 2: Table of results of the test for fine aggregate

S No.	Test conducted on Fine Aggregate	Test Results
1	Specific gravity	2.6
2	Fineness modulus	2.81
3	Bulk density	1654 kg/m^3
4	Free moisture content	0.1%

Coarse Aggregate

Machine crushed granite aggregate conforming to IS:383-1970 consisting of 20mm maximum size of aggregates has been obtained.

The following data was obtained from the conducted tests:

Table 3: Table of results of the test for coarse aggregate

S No.	Test conducted on Coarse Aggregate	Test Results
1	Specific gravity	2.7
2	Fineness modulus	2.04

RESULT AND DISCUSSION

Step 1: Stipulations for Proportioning

a) Grade designation : M25
b) Type of cement : OPC 53 grade conforming IS:12269-13
c) Type of admixture : Saw dust ash
d) Maximum nominal size of aggregate: : 20mm
e) Minimum cement content : 280 kg/m^3
f) Maximum water-cement ratio : 0.40
g) Workability : 100mm (slump)
h) Exposure condition : Extreme (Plain)
i) Method of concrete placing : By Hand
j) Degree of supervision : Good
k) Type of aggregate : Crushed angular aggregate
l) Maximum cement content : 450 kg/m^3

Step 2: Test Data for Materials

m) Cement used : OPC 53 grade conforming IS:12269-13
a) Specific gravity of cement : 3.13
b) Specific gravity of saw dust ash : 1.8
c) Specific gravity of:
   i. Coarse aggregate : 2.7
   ii. Fine aggregate : 2.6
d) Water absorption
   i. Coarse aggregate : 0.6%
   ii. Fine aggregate : 0.75%
e) Free (surface) moisture
   i. Coarse aggregate : Nil
   ii. Fine aggregate : Nil

Step 3: Target Strength for Mix Proportioning

$f'_{ck} = f_{ck} + 1.65s$

where:

f'_{ck} = target average compressive strength at 28 days,

f_{ck} = characteristic compressive strength at 28 days, and

s = standard deviation (From Table 1, Standard Deviation, s = 4 N/mm^2)

Therefore: $\text{Target Strength} = 25 + 1.65 \times 4 = 31.6$ N/mm^2

Step 4: Selection of Water-Cement Ratio

From Table 5 of IS:456-2000, water-cement ratio = 0.40

Step 5: Selection of Water Content

From Table 2 of IS:10262-2009:

For 20 mm aggregate	= 186 litres (for 25 to 50 mm slump range)
Estimated water content for 100 mm slump	= $186 + \frac{6}{100} \times 186 = 197.16$ litres

Step 6: Calculation of Cement

Water-Cement ratio	= 0.40
Cementitious material (cement + saw dust ash)	= $\frac{140}{0.4} = 350$ kg/m^3

From Table 5 of IS 456, minimum cement content for 'extreme' conditions = 280 kg/m^3

350 kg/m^3 > 280 kg/m^3, hence, O.K.

Step 7: Proportions of Volume of Coarse Aggregate and Fine Aggregate Content

From Table 3 of IS 10262:2009,

The volume of coarse aggregate per unit volume of total aggregate corresponding to 20mm size aggregate and fine aggregate (Zone I) for the water-cement ratio of 0.40

The volume of coarse aggregate per unit volume of total aggregate = 0.60

The volume of fine aggregate per is taken as = $1 - 0.60 = 0.40$

Step 8: Mix Calculations

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete (cube) = **0.003375 m^3**

b) Volume of cement (cube)

$$= \frac{\text{Mass of cement}}{\text{Specific gravity of cement}} \times \frac{0.003375}{1000}$$

$$= \frac{350}{3.15} \times \frac{0.003375}{1000}$$

= **0.000375 m^3**

c) Volume of water (cube)

$$= \frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{0.003375}{1000}$$

$$= \frac{140}{1} \times \frac{0.003375}{1000}$$

= **0.0004725 m^3**

d) Volume of concrete (beam) = **0.005 m^3**

e) Volume of cement (beam) $= \frac{\text{Mass of cement}}{\text{Specifi gravity of cement}} \times \frac{0.005}{1000}$

$= \frac{350}{3.15} \times \frac{0.005}{1000}$

= **0.00056 m³**

f) Volume of water (beam) $= \frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{0.005}{1000}$

$= \frac{140}{1} \times \frac{0.005}{1000}$

= **0.0007 m³**

g) Volume of concrete (cylinder) = **0.0053 m³**

h) Volume of cement (cylinder) $= \frac{\text{Mass of cement}}{\text{Specifi gravity of cement}} \times \frac{0.0053}{1000}$

$= \frac{350}{3.15} \times \frac{0.0053}{1000}$

= **0.00059 m³**

i) Volume of water (cylinder) $= \frac{\text{Mass of water}}{\text{Specific gravity of water}} \times \frac{0.0053}{1000}$

$= \frac{140}{1} \times \frac{0.0053}{1000}$

= **0.000742 m³**

j) Volume of aggregates (cube) $= [a - (b + c)]$

$= 0.003375 - (0.000375 + 0.0004725)$

= **0.0025275 m³**

k) Mass of coarse aggregate (cube) $= e \times \text{Volume of coarse aggregate} \times \text{Specific gravity of coarse agregate} \times 1000$

$= 0.0025275 \times 0.6 \times 2.7 \times 1000$

= **4.095 kg**

l) Mass of fine aggregate (cube) $= e \times \text{Volume of fine aggregate} \times \text{Specific gravity of fine agregate} \times 1000$

$= 0.0025275 \times 0.4 \times 2.6 \times 1000$

= **2.629 kg**

m) Volume of aggregates (beam) $= [d - (e + f)]$

$= 0.005 - (0.00056 + 0.0007)$

= **0.00374 m³**

n) Mass of coarse aggregate (beam) $= e \times \text{Volume of coarse aggregate} \times \text{Specific gravity of coarse agregate} \times 1000$

$= 0.00374 \times 0.6 \times 2.7 \times 1000$

= **6.059 kg**

o) Mass of fine aggregate (beam) $= e \times \text{Volume of fine aggregate} \times \text{Specific gravity of fine agregate} \times 1000$

$= 0.00374 \times 0.4 \times 2.6 \times 1000$

= **3.890 kg**

p) Volume of aggregates (cylinder) $= [g - (h + i)]$

$= 0.0053 - (0.00059 + 0.000742)$

= **0.003968 m³**

q) Mass of coarse aggregate (cylinder) $= e \times \text{Volume of coarse aggregate} \times \text{Specific gravity of coarse agregate} \times 1000$

$= 0.003968 \times 0.6 \times 2.7 \times 1000$

= **6.428 kg**

r) Mass of fine aggregate (cylinder) $= e \times \text{Volume of fine aggregate} \times \text{Specific gravity of fine agregate} \times 1000$

$= 0.0025275 \times 0.4 \times 2.6 \times 1000$

= **4.127 kg**

Table 4: Values obtained from design mix calculations.

	CUBE	BEAM	CYLINDER
VOLUME OF CONCRETE	0.003375 m^3	0.005 m^2	0.0053 m^3
VOLUME OF CEMENT	0.000375 m^3	0.00056 m^3	0.00059 m^3
VIOLUME OF WATER	0.0004725 m^3	0.0007 m^3	0.000742 m^3
VOLUME OF AGGREGATES	0.0025275 m^3	0.00374 m^3	0.003968 m^3
MASS OF COARSE AGGREGATES	4.095 kg	6.059 kg	6.428 kg
MASS OF FINE AGGREGATES	2.629 kg	3.890 kg	4.127 kg

Step 9: Calculating Requirements

For the case of this study, a total of 32 cubes, 16 beams, and 16 cylinders will be made. Thus:

a) Total mass of coarse aggregate $= 32k + 16n + 16q$
$= 32(4.095) + 16(6.059) + 16(6.428)$
= **330.832 kg**

Total mass of fine aggregate $= 32l + 16o + 16r$
$= 32(2.629) + 16(3.890) + 16(4.127)$
= **212.4 kg**

b) Mass of cement:

Cube $= 0.000375 \times 1440$
= **0.54 kg**

Beam $= 0.00056 \times 1440$
= **0.806 kg**

Cylinder $= 0.00059 \times 1440$
= **0.850 kg**

For the case of this study, cement will be replaced with sawdust ash in quantities of 5%, 10%, and 15% respectively. Therefore:

Table 5: Mass of cement used

PERCENT USED	85%	90%	95%	TOTAL
CUBE	0.459O kg	0.4860 kg	0.5130 kg	**1.4580 kg**
BEAM	0.6851 kg	0.7254 kg	0.7657 kg	**2.1762 kg**
CYLINDER	0.7225 kg	0.7650 kg	0.8075 kg	**2.2950 kg**

Total mass of cement used $= 32(1.4580) + 16(2.1762) + 16(2.2950)$
= **118.1952 kg**

Table 6: Mass of sawdust ash

PERCENT USED	5%	10%	15%	TOTAL
CUBE	0.0270 kg	0.0540 kg	0.0810 kg	**0.1620 kg**
BEAM	0.0403 kg	0.0806 kg	0.1209 kg	**0.2418 kg**
CYLINDER	0.0425 kg	0.0850 kg	0.1275 kg	**0.2550 kg**

Total mass of saw dust ash used $= 32(0.1620) + 16(0.2418) + 16(0.2550)$
= **13.1328 kg**

Compressive Strength

Testing of Cubes for Compressive Strength

Concrete cubes of sizes 150mm × 150mm × 150mm were tested for crushing strength. The compression test is done in a compression testing machine confirming to IS:516-1959. All the concrete specimens were tested in a 1500 KN capacity Compression Testing Machine (CTM). The experimental arrangement is as shown in the figure. The crushing strength of concrete was determined by applying load at the rate of 140 kg/cm^2/min till the specimen fails. The maximum load applied on the specimen was recorded. Crushing strength is the ratio of failure load to the area of cross-section of specimen.

Figure 2: **Compressive Testing arrangement**

The cube compressive strength can be calculated as follows:

If f_c is the cube compressive strength, then

$$\mathbf{f_c = P/A} \text{ N/mm}^2$$

where; **P**= Ultimate Load in Newtons,

A= Cross-Sectional Area of the cube in mm^2

Table 7: Compressive strength for cubes

MIX	COMPRESSIVE STRENGTH (N/mm^2)	
	7 DAYS	28 DAYS
Nominal Mix	24.16	28.84
5%	25.67	33.73

10%	25.05	31.51
15%	20.61	23.51

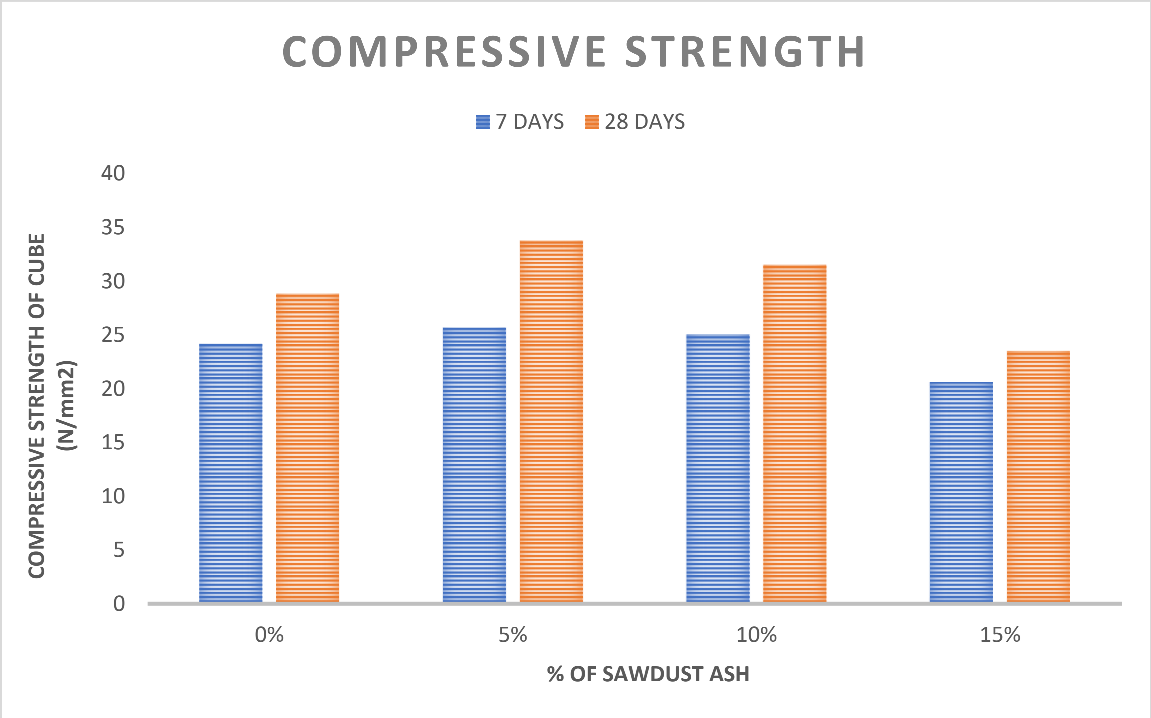

Figure 3: Compressive strength graph.

- A slight increase in the compressive strength in the concrete is observed upon replacing 5% of cement with sawdust ash in the concrete mix. Further replacing of cement with sawdust ash from 5% onwards, will in turn start to gradually decrease the compressive strength of the concrete samples.
- Thus, satisfactory results with a vivid increase in compressive strength are obtained at 5% replacement.

Flexural Strength

Concrete beams of sizes 100mm × 100mm × 500mm were tested for flexural strength. Flexural strength is done in a flexural test machine confirming to IS:516-1959. All the concrete specimens were tested in a 1500 KN capacity Flexural Test Machine. The arrangement is as shown in the figure. Flexural strength. The flexural strength was observed by applying load uniformly at a constant rate till the failure of the specimen. The maximum load applied to the specimen was recorded.

The beam flexural strength can be calculated as follows:
If flexural strength is denoted by σ, then

$$\sigma = FL / wd^2 \ N/mm^2$$

where; F= Maximum force applied
L= Length of the sample
w= Width of the sample
d= Depth of the sample

Figure 4: Flexural Testing arrangement

Table 8: Flexural strength for beams

MIX	FLEXURAL STRENGTH (N/mm^2)	
	7 DAYS	28 DAYS
Nominal Mix	3.350	4.277
5%	3.046	3.862
10%	3.831	4.933
15%	2.915	3.611

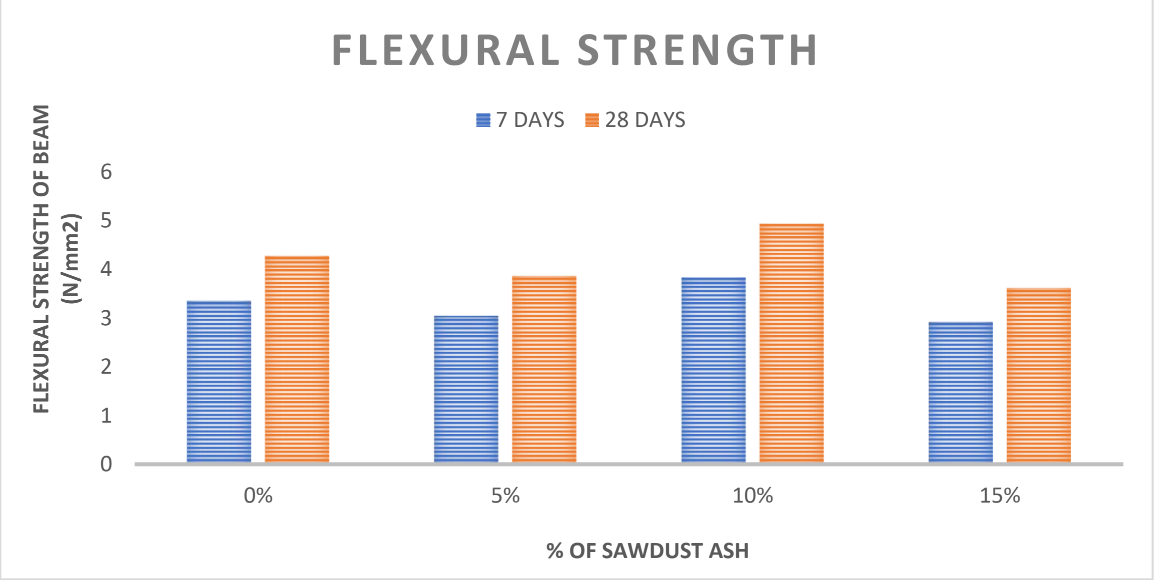

Figure 5: Flexural strength graph.

- A slight decrease of flexural strength is observed at 5% replacement of cement with sawdust ash but suddenly increases at 10% replacement. A further replacement of cement with sawdust ash will cause a gradual decrease of flexural strength in the concrete samples.
- Satisfactory results will be vivid for 10% replacement for the case of flexural strength.

Split Tensile Strength

Figure 2: Flexural Testing arrangement

A split tensile strength test was conducted on cylinders of 150mm X 300mm diameter and height respectively. The test specimens were placed between two platens with two pieces of 3mm thick and approximately 25mm wide plywood strips on the top and bottom of the specimens.

The split tensile strength test was conducted in the same machine on which the compressive strength test was performed. The specimens were tested for 7 and 28 days. This test is conducted in a 1500KN capacity Compression Testing Machine by placing the cylinder specimen so that its axis is horizontal to the plates of the test machine. Narrow strips of packing materials i.e., plywood are placed between the plates and the cylinder to receive compressive stress. The load was applied uniformly at a constant rate until failure by splitting along the vertical axis takes place. Load at which the specimens failed is recorded and the split tensile stress is obtained using the formula based on IS:5816-1999. The results obtained were recorded.

The following formula is used to find out the Split tensile strength of the cylinder

$$\mathbf{ft = 2P / \pi DL} \text{ N/mm}^2$$

where; **P**= Compressive load on the sample

L= Length of the sample

D= Diameter of the sample

The identification of the specimens is as follows:

1. M_1 represents a nominal mix without the replacement of wood ash.
2. M_2 represents a 5% replacement of cement with wood ash.
3. M_3 represents a 10% replacement of cement with wood ash.

M_4 represents a 15% replacement of cement with wood ash.

Table 9: Split tensile strength for cylinders

MIX	SPLIT TENSILE STRENGTH (N/mm^2)	
	7 DAYS	28 DAYS
Nominal Mix	2.21	2.91
5%	2.47	3.15
10%	2.71	3.55
15%	1.97	2.75

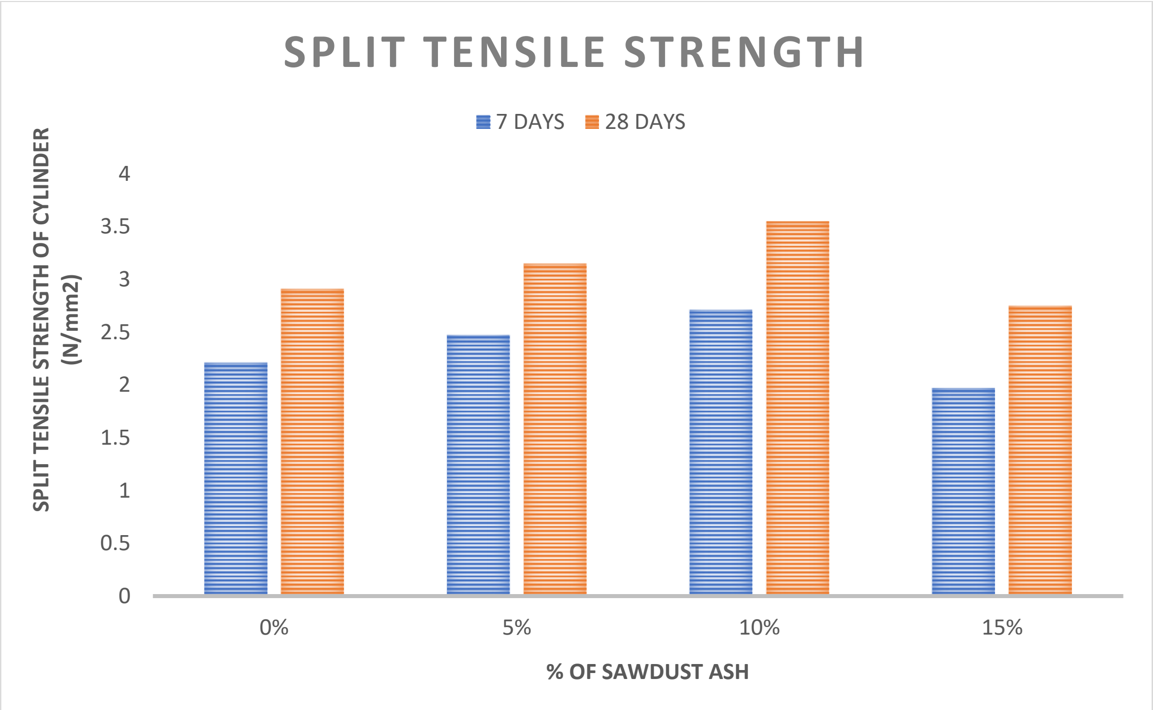

Figure 7: Split tensile strength graph.

- A steady increase of split tensile strength is observed at 5% to 10% replacement of cement with sawdust ash. A further replacement of cement with sawdust ash causes a gradual decrease of split tensile strength in the concrete samples.

- Thus, satisfactory results with a vivid increase in split tensile strength are obtained at 10% replacement.

CONCLUSION

From the preliminary study of the technical use of sawdust ash as a partial replacement of cement in concrete production as a binder (i.e., pozzolana), the following conclusions were obtained;

- The use of sawdust ash in concrete provides additional environmental as well as other technical benefits for all related industries. Partial replacement of cement with sawdust ash reduces the cost of concrete manufacturing.
- The results of the compressive test have indicated that the strength of concrete slightly increases up to a certain percentage and upon further addition, the strength starts to decrease with respect to the percentage of sawdust ash added. That is 5% gives the best result for the compressive strength test after 28 days of curing of the specimens (i.e., 33.73 N/mm^2).
- The results of the split tensile strength test have indicated that the strength of concrete increases to a certain degree of cement replacement with sawdust ash and starts decreasing upon further replacement of cement with respect to sawdust ash. That is 10% gives the best result for the split tensile strength test after 28 days of curing of the specimens (i.e., 3.55 N/mm^2).
- The results of the flexural strength test have indicated that the strength of concrete slightly increases with a slight increase of sawdust ash but gradually decreases upon further addition of sawdust ash in the concrete. That is 10% gives the best result for the flexural strength test after 28 days of curing of the specimen (i.e., 4.933 N/mm^2)
- There is a significant reduction in the density of concrete with the increase in the percentage of sawdust in the concrete.
- Sawdust ash is can be used as a cement replacement due to its pozzolanic properties as seen in some of the strength tests conducted. Thus, sawdust ash can replace cement in the concrete up to a certain degree without compromise to the concrete strength.

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