RESPONSE OF SELF-COMPACTING CEMENTITOUS SYSTEMS USING WOOD SAWDUST

MS STRUCTURES THESIS DISSERTATION

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Dedication

Let me dedicate this piece to

Cristiano Ronaldo, whose incredible work ethics and persistent drive motivates me every day.

Siiiiiiiiiii!

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All praise be to Allah Almighty alone

I extend my heedful thanks to my research supervisor Muhammad Usman and co-supervisor Asad Hanif. Also my class fellows and the structures' lab staff for their continuous co-operation and help in the lab. I am also indebted to all the faculty members of NUST Institute of Civil Engineering (NICE) for their knowledgeable suggestions.

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ABSTRACT

It's no surprise that preventive measures to matters of resource reduction and global pollution are the prime aspects if not the main objective of most of the researches. The construction industry is no exception to that and having a direct major impact on environment and its localities, the need is more than ever for an environment friendly material in construction material. An attempt is made in the field of high performance self-compacting cementitious system to have an eco-friendly construction material utilizing raw materials, in this case wood waste sawdust, to not only benefit the environment but also keeping the material quality and its standard intact. Sawdust has been used previously in conventional concrete and mortar systems with mix reporting of results. This the first study of sawdust being used in high performance self-compacting cementitious system. Two different sizes of wood sawdust (SD) namely, coarse sawdust(CSD) and fine sawdust(FSD) were used with neat Portland cement paste system in replacement mode. The replacement of SD was 2%, 5% and 7% in each case i-e coarse and fine. While the results showed a consistency in the slight decrease of compressive strengths, the reduction in shrinkage with samples having sawdust (SD) were highly significant. Densities and weights were also reduced of the hardened specimens having sawdust. Moreover, the effect of water and air curing along with the water absorption capacity of sawdust in powder form and the comparison of water uptake of self-compacting paste samples with and without sawdust at different days during wet curing showed that sawdust has the potential to serve as an internal curing agent in Self compacting cementitious system.

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LIST OF NOTATIONS\ABBREVIATIONS

ACI	American Concrete Institution
SD	Sawdust
FSD	Fine Sawdust
CSD	Coarse Sawdust
ASTM	American Society of Testing Of Materials
SCP	Self-Compacting Paste
SCM	Self-Compacting Mortar
SCC	Self-Compacting Concrete
XRD	X-ray diffraction
XRF	X-ray Fluorescence
SP	Super plasticizer
SRM	Secondary Raw Material
W/C	Water to Cement Ratio
SCCS	Self-Compacting Cementitious Systems
PC	Portland Cement
FTIR	Fourier transform infrared spectrometry
TGA	Thermal gravimetric analysis
SEM	Scanning electron microscopy

Chapter 1

INTRODUCTION

1.1 PROBLEM STATEMENT

The main aim of this research is to utilize wood waste(sawdust) in a self-compacting cementitious systems as an internal curing agent and explore the overall response of the paste system when treated with wood sawdust.

1.2 RESEARCH SIGNIFICANCE

In the literature, petite work is reported on the use of sawdust as a lightweight aggregate and thermal insulator in conventional concrete and mortar systems. In some cases, especially in mortar system, the sawdust specimen is reported to have slight strength reduction but improved heat response. The previous works have not elaborated the effect of the size of sawdust particles that may have over the system and the prospect of it acting as an internal reservoir for the system. This study investigates in detail the sawdust absorption and desorption properties and its effect on the shrinkage, strength and overall behaviour of the high performance paste specimen, also the effect of size difference of sawdust used on the properties of the system. Different proportions of the cement replacement with sawdust were studied and the difference in results were compared. The effect of water curing and air curing on the samples treated with different proportions of sawdust in the self-compacting paste system was also studied.

1.3 RESEARCH METHODOLOGY

Keeping in view the previous work done on sawdust in cementitious system, in this study the emphasize was to use sawdust in replacement mode in self compacting cementitious system. Self-compacting/consolidating concrete is a type of concrete which flows and encapsulates the form work without any use of external vibrators due to its own weight and workability. Two different sizes of sawdust were used, coarse sawdust(CSD) and fine sawdust (FSD). Self-compacting cementitious systems having wood sawdust in replacement mode were characterized by bending and compression tests, Water-demand measurements, flow measurements, Superplasticizer demand, water absorption capacity, total linear shrinkages, fresh paste densities comparison, wet curing and air curing effect on samples.

1.4 OBJECTIVES

The objective of this research was to test and analyse the use of sawdust in cementitious system with emphasize on mechanical properties, effect of air and water curing and over all possibility of using sawdust as an internal curing agent.

1.5 THESIS ORGANIZATION

The first chapter gives an introduction to the thesis topic. The 2^{nd} gives the literature review. The third chapter presents various standard methods and apparatuses employed for conduction of laboratory tests. The fourth chapter presents discussions and reasoning. The fifth chapter gives conclusions and recommendations.

Chapter 2

LITERATURE REVIEW

2.1 SELF-COMPACTING CEMENTITIOUS SYSTEMS (SCCS)

Self-consolidating concrete or sometimes self-compacting concrete (SCC) is an extremely fluid mix of concrete having better segregation resistance with moderate viscosity and hence fills the complex formwork by flowing through obstructions and narrow corners without the need of any external vibrators. As per ACI committee 237R-07 [1] Self-compacting concrete (SCC) is a highly flow-able, non-segregating concrete that can spread into place, fill formwork and encapsulate the reinforcement without any mechanical consolidation. Its inception roots back to 1980 in japan where thereafter in no time it quickly worked its charm over all of Europe and the research community all over the world could not resist investigating it further to its limits. The same attempt is made here in this research. It has also been suggested as per European Guidelines that it has the same Engineering behaviour as that of the conventional concrete which is uniformly and carefully vibrated externally. Depending upon how the segregation resistance is being achieved SCC can be one of the various type in itself, it can be powder type SCC, viscosity agent type SCC or combination of both.

In a broad sense self-compacting cementitious system can be any of these three types

- Self-compacting paste systems
- Self-compacting mortar systems

- Self-compacting concrete systems

2.1.1 Self-compacting paste systems

The major controlling factor in the behaviour of concrete and its properties goes to its comprising paste portion system [2]. Hence Self-compacting paste systems serves as not only an important demonstrative but a major representative sample for the self-compacting mortar (SCM) and self-compacting concrete (SCC) systems having a significant effect on the properties of overall system. Addition of different admixtures, internal curing agents and SRM's to a paste system are some of the several techniques used to get a paste of desired properties in a system.

2.2 LITERATURE ON SAWDUST

It's no surprise that preventive measures to matters of resource reduction and global pollution are the prime aspects if not the main objective of most of the research programs being carried out in any field [3]. The construction industry is no exception to that and having a direct major impact on environment and its localities, the need is more than ever for an environment friendly material which utilizes raw/waste materials to not only benefit the environment but also keeping the material quality and its standard intact [4]. On the same lines, an attempt is made in the field of self-compacting cementitious system using wood waste. Wood is one of the major construction and accommodating material, hence generation of continuous large piles of wood waste in sawmills and farms is inevitable. Hence, wood waste specially in the form of sawdust is amassed all over the world and have serious environmental and health issues [5].The table 2.1 shows the annual wood waste data in major regions around the world. The storage of sawdust in large piles and their consequent decomposition at rapid rate could also worsen the green-house effect [6].

Table 2.1: Wood waste data in some important regions

Country/Region	Total Wood Waste (tonnes/year)	Non-Recycled Wood Waste (tonnes/year)
United States of America	64,047,240	25,764,050
United Kingdom	4,600,000	1,840,000
Germany	8,800,000	3,520,000
Australia	4,508,136	1,741,000
Pakistan	1,730,948	1,384,758

Previously wood sawdust being used in conventional concrete as lightweight aggregate and reduction in compressive strength was prominent [7]. Valeria [5] showed the effect of wood sawdust in mortar and suggested a better performance of mortar with fine sawdust rather than using coarse size. Bouguerra et al. [8] used wood waste as light weight aggregate in cement clay mix and observed an increase in porosity and reduction in water absorption of the system. demonstrated the that better thermal and insulation properties are achieved when wood waste used in cement and clay mix. Adebaku et al [9] used sawdust in hollow concrete sand blocks and showed that at 10% replacement sawdust with sand in mortar, the over-all cost and weight can be lessened by 3% and 10% respectively. Bederina et al. [10-12] demonstrated that by coating wood shavings with cement paste prior to its corporation in the system improved the thermal conductivity and compressive strength of the system. Also it was observed that densities tend to decrease when sawdust was used. Turgut et al. [13, 14] conducted experimental studies and insisted the potential use of sawdust with limestone bricks to have lightweight cost effective bricks. Rojas et al. [15] suggested that better acoustic and thermal properties were achieved with false ceiling plates when wood sawdust shaving were used in the mix as opposed to conventional plaster mixes. Morales et al. [16] investigated the physical and mechanical behaviour of wood-gypsum composites by using wood waste as an additive. It was observed that the incorporation of wood in the system lowered the hardness and thermal conductivity of the composites, whereas the compressive strengths were also reduced of the composites. Coatanlem et al. [17] used wood chippings in the concrete system and studied its durability, it was suggested that better results were achieved due to an improved bonding between chippings and cement paste when wood chippings were saturated with sodium silicate solution prior to its use.

All in all, while some projects have not very satisfied results in terms of mechanical properties of cement when used with sawdust [18, 19] some have better results when used sawdust in replacement mode [20, 21]. Keeping in view the previous work done on sawdust in cementitious system, in this study the emphasize was to use sawdust in replacement mode in self compacting cementitious system. Self-compacting/consolidating concrete is a type of concrete which flows and encapsulates the form work without any use of external vibrators due to its own weight and workability. Two different sizes of sawdust were used, coarse sawdust (CSD) and fine sawdust (FSD). Although the difference in size was of a few hundred microns between them, the reason for choosing two different size of sawdust were as fallows

1) The idea in using coarse sawdust was to have a minimal amount of pre-treatment before its use in cement. The coarse sawdust can easily and directly be obtained from majority of the sawmills and farms because the machines used to cut wood logs are typically the same and produce the same size sawdust waste which we call here coarse sawdust. They were picked and packed in plastic bags before they were directly utilized without any extra special treatment.
2) The coarse sawdust was then grinded in grinders to have the size reduced in order to make a comparison and get an idea of the effect of different sizes of sawdust in self-compacting cementitious system.

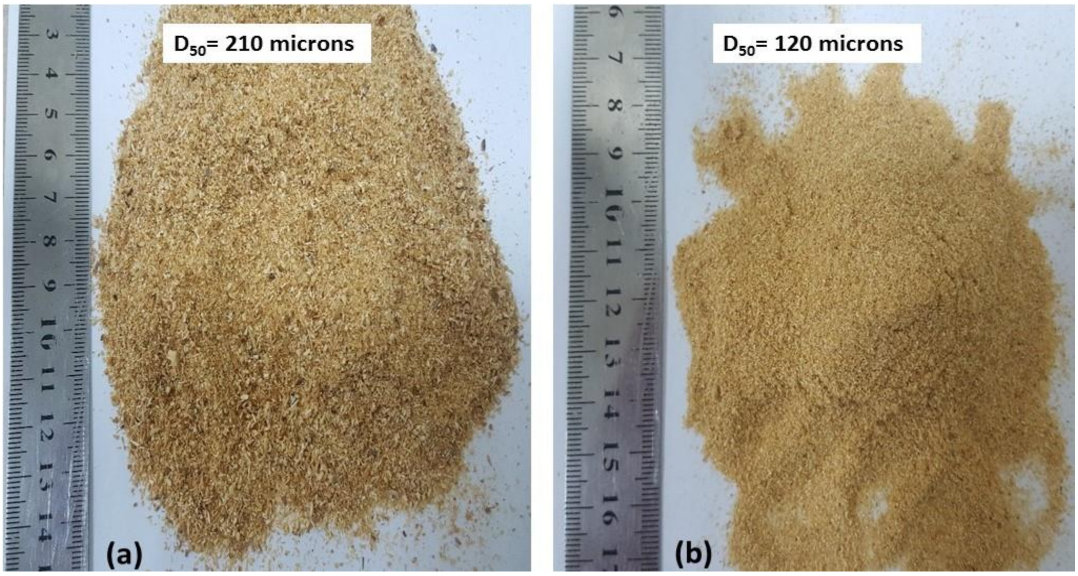

Fig 2.1: a) Coarse sawdust (CSD) b) Fine sawdust (FSD)

Fig 2.1 shows the visual of the coarse and fine sawdust.

Self-compacting cementitious pastes having wood SD as partial replacement of cement were characterized by compression tests conforming to DIN 196-1. A total of 112 prisms were tested after wet and air curing regimes with a loading rate of 0.25 N/mm^2 to study the effect of SD replacement on strength of cementitious system at

3, 7, 14 and 28 progressive curing days. Vicat Water-demand measurements according to EN 196-3 keeping the water temperature and relative humidity in the testing chamber constant i-e 21±1º C and 55% respectively, to accurately measure the absorption of SD in cementitious system using Vicat apparatus. Flow measurements and flow times using Hagerman's mini slump cone apparatus to have an idea about the viscosity and yield stress of the systems having SD. Superplasticizer demand by doing trials on flow table to achieve the desired target flow of 30±1 cm and its co-relation with SD replacement. Air content of fresh self-compacting paste systems with and without sawdust using Luftgehaltspruefer device. Water absorption capacity of powdered SD of fine and coarse SD to observe the effect of different particle sizes on absorption capacity of SD. Comparing total linear shrinkages using German apparatus Schwindrine and fresh paste densities of all formulation samples to establish a co-relation of samples with and without SD.

2.3 SUPER PLASTICIZERS

One of the major advances in cement based materials and technology are super plasticizers. These are admixtures (chemical), when added to cement based system, further improves its workability. The workability of the system is related to its particle mobility, for which excess water is needed. Excess water in cement system is never favoured due to its detrimental effects. To counter this, super plasticizers are always favoured which disperse the particles into spaces within their size range keeping water content constant. In a broad sense a super plasticizer reduces the excess water demand needed for a system to have a desired flow and workability. To summarize,

1) When used, gives desired workability at low water to cementitious material ratio.
2) Achieves Workability through “electrostatic repulsive forces” in the system, an ensured mechanism which is uniform throughout the system and gives better dispersion of fine materials such as cement and different SRMs [22].
3) Also responsible for lowering the porosity of cementitious systems in hardened state [23].

These admixtures can be Type G or Type F high-range water reducing agents and can be any of the two types, Type 1 or Type 2 category of ASTM C 1017 when utilized for better flow of concrete. The important chemical substances on which Super plasticizers are classified into three groups are namely, sulfonated melamine and naphthalene-formaldehyde condensates and polyether poly-carboxylates.

2.3.1 Melflux

It is a widely used third generation poly-carboxylate ether (PCE) super plasticizer used in high performance cement systems. The origin of 3rd generation PCE Super plasticizers dates back to late seventies in Japan and Germany [24]. An important and fundamental ingredient of high performance cement system, not only it reduces the water demand but can also be utilized to control open time and setting time of the system. Structure wise, they are like “comb” type molecules made from the combination of poly-carboxylate and polyether groups as the name “PCE” suggests. Poly-carboxylate comprises the main trunk or main chain portion of the molecule while polyether groups called as the “side chains” or sometimes “grafts“ are attached to the main trunk(poly-carboxylate) by strong chemical bonds.

Melflux being from PCE powdered Family, when used in correct proportions reduces water demand effectively and also helps in prevention of segregation and bleeding.

2.4 BINGHAM MODEL FOR CEMENT PASTE

A chemistry professor, Eugene Bingham, working on concentrated suspensions like paints, perceived the idea of the term “Rheology” after observing the unusual behaviours in flow during his work. Hence, in a generic sense, Rheology is basically the study of behaviour of a particular substance in-terms of its flow and deformation. A more sophisticated definition of rheology is “the deformation and flow upon application of shear stress to matter”. As every material is studied by following some basic model for its Rheological properties. In cement based system that model is called Bingham model. Bingham model explains the rheological characteristics of any cement based system. There are two primary parameters to Bingham model in-case of cement based systems.

1) Viscosity
2) Yield stress

Being a non-Newtonian fluid, upon application of shear stress its viscosity tends to decrease, once the shear stress is removed it regains its original stationary viscosity. The phenomena is called Brownian motion, which is dominant in cement paste system once it is motionless. The Brownian motion works in the following way, when the system is stationary the particles naturally collide and push each other when finally, each particle moves to its respective favourable spot and settles there firmly, hence increasing the overall temporary viscosity of the system. This process is isothermal and also reversible meaning once the shear stress is again applied to the system, the viscosity decreases and the flowing ability can again takeover [25]. This over all process repeating again and again is called shear thinning and the temporary gain and loss in viscosity is called pseudo-plasticity [26]. The exact calculation of thixotropic and pseudo plasticity is a complex mechanism, specially, when cement is involved because of its highly time dependent behaviour i-e the hydration process, which assumes charge over the system as soon it comes in contact with water. Moreover, after a certain time period, the shear thinning and viscosity behaviour of cement based systems becomes non dominant and irreversible respectively [27, 28].

In case of cement paste systems the thixotropic phenomena can best be explained in terms of coagulation and dispersion, the two particles hold each other by virtue of potential energy and are only separated when some work is done on them [24].

2.5 WORKABILITY

The ease with which the mix in its fresh state encapsulates and fills all the corners of the formwork is called its workability. It is calculated through Hagerman's cone using slump cone test apparatus. The procedure is illustrated in chapter 3

2.6 SHRINKAGE

Shrinkage in concrete is inevitable and throughout the life of concrete it is subjected to volume loss either it maybe autogenous or it might be induced. Especially in case of HP paste system, where the w/cm ratio is comparatively low which causes a general decrease in the internal humidity of the system resulting in a consequent higher shrinkage. However, how much of it can be controlled or reduced is a topic of much debate and is a fertile ground for research communities. The phenomena of shrinkage begin to take place as soon as water is added to the cementitious system. Shrinkages are of different types and nomenclature, it can be plastic shrinkage, drying shrinkage, carbonation shrinkage and autogenous shrinkage. Which type of shrinkage precedes another depends on the material used and time taken for different parts of cement hydration process to take place. Generally speaking, the type of shrinkage that occurs while the system is still in its plastic phase is called plastic shrinkage, drying shrinkage is mainly occurs due to the loss of water occupied in pores of the cement system. When CO_2 reacts with hydrated cement in the presence of moisture, the type of shrinkage that occurs is called carbonation shrinkage. . Autogenous shrinkage is “the bulk strain of a closed, isothermal, cementitious material system not subjected to external forces” [23]. Chemical shrinkage is also often used in literature and it denotes the volume reduction due to hydration reactions of cementitious material.

2.7 WET CURING

Every cementitious system needs water to fully complete its internal hydration process through its course of time. Curing is that amount of excess water which is not part of the initially mixing water content mixed at early stages which helps to achieve the above mentioned goal i-e full hydration of the cement system. Adequate amount of moisture around cement when it is set is very important, because subsequently the desired mechanical and physical properties of the cementitious system are greatly influenced by it. The quality of the properties like strength, serviceability, durability and resistance to wear and abrasion is mainly dependent on the products of hydration which in turn depends on the smooth supply of water to its reactants.

2.7.1 Internal Curing:

The conventional curing method we are familiar with is to keep the sample wet for sufficient amount of time so that hydration continues without any hobble. This type of curing is known to have proven well for typical water cement w/c ratios of more than .42 [29], as it makes sure the sample stays moist and warm at the surface and the high added water content does the rest of its intended job during hydration. But with high performance cement systems, where the water to cement w/c ratio is kept very low and he strength requirements are always high, this conventional curing fails to fully cope and appreciate the complex hydration process of these high strength cement systems, a typical example is the formation of cracks at early stages of the sample. Therefore, there is a need for such a material which can serve as a reservoir inside the matrix. They may be induced in the form lightweight fine aggregates, super absorbed polymers or in this case saturated wood fibres. This internal curing not only helps in the hydration stages but can prevent early age cracking and subsequently giving better results in terms of strength and reduced shrinkage. Internal curing can also be called ‘self-curing’.

2.8 AIR CURING:

The air curing was also done for all the samples according to ACI and ASTM guidelines and the average laboratory conditions were 32ºC and 55% humidity.

2.9 WATER ABSORPTION

The water absorption of sawdust is one of its main properties and a major concern here. Sawdust when submerged in water for a predefined period, absorbs a uniform amount of water, which can later be desorbed when needed, it's like internal curing agent but the capacity of sawdust holding water is significantly less when compared to Super Absorbent Polymers (SAP). To exactly calculate and have a better understanding of how much water sawdust absorbs when submerged in water, two different techniques were utilized, namely sieve method and teabag method.

2.9.1 Sieve method

In this method [30] sawdust was poured in beaker full of water and kept it submerged for 24 hours. After 24hrs the sample was passed through a 200 sieve, through which whole water is passed while the sawdust is remained on it. The remaining sawdust quantity was kept at room temperature for about 15 mints so that the water which accumulated at the surface is evaporate and only the absorbed amount water is left. Known amount of saturated sawdust sample was placed in oven for 24 hours at 120 ºC. After 24 hrs all the water is being evaporated and only the fully dried sawdust is being left. Weight was taken at every step and the results are reported in the next chapter.

2.9.2 Tea bag method

As the names suggests, a tea bag method [31] is used to accurately measure the water absorption of a powder material which do not pass through the tea bag filter. Both empty and wet weight of a tea bag is noted before a known amount of weighted fully dry powder is poured and the teabag is sealed. The sealed tea bag is then placed in a beaker of water for 24 hrs so that the material absorbs the water to its capacity. The weight of the wet teabag is subtracted from the total weight of saturated sample that is enclosed in a teabag which was previously submerged in the water for 24 hrs. The difference between the dry poured sample and fully saturated sample in the teabag after it was kept submerged in water for 24 hrs gives is the idea about its absorption capacity.

Chapter 3

EXPERIMENTAL PROGRAM

The procedures adopted and the materials used to carry out the study are narrated here in this chapter.

3.1 MATERIALS:

The main and primary materials which had an extensive use in this study with their details are listed below.

3.1.1 Cement type:

Ordinary Portland cement type 1 of grade 53 meeting the requirements of ASTM C150-07 [14] was used. Manufactured by Best-way Industries Pakistan and is locally available in Islamabad, Pakistan. The chemical composition is given in a table at later chapter.

3.1.2 Sawdust:

The Sawdust collected was ordered specially to be fully hundred percent uniform and of the same source to avoid compatibility issues in their consequent usage and comparison. The source tree and logs of which sawdust was collected was pure deodar, a preferred wood by consumers for their furniture and wood construction due to its durability and smooth finishing quality.

Two different sizes of sawdust were utilized, as shown previously.

- Coarse Sawdust (CSD), 0-400 microns
- Fine Sawdust (FSD), 0-250 microns

3.2 FORMULATIONS:

The sawdust was used with cement in replacement modes and the replacement of sawdust in cement was 2%, 5% and 7% of the total weight of cement used. Making a total of 7 formulations, 3 for CSD replacement, 3 for FSD replacement and one control formulation having no replacement at all as shown in Table 3.1.

Table 3.1: List of formulations with fine and coarse sawdust

S.No	Cement	FSD %	CSD %	SP Demand %	W/C %	Formulation ID
1	C1	0	0	.19	26.25	S-0-0
2	C1	2	0	.253	30	S-2-0
3	C1	5	0	.706	33.5	S-5-0
4	C1	7	0	1.413	36.5	S-7-0
5	C1	0	2	.307	28.5	S-0-2
6	C1	0	5	.418	33	S-0-5
7	C1	0	7	1.04	36.5	S-0-7

The clarification on the nomenclature of each formulation goes like this. For example, a formulation S-2-0 means that a CEM 1 type cement used with 2% replacement of Fine sawdust (FSD) having a dose of SP of 0.253 percent of the total quantity of the sample with 30% percent of the total weight of the system added water. Similarly, S-0-2 means 2% replacement of coarse sawdust. The rest of the formulations should be called respectively.

3.3 MIXING REGIME:

The mixing regime followed is as under and was kept the same for all formulations. After addition of water to the system, an immediate slow (145 rpm) mixing of 30 seconds followed by a quick unlocking, unloading of the Hobart mixer bowl and scraping the material that may have stick to the walls of the bowl hence making it ineffective during the mixing process before resuming the mixing regime, this time fast (285 rpm) mixing for about 2.5 minutes. So 30 secs slow pace (145 rpm) plus 2.5 mints fast pace (285 rpm) mixing, making a total of 3 minutes mixing time.

It is important to note that for paste systems containing sawdust in replacement mode, a 30 seconds slow (145 rpm) dry mixing prior to addition of water was also done.

3.4 FLOW MEASURMENTS:

For a target flow of 30±1cm, different trials were done using Hagerman's mini cone apparatus as shown below with cone dimensions 10 x 7 x 6 cm^3. The SP demand which mainly controls the flow of the SCP system was calculated through trials for each formulation.

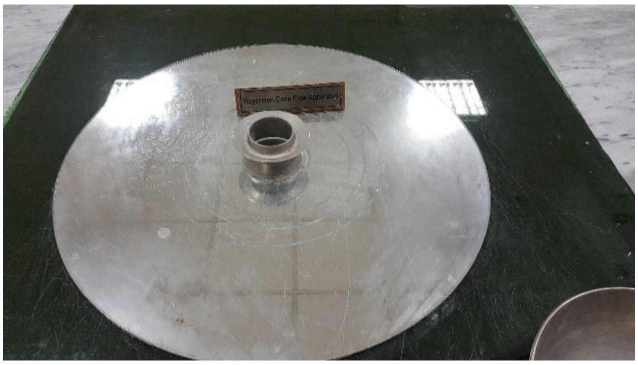

Fig 3.1: Hagerman's mini cone apparatus for flow

3.5 STRENGTH TESTS:

The strength tests for compression were carried conforming to EN 196-1:1994. The tests were conducted at 3, 7,14 and 28 days for each formulation. Four prism specimens moulded in steel moulds of dimensions 4 x 4 x 16 cm at each day for each formulation individually were tested, making a total of 64 compression tests for each formulation and average was taken.

3.6 SHRINKAGE:

The total shrinkage response of all the seven formulations was calculated using German Schwindrine apparatus as shown below having channel dimensions of 4 x 6 x 25 cm^3. The response was recorded of the first 48 hours for each formulation. The relative humidity and temperature of the laboratory was 55% and 32°C.

Fig 3.2: German shrinkage apparatus Schwindrine

3.7 CHEMICAL TESTS:

Chemical tests were done on the materials to understand its chemical composition and compounds/elements involved. The tests that were performed are namely FTIR, XRD, TGA and XRF.

3.8 WATER ABSORPTION:

The water absorption capacity was calculated by two methods as discussed previously in detail i-e the teabag method [37] and the sieve method [38].

It was also noted that the absorption rate of SD is not immediate when added to water, it takes several hours for SD to absorb the water and reach its saturation capacity and settling down. The results are given below

Table 3.2: Water absorption capacity of FSD and CSD

sample	**Method Used**		**Average Water absorption capacity (g/g)**
	Teabag method (grams/gram)	Sieve method (grams/gram)	
Coarse sawdust	4.5	5.5	5
Fine sawdust	6.8	7.5	7.15

3.9 AIR CONTENT:

Air content in fresh paste samples were calculated to have an idea about porosity and density of the system. The device used was Luftgehaltspruefer as shown

Fig 3.3: Air content measuring device Luftgehaltspruefer

Chapter 4

RESULTS AND DISCUSSIONS

4.1 PHYSICAL PROPERTIES OF SAWDUST:

Particle size distribution of both coarse and fine sawdust was performed using Master-sizer Malvern 3000 particle size analyser. The graphs are shown below. The D_{v50} which is called the median particle size was calculated for each size and also for cement. Moreover, specific gravities and bulk density was also calculated by cylinder method using Ethanol. As the size decreased of sawdust, its density increased slightly as seen below.

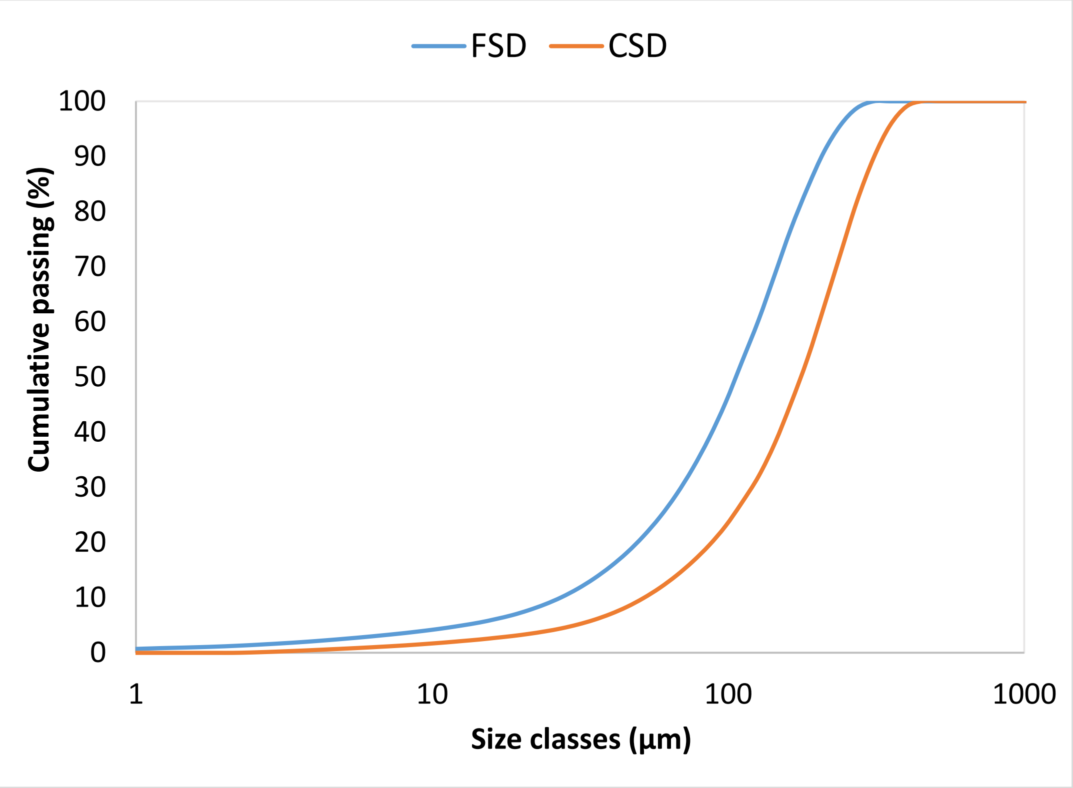

Fig 4.1: Particle Size Distribution curves for both FSD and CSD

Table 4.1: Particle size distribution of fine and coarse sawdust

Property	Fine sawdust (FSD)	Coarse sawdust (CSD)
D_{v10} (μm)	30	60
D_{v50} (μm)	120	210
D_{v90} (μm)	230	360
Loose Bulk Density (gm/cm^3)	.24	.21
Solid particle Density (gm/cm^3)	1.108	1.054

4.2 CHEMICAL COMPOSITION OF MATERIALS:

The FTIR, XRD and TGA was done for sawdust to understand its chemical nature and XRF was performed for cement.

4.2.1 FTIR of sawdust:

The FTIR of Sawdust was done using Bruker model ALPHA 1 FT-IR Tensor with Laser class 1 beam splitter technology in the scanning range of 500 – 4000 cm^{-1}. The results are shown

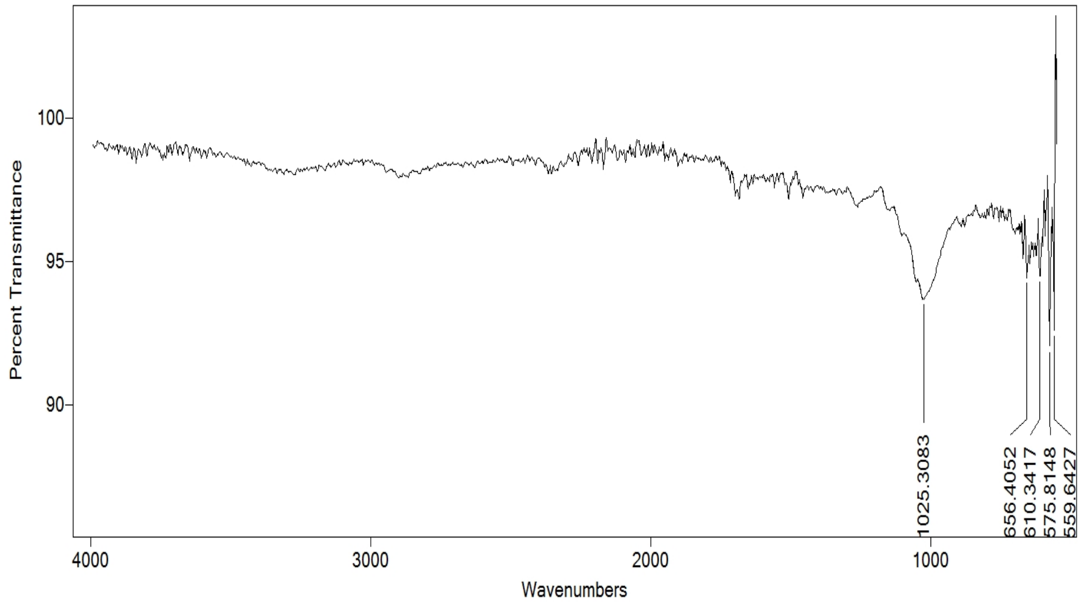

Fig 4.2: FT-IR analysis of powdered sawdust specimen

The peaks were mostly from 500 to 1100 range sparingly distributed. The FTIR test showed a pattern similar to hemp seed. Peaks in FTIR graph were corresponded with FTIR chart, the result showed dominance of Alkyl halide groups and cellulose with lignin. The analyses showed the high presence of Alkyl halide functional groups having strong bonds with carbon.

4.2.2 X-Ray Diffraction (XRD) of Sawdust

The XRD test of sawdust was done using Bruker X8 Apex diffractometer. Three major peaks were detected as shown below. The data obtained was analysed qualitatively using MATCH software and phases were searched in the internationally available data base to look for pattern. The compounds discovered are shown in table.

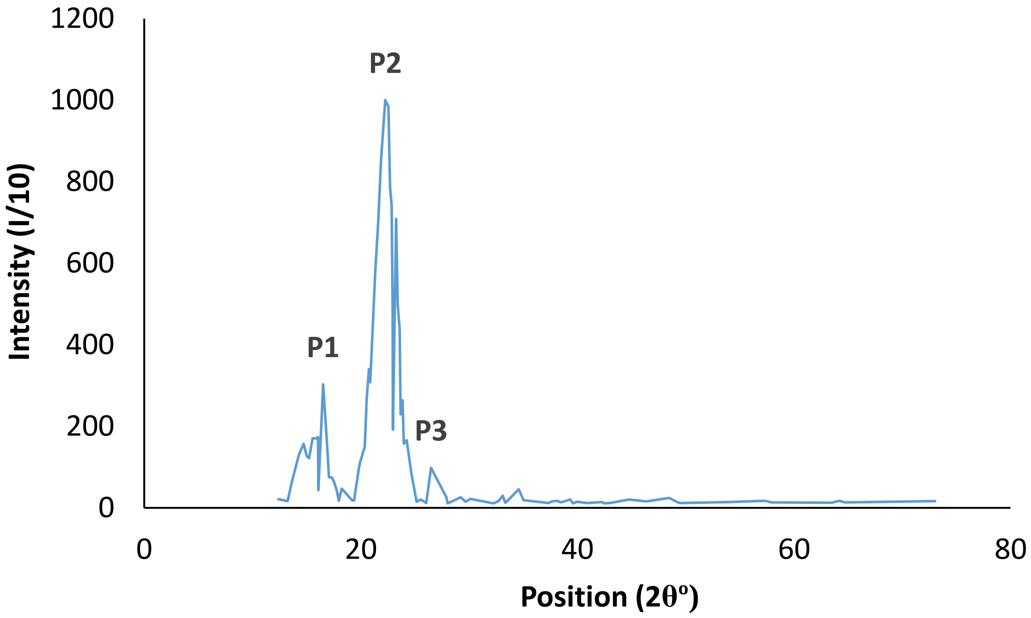

Fig 4.3: XRD analysis of powdered sawdust

Table 4.2: Data from XRD analysis of powdered sawdust

sample	OCH_3 %	Cellulose ($C_6H_{10}O_5$) %	Lignin %
Wood sawdust	4.9	57.6	28.1

4.2.3 Thermal Gravimetric Analysis (TGA) of sawdust:

The thermal gravimetric analysis (TGA) was done of the powdered sawdust. Four primary weight loss intervals were prominent with the details as follow. The first interval starting at 25ºC and ending at 205ºC. First interval is due to extraction of internal moisture and adsorbed water with a weight loss of 11.38%. Second and third interval starting and ending at 205ºC, 363ºC and 363ºC and 500ºC respectively. During these intervals the depolymerisation of hemi-cellulose and lignin occurs and the total weight loss is 82.94%. The fourth interval starting at 480ºC and ending at 800ºC. At this interval the degradation of cellulose and lignin occurs with weight

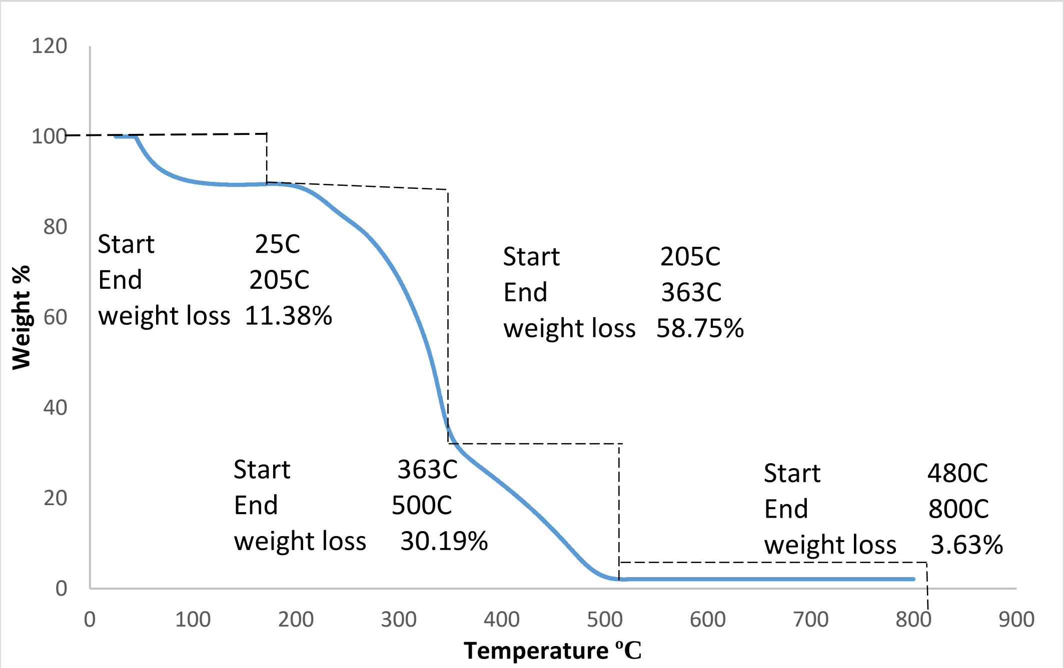

Fig 4.4: TGA curve for sawdust with intervals

loss of 3.63%. The total loss on ignition was 97%.

4.2.3.1 **TGA of hard paste systems:**

For comparison the TGA of all the formulations are drawn on a single graph. The following observations were made.

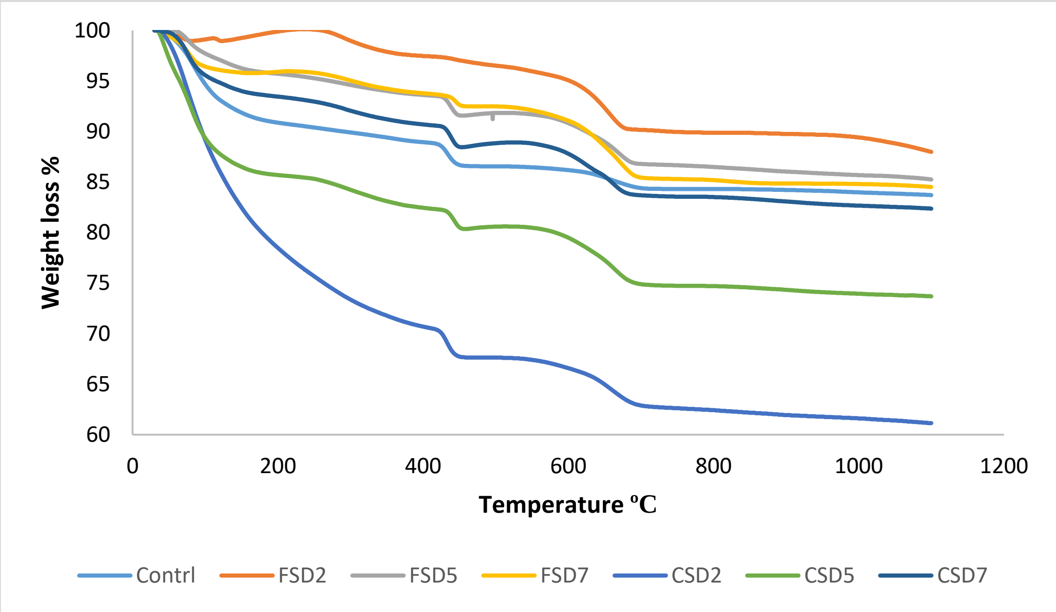

Fig 4.5: TGA of powdered SD and hard paste samples

As previously the loss on ignition of SD is 97 percent while the maximum loss on ignition with hard cement paste is around 38 percent. Reason is obvious, SD is powdered and highly combustible as compared to cement matrix. Also the maximum temperature for SD is 500 degrees centigrade after which the weight loss is constant, while for pastes the temperature can get as high as 1100 degrees centigrade.

Comparing the cement matrix, the range for LOI is 10 to 40 percent suggesting low combustion. Furthermore, the matrix specimen's lines are in close proximity to each other, but if we are to draw a comparison, the CSD specimens has more weight loss than FSD specimens. Also the weight loss of the FSD ones is less than control while CSD has more weight loss than control sample

The maximum weight loss is observed with CSD2 formulation, the one important factor here could be the internal moisture content which contributes to loss of that material, Although the samples were heated at 100 ºC for drying they may have absorbed moisture during room cooling of the samples. Also one important observation made here was that the peaks and line patterns of TGA of cements samples were somewhat similar with respect to temperature suggesting a similar activity at corresponding temperature.

The first effect is due to evaporation of surface adsorbed water because samples adsorbed water. The second endothermic effect is attributed to the dehydration of C–S–H and ettringite and calcium aluminate hydrate. The temperature at which these compounds lose water depends upon the available CaO:SiO_2 ratio in the hydrated cement matrix. The third effect, shows the decomposition of $Ca(OH)_2$ formed during hydration. Finally, an endothermic reaction indicates the decarbonation of calcium carbonate in the hydrated compound.

4.2.4 X-Ray Fluorescence (XRF) of Cement

For chemical composition X-ray Fluorescence analysis was done using Axios Advanced WD XRF PANylitical by pellet method and the results are shown in the table below.

Table 4.3: Chemical and Physical analysis of Cement

Sample	Al_2O_3 (%)	MnO (%)	MgO (%)	SiO_2 (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	LOI (%)	D_{50}, µm	BET m^2/g	TiO_2 (%)	Fe_2O_3 (%)
OPC	4.96	0.04	2.23	19.17	65.11	0.57	0.51	0.07	3.85	16.2	1.1	0.28	3.21

4.3 WATER DEMAND:

The vicat water demand for each formulation was separately calculated by doing trials conforming to EN 196-3 and keeping the water temperature 21±1 ºC. The water to cement ratio was kept the same as their respective water demands for each formulation. The results are shown.

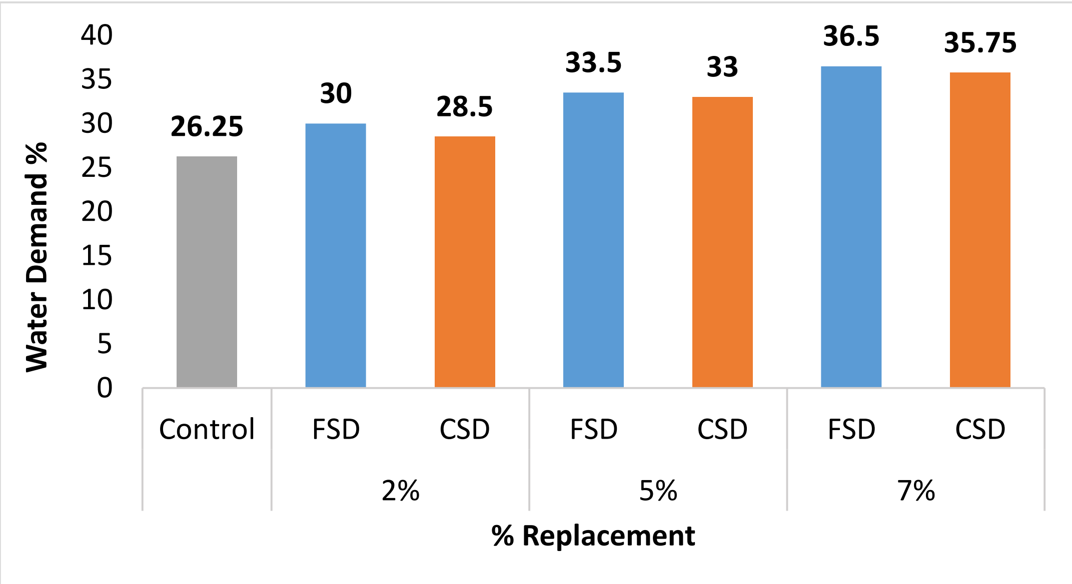

Fig 4.6: Water demands of the corresponding formulations

It was observed that the increase in water demand of the system is directly proportional to the percent of SD replaced. This is due to the fact that sawdust, during its mixing in the system tends to absorb the water initially added and increases the over-all demand. Moreover, in the comparison of coarse and fine sawdust at their respective replacement modes, there was a slight increase in water demand of fine sawdust formulations confirming the fact that FSD attracts and absorbs more water than CSD, this is because by reducing and refining the sawdust size the effective absorption capacity of the same SD sample increases.

4.4 SUPER PLASTICIZER (SP) DEMAND:

The SP Demand for each formulation was calculated by doing trials for each formulation using the Hagerman's mini cone apparatus with cone dimensions 10 x 7 x 6 cm^3 for the target flow of 30±1 cm. It is important to note here that the water to cement ratio was kept the same as their respective water demands previously calculated. The results are shown below.

It can be observed that with increase in SD content the SP demand also increases proportionally. An understood reason for this is the increased internal adhesion and abrasion provided to the smooth flow of the paste by the addition of irregularly shaped SD particles added to the system. This study and the matrix system follows Bingham plastic model for behaviour of Newtonian fluids [15].

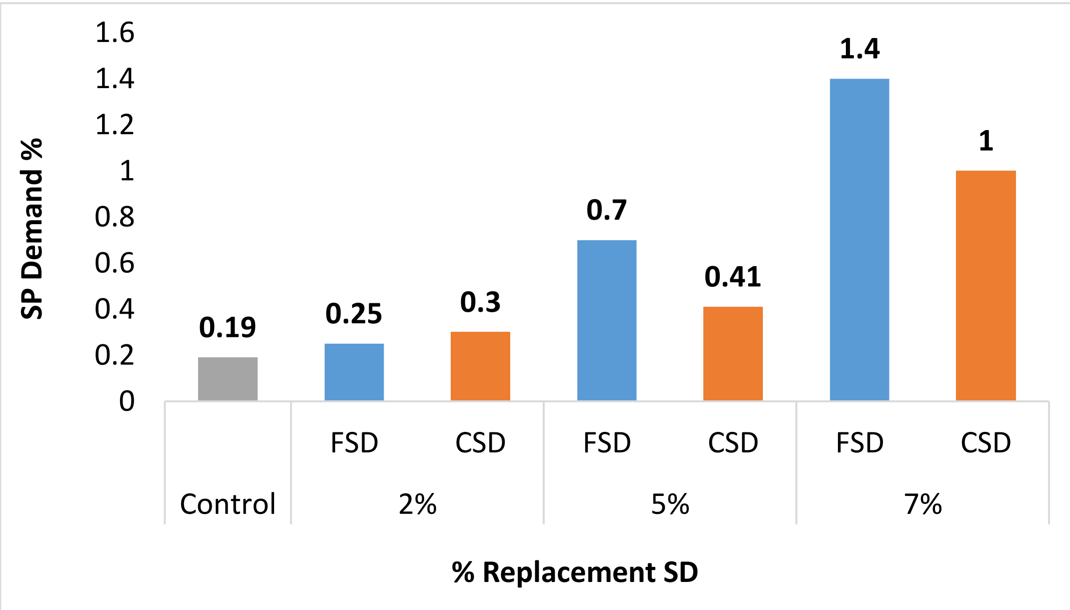

Fig 4.7: Superplasticizer demand of the corresponding formulations

4.5 SETTING TIMES:

The initial and final Vicat setting times adhering to DIN 196-1 were calculated for all formulations as shown.

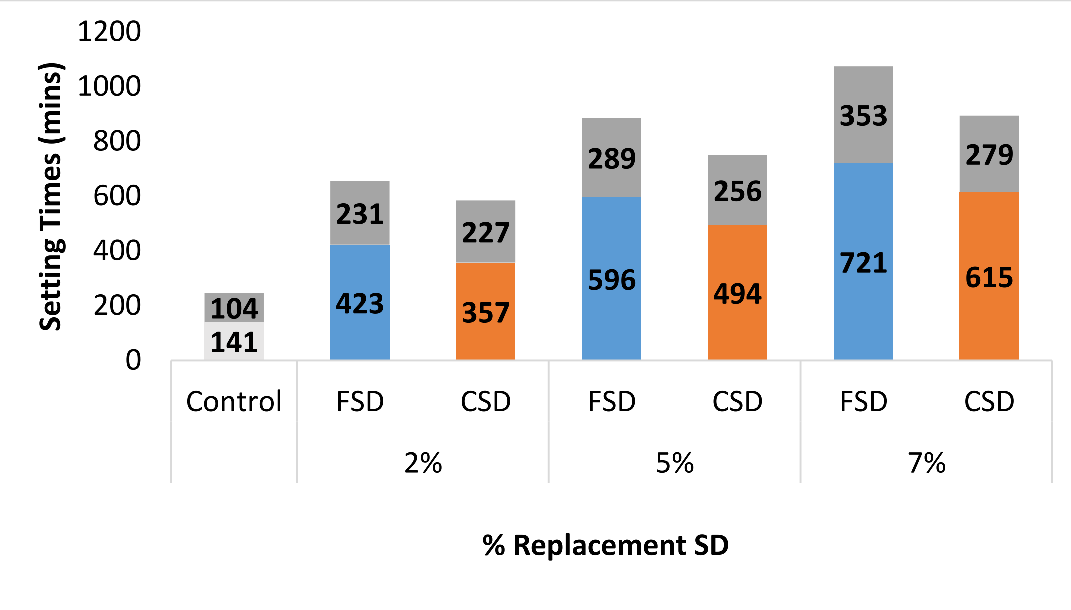

Fig 4.8: Initial and Final Vicat setting times of the formulations

For samples having SD, the setting times both initial and final increased proportional to their replacement percentages as compared with the control specimen. The delay in setting times can be due to the fact that sawdust on top of being a highly inert material which makes it difficult to react with cement and water, with time tends to absorb and physically uptake water (with time as discussed previously) which is available to the cement matrix for its hydration process, hence making the effective water content below the required water content level in the respective sawdust paste specimens. The SD particles release back the water to the system once the temperature gets higher. Moreover, the high dose of superplasticizer also contributes to the delaying process in the system

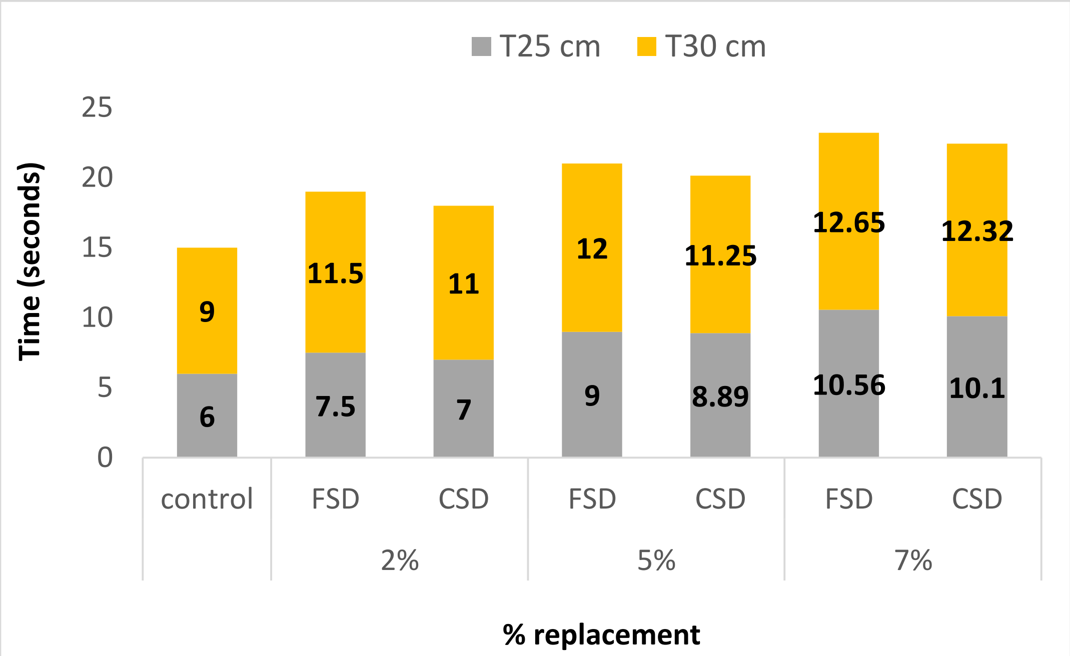

Fig 4.9: T25cm and T30cm time for each formulation

The viscosity and yield stress can also be calculated using time measurements of flow. The time which flow takes to reach 25cm of target on Hagerman's apparatus is called the T_{25}cm and similarly for a target of 30cm the time is called T_{30}cm. The T_{25}cm and T_{30}cm was recorded for each formulation as shown in Fig 4.9. T_{25}cm is the indication of the viscosity of the system while T_{30}cm is the indication of yield stress of the flow system. It was observed that viscosity and yield stress both increased by adding sawdust to the system. Yield stress, shear rates and apparent viscosity follows Bingham's model as discussed previously.

4.6 AIR CONTENT:

The air content in fresh paste was calculated for each SCP formulation using Luftgehaltspruefer device of one litre capacity. The water content and SP content for each formulation was kept as their respective water demand and SP demand calculated previously through Vicat apparatus and flow tests respectively. The fig shows the air content in fresh paste mixes.

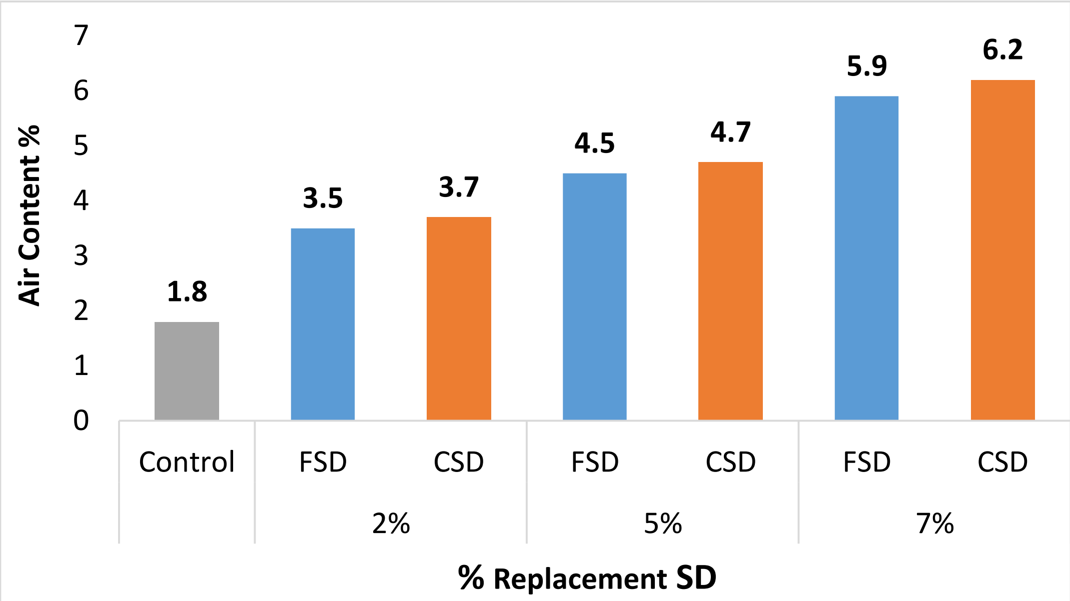

Fig 4.10: Air content of each formulation

As observed, the air content increase proportionally with sawdust replacement percentage. Few possible reasons that may have contributed to this increase are as followed. Air induction by SP added, the shape of sawdust particle, which previously established that it is not a perfect round particle but an irregular fibre structure and also the absorption of water due to sawdust particles and entrapped air between the sawdust and cement paste interface due to viscosity during mixing in Hobart mixer. Also section 4.8 shows that with decrease in density(fresh) air content increases and compressive strength decreases.

4.7 COMPRESSIVE STRENGTH:

4.7.1 Wet curing:

The compressive strength was calculated at 3, 7, 14 and 28 days. Four prism were tested at each respective day for each formulation making a total of sixteen prisms for each formulation. The dimensions of the prism steel moulds were 4 x 4 x 16 cm^3 and were tested conforming to DIN 196-1

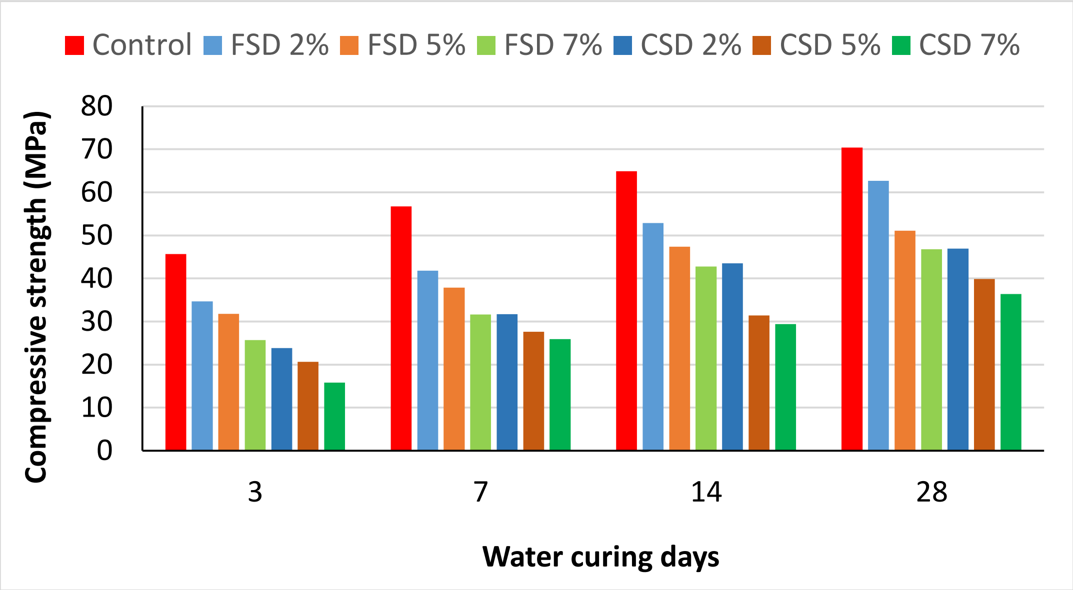

Fig 4.11: Progressive compressive strength at corresponding wet curing days

The compressive strength of samples with sawdust was decreased as compared to control at respective days. The decrease in strength is directly proportional to the percent of sawdust replaced, the reason for reduced strength could be attributed to the large size of sawdust particles which increased the air content of the sample, hence increasing the overall porosity and weakening the internal structure. The over-all average strength reduction for specimens having fine sawdust was observed to be 11%, 27% and 34% with sawdust in replacement mode of 2%, 5% and 7% percent respectively at 28 days. Moreover, coarse SD due to its large particles, on the same lines discussed, had a severe effect on the strength. In terms of XRD analysis of control sample and sample having sawdust at 28 days wet curing. It was observed that the calcium carbonate in the form of calcite which contributes largely in strength formation was predominant in control sample but was diminished in sawdust sample. Also the further formation of calcium hydro oxide in sawdust sample in higher concentrations as compared to control can be the cause of reduction in strength of sawdust samples.

4.7.2 Air curing:

Similarly, air curing was also done for the samples to compare it with the results of the wet curing. The results are shown below.

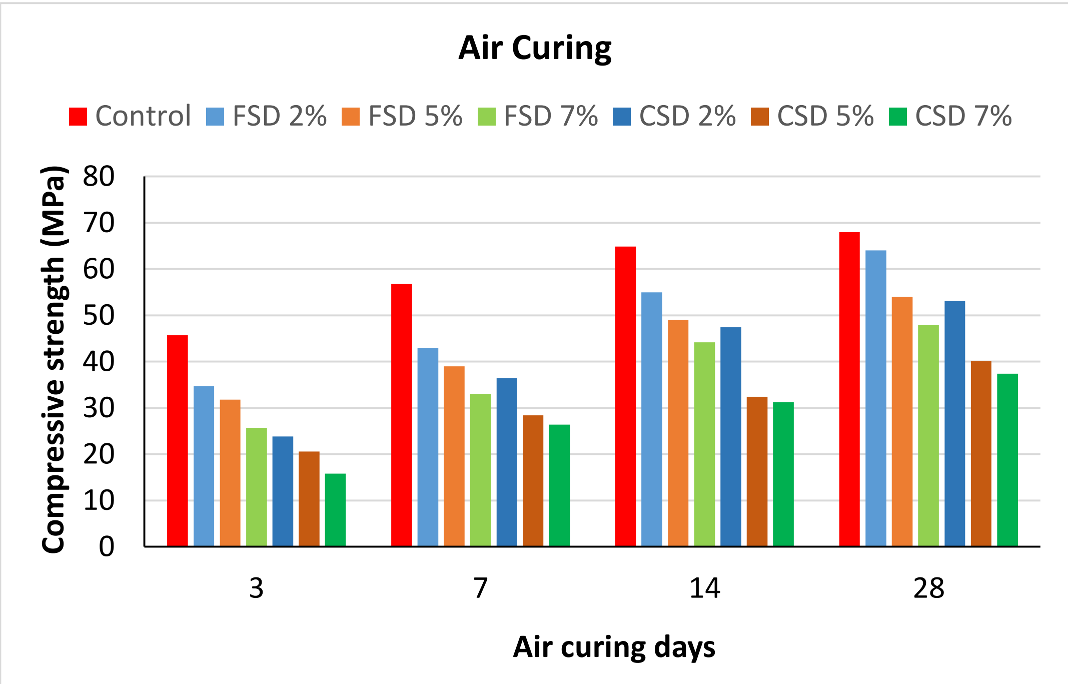

Fig 4.12: Progressive compressive strength at corresponding Air curing days

As compared to wet curing the reduction in strength of samples that were air cured was comparatively less. The reduction was 6, 20 and 30 percent for 2, 5 and 7 percent of fine sawdust replacement respectively. It means that sufficient water was provided by sawdust particles to the system as the case was with wet curing.

4.8 DENSITY OF FRESH SCP SYSTEMS:

The fresh paste densities of all the formulations were calculated by pouring the mix in a known volume of mould and noting down their weights in weighing balance after mixing in the Hobart mixer. The results of density with formulation of control and fine sawdust and their respective 28 days compressive strength is shown.

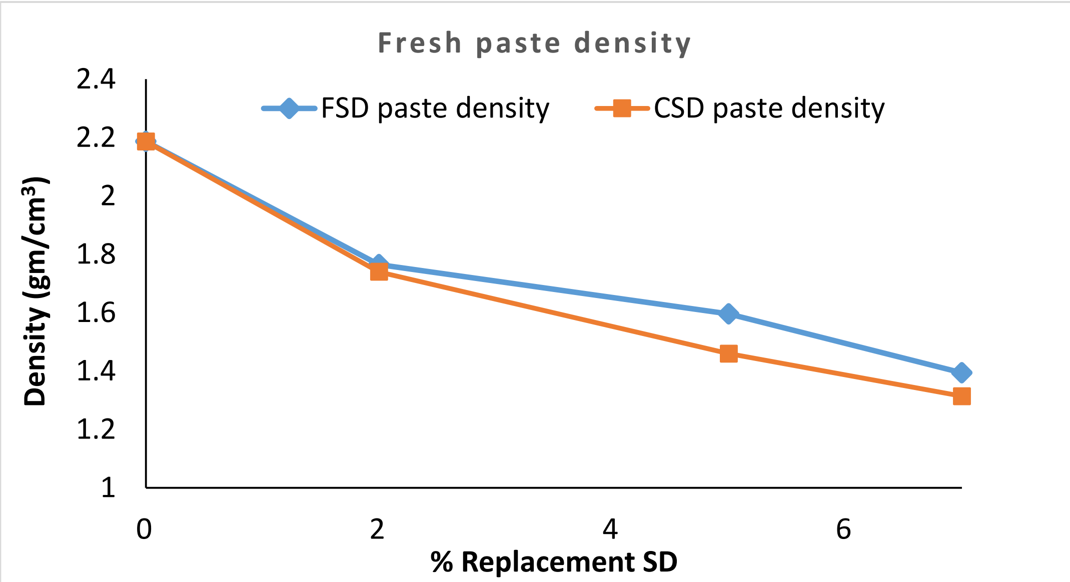

Fig 4.13: Fresh paste densities of both Fine Sawdust (FSD) and Coarse Sawdust (CSD)

As obviously visible, formulations having sawdust had a significant reduction in their fresh paste densities. The reduction in density increases as the replacement of sawdust increases. For fine sawdust formulations with 2%, 5% and 7% of sawdust replacements reduced the weight up-to 19%, 28% and 36% respectively when

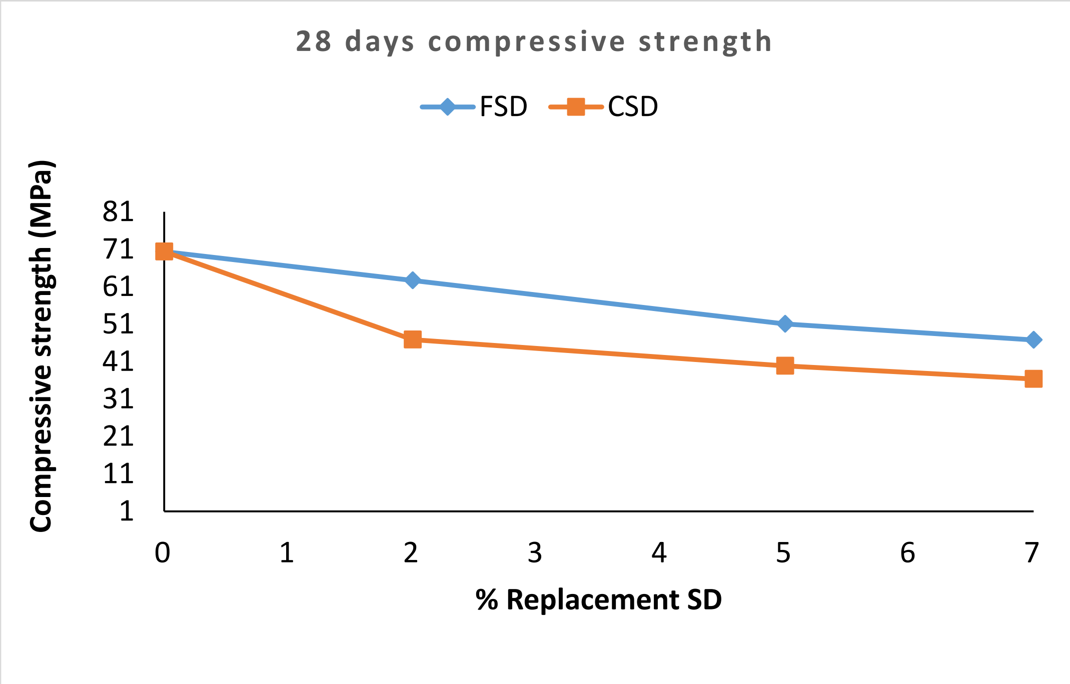

Fig 4.14: Corresponding 28 days compressive strength for FSD and CSD

compared to control specimen. Also from graphs, it can be established here that the difference in size of the sawdust particles had a slight effect on the density results. Meanwhile the over-all results further support and reiterates the use of sawdust in cementitious system as a potential lightweight aggregate along with internal curing agent.

4.9 WATER ABSORPTON/LOSS:

4.9.1 Wet curing:

The water absorption of all the samples after 28 days curing was calculated. After setting the steel moulds were demoulded and the samples were removed before they were weighed and placed in a curing tank at the laboratory. The standard conditions at the laboratory were, temperature 18 ± 1 ºC, relative humidity 55 %. After each progressive week the samples were weighed at Surface Saturated Dry (SSD) and the difference in weights were noted to calculate the percentage of water

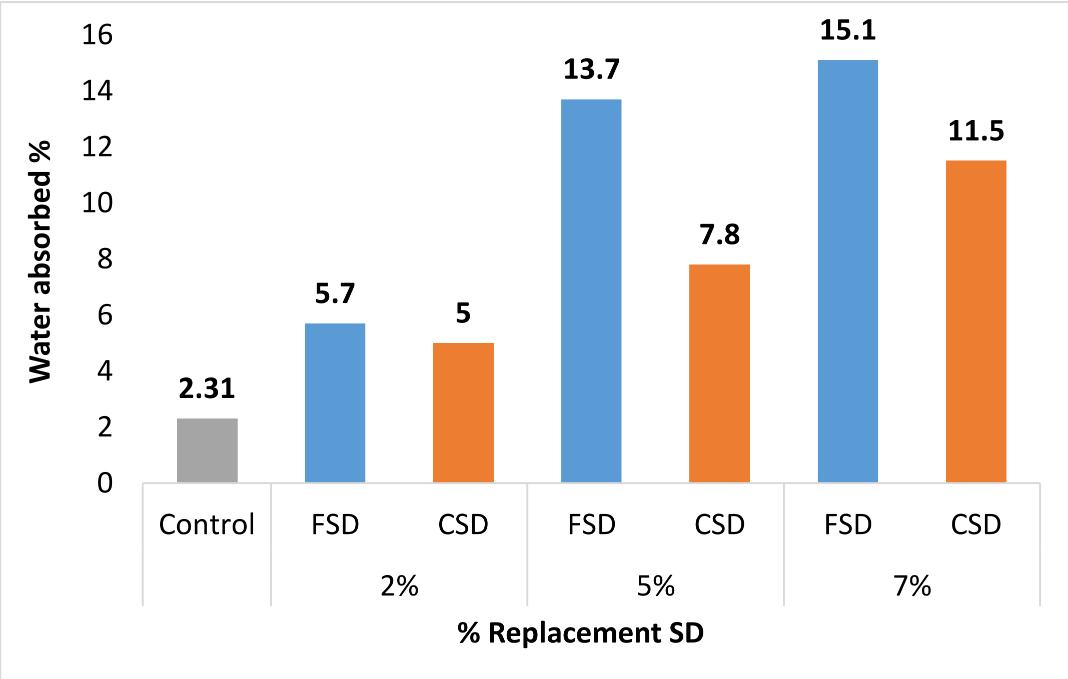

Fig 4.15: Water absorption after 28 days of wet curing

absorbed. Here the 28 days water absorption of the samples in percent are reported. It was observed that samples having sawdust replacement absorbed considerable amount of water during its course in water tank as compared to control sample. The highest amount of water was absorbed by the sample having 7% sawdust in fine mode. The results further confirm that sawdust particles in the matrix of cementitious system tends to absorb water that is surrounding the over-all specimen before releasing it back in the matrix once the temperature gets higher due to hydration.

4.9.2 Air Curing:

The air curing showed opposite response to previous results. The samples

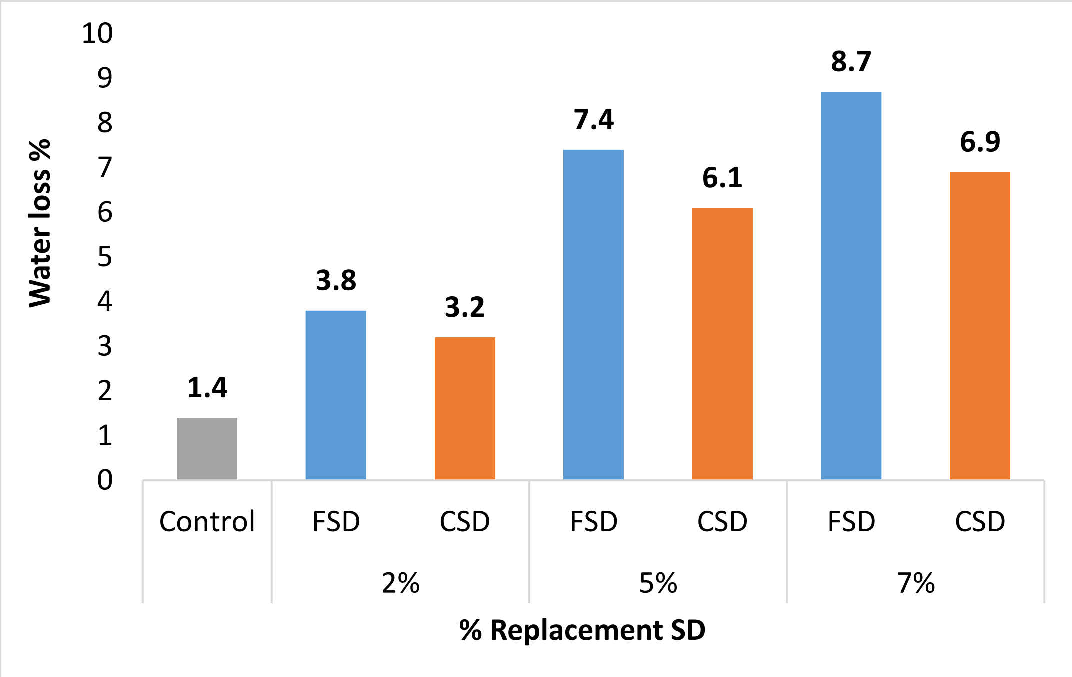

Fig 4.16: Water loss at 28 days of air curing of the samples

cured at air actually decreased the weight with time. It was observed that higher the replacement of sawdust higher is the loss of water and consequent decrease in overall weight of the sample. This behaviour further re-affirms that sawdust particles which initially absorb certain mass of water releases it back to matrix for its hydration.

4.10 LINEAR SHRINKAGE OF SCP SAMPLES:

Early Shrinkage is one of the main issues associated with high performance cementitious systems and it greatly effects the volume stability of such systems. To record the early linear shrinkage of all the formulations having ordinary Portland cement with and without sawdust a German shrinkage apparatus Schwindrine having channel dimensions of 4 x 6 x 25 cm^3 with a sensitivity of 0.31 μm was used. The

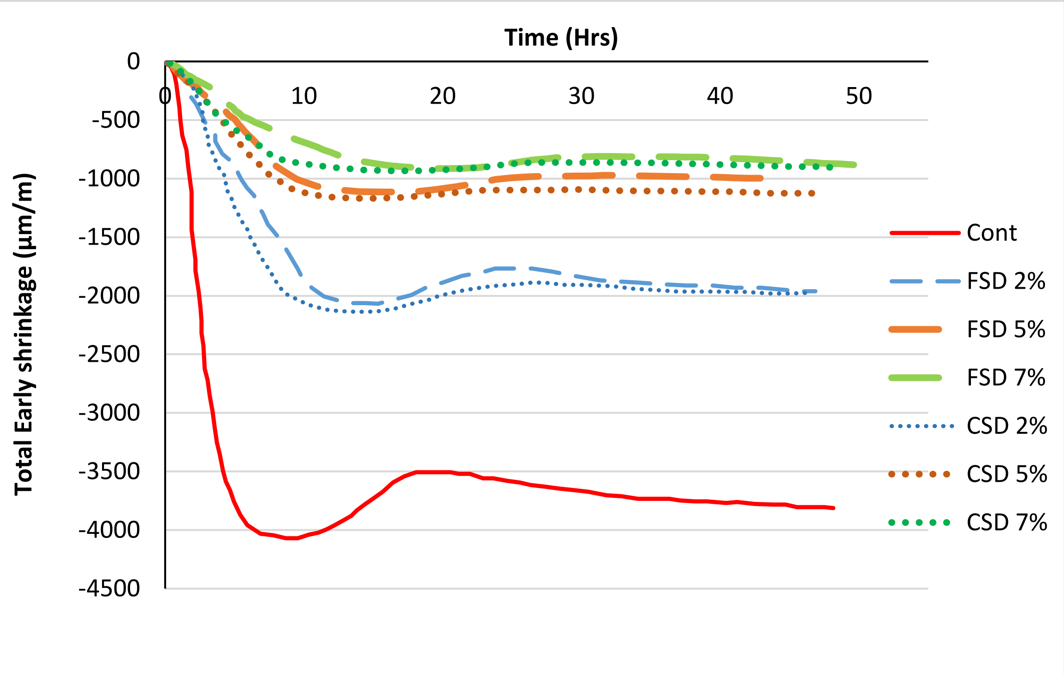

Fig 4.17: Shrinkage response of SCPs with and without sawdust

average laboratory temperature was 30°C and a relative humidity of 55%. The early shrinkage response of all the formulations was recorded for 48 hrs each and the results are reported.

It can be observed that the shrinkage of samples having sawdust is significantly reduced. The reduction in shrinkage is further increases as we increase the percentage of sawdust in the system. For 2 percent of fine sawdust replacement, the shrinkage is reduced to half as compared to control (formulation 1) and with 5 percent replacement the reduction is almost 70%. The reduction is due to the creation of expansive species and consequent release of water by sawdust in the system. Moreover, the creation of calcium hydro oxide (CH) in high concentration in the samples having sawdust as depicted in XRD analysis below also helps greatly in limiting the shrinkage of the system.

4.11 X-RAY DIFFRACTION:

To understand the internal chemical mechanism involved and the formation of hydration products particularly calcium carbonate and calcium hydro oxide, XRD analysis was done using the equipment for samples with and without sawdust at 28 days of water curing. The results are shown below for control specimen and specimen having 2 percent fine sawdust respectively.

There wasn't any major difference in the XRD pattern of samples with and without sawdust, one can assert that sawdust being a highly inert material does not take part in the chemical reaction itself. However, because of sawdust the consequent desorption of water into paste had consequences in terms of hydration products. The XRD of control sample shows higher concentration of calcium carbonate in the form of calcite which helps in formation of strength. This calcite gets diminished or have lower intensities in samples having sawdust. Moreover, the formation and concentration of calcium hydro oxide (Portlandite) was much higher in sawdust samples as compared to control.

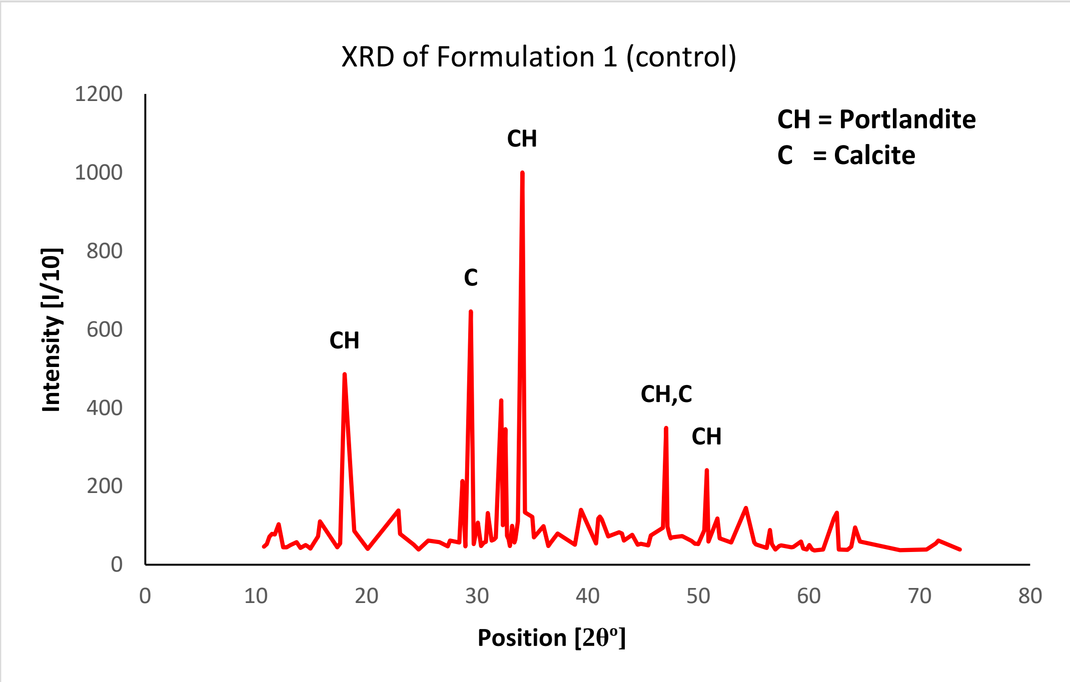

Fig 4.19: XRD analysis of control sample

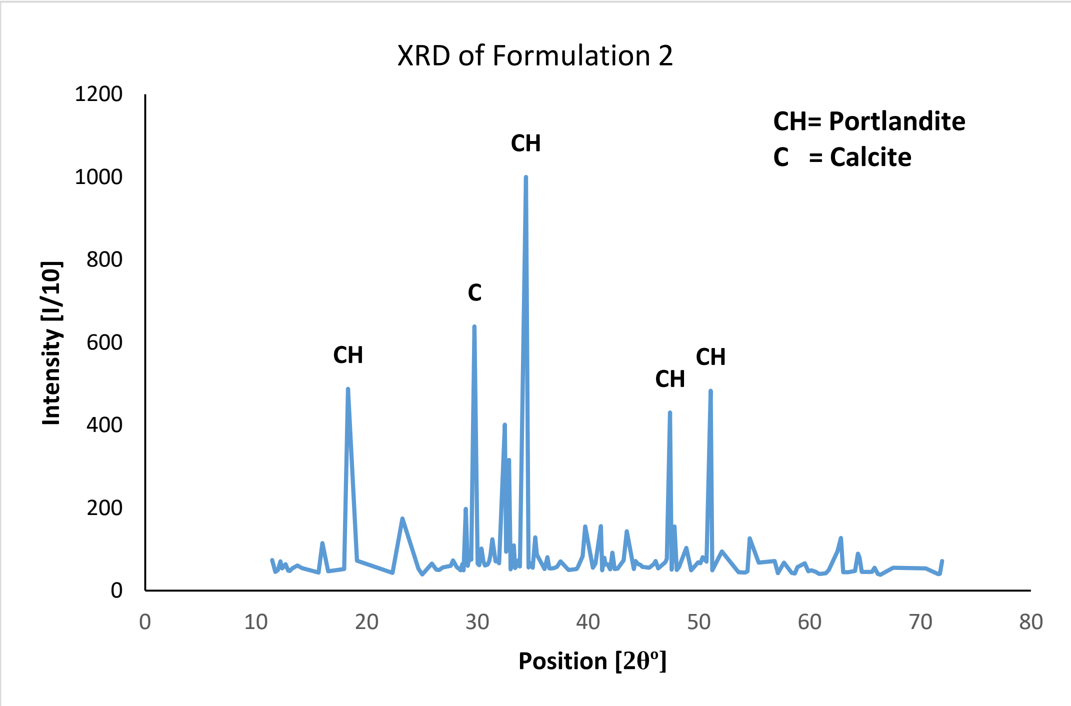

Fig 4.18: XRD analysis of FSD2 sample

4.12 SCANNING ELECTRON MICROSCOPY (SEM):

To study the internal mechanism and structure of the SCP systems SEM was performed for systems with and without sawdust at 28 days of water curing. Fig 4.20c shows the formation of Ettringite in control sample while Fig 4.20b and Fig 4.20a shows crystals of calcite that are dominant in control system. The SEM was performed in detail for the samples with sawdust. In Fig 4.21a, a single sawdust particle within cementitious paste is shown as a whole. Fig 4.21b is a close up of the same sawdust particle and interfacial transition zone (ITZ) can be observed. As

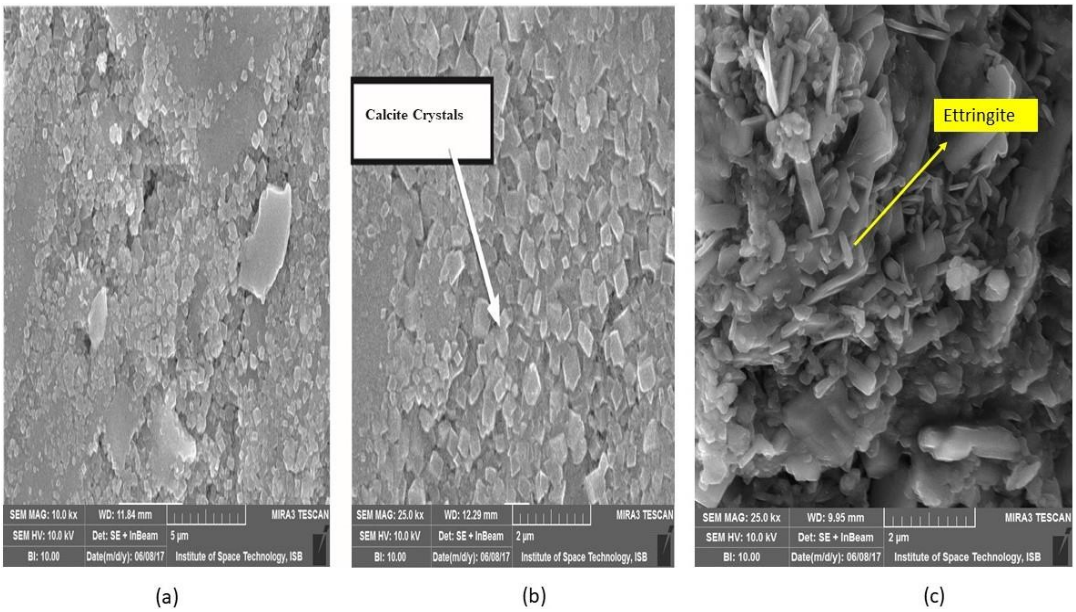

Fig 4.20: SEM analysis of control sample after 28 days of wet curing

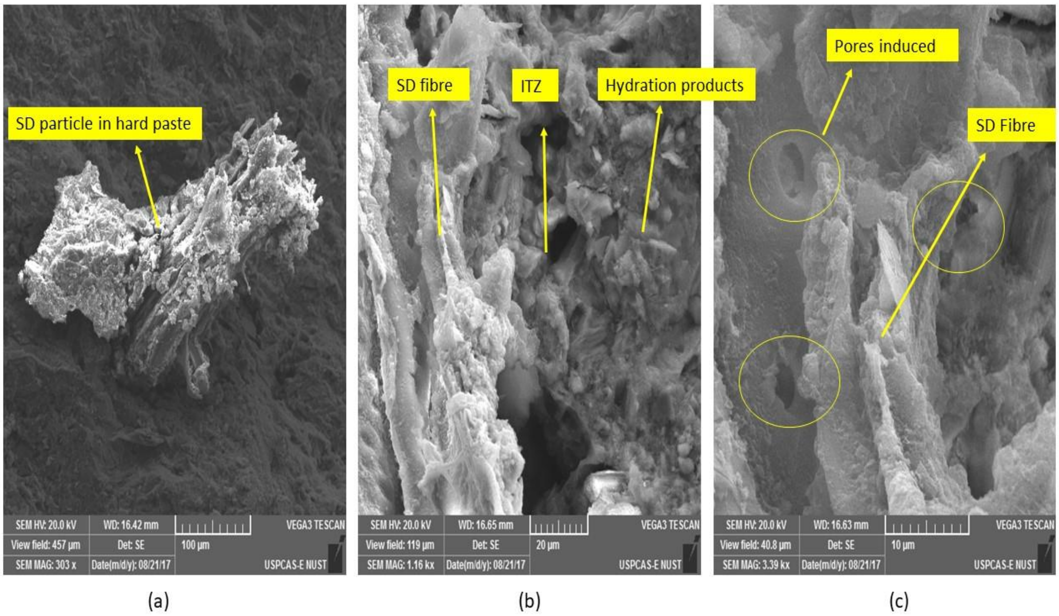

Fig 4.21: SEM analysis of FSD2 after 28 days of wet curing

shown in Fig 4.21c the sawdust particle due to its fibre shaped structure induces pores in the cementitious system at its tip and the ITZ is clearly visible.

4.13 SUMMARY OF RESULTS:

Sawdust when used in self compacting systems.

- Reduces compressive strength
- Absorbs huge amounts of water during wet curing.
- Releases water during air curing of hard samples
- Reduction in shrinkage is significant
- Can be used as retarders to delay setting times.
- Does not react with cementitious systems due to its inert nature.
- Reduces overall weight and can be used as lightweight aggregate.

Chapter 5

CONCLUSIONS AND RECCOMENDATIONS

5.1 CONCLUSIONS:

Due to its greater size than cement particles and irregular fibrous structure the sawdust incorporated in the system decreased the overall compressive strength of the system. Also during air curing regime it was observed that enough water was provided to the system by the sawdust particles acting as an internal curing agent to achieve the desired strength that was obtained with water cured samples.

Due to continuous release of water in the system by SD particles, the expansive species are formed during the hydration process which increases the internal stiffness of the system and that is why the reduction in shrinkage with SD samples was more than 50 percent. This effect also minimizes the heat of hydration of the system which prevents any early age cracking.

No chemical alteration was observed in XRD and TGA results of the system when SD used to confirm the role of SD as an inert material throughout the hydration process.

Because of the significant reduction in both density and Vicat setting times of the system due to SD particles, it can be used as lightweight aggregate cum retarders.

5.2 RECCOMENDATIONS:

To cater for strength, it is recommended to use fly-ash/silica fume in conjunction with SD in the system. Also for over-all better results reduce the size of SD particles to cement particle size before using it in the system.

References:

1. 237, A.C., *Self Consolidating Concrete*, 2007: Farmington Hills, Mich.
2. Rizwan, S.A. and T.A. Bier, *Blends of limestone powder and fly-ash enhance the response of self-compacting mortars.* Construction and building materials, 2012. **27**(1): p. 398-403.
3. Ijigah, E.A., et al., *An assessment of environmental impacts of building construction projects.* Civil and Environmental Research, 2013. **3**(1): p. 93-105.
4. Alaa, A., S. Sivakumar Naganathan, and B. Kamal Nasharuddin, *Development of bricks from waste material: A review paper.* Australian Journal of Basic and Applied Sciences, 2013. **7**(8): p. 812-818.
5. Corinaldesi, V., A. Mazzoli, and R. Siddique, *Characterization of lightweight mortars containing wood processing by-products waste.* Construction and Building Materials, 2016. **123**: p. 281-289.
6. Wihersaari, M., *Evaluation of greenhouse gas emission risks from storage of wood residue.* Biomass and Bioenergy, 2005. **28**(5): p. 444-453.
7. Kamlesh Saini, V.C., Ankush Bisnohi, *Effect on strength properties of concrete by using waste woodpowder as partial replacement of cement* SSRG International Journal of Civil Engineering, 2016. **3**.
8. Bouguerra, A., et al., *Water sorptivity and pore structure of wood–cementitious composites.* Magazine of Concrete Research, 2002. **54**(2): p. 103-112.
9. Adebakin, I., et al., *Uses of sawdust as admixture in production of lowcost and lightweight hollow sandscrete blocks.* American journal of scientific and industrial research, 2012. **3**(6): p. 458-463.
10. Belhadj, B., et al., *Effect of substitution of wood shavings by barley straws on the physico-mechanical properties of lightweight sand concrete.* Construction and Building Materials, 2014. **66**: p. 247-258.
11. Bederina, M., et al., *Effect of the addition of wood shavings on thermal conductivity of sand concretes: experimental study and modelling.* Construction and Building Materials, 2007. **21**(3): p. 662-668.
12. Bederina, M., et al., *Effect of the treatment of wood shavings on the physico-mechanical characteristics of wood sand concretes.* Construction and Building Materials, 2009. **23**(3): p. 1311-1315.
13. Turgut, P., *Cement composites with limestone dust and different grades of wood sawdust.* Building and Environment, 2007. **42**(11): p. 3801-3807.
14. Turgut, P. and H.M. Algin, *Limestone dust and wood sawdust as brick material.* Building and Environment, 2007. **42**(9): p. 3399-3403.
15. Pedreño-Rojas, M., et al., *Eco-efficient acoustic and thermal conditioning using false ceiling plates made from plaster and wood waste.* Journal of Cleaner Production, 2017.
16. Morales-Conde, M., C. Rodríguez-Liñán, and M. Pedreño-Rojas, *Physical and mechanical properties of wood-gypsum composites from demolition material in rehabilitation works.* Construction and Building Materials, 2016. **114**: p. 6-14.
17. Coatanlem, P., R. Jauberthie, and F. Rendell, *Lightweight wood chipping concrete durability.* Construction and building Materials, 2006. **20**(9): p. 776-781.
18. Udoeyo, F.F. and P.U. Dashibil, *Sawdust ash as concrete material.* Journal of Materials in Civil Engineering, 2002. **14**(2): p. 173-176.

19. Elinwa, A.U. and Y.A. Mahmood, *Ash from timber waste as cement replacement material.* Cement and Concrete Composites, 2002. **24**(2): p. 219-222.
20. Siddique, R., *Utilization of wood ash in concrete manufacturing.* Resources, conservation and Recycling, 2012. **67**: p. 27-33.
21. Cheah, C.B. and M. Ramli, *The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview.* Resources, Conservation and Recycling, 2011. **55**(7): p. 669-685.
22. Bell, L.W., et al., *AGGREGATES FOR CONCRETE.* 1999.
23. Sant, G., P. Lura, and J. Weiss, *Measurement of volume change in cementitious materials at early ages: review of testing protocols and interpretation of results.* Transportation Research Record: Journal of the Transportation Research Board, 2006(1979): p. 21-29.
24. Roussel, N., *A thixotropy model for fresh fluid concretes: theory, validation and applications.* Cement and Concrete Research, 2006. **36**(10): p. 1797-1806.
25. Barnes, H.A., J.F. Hutton, and K. Walters, *An introduction to rheology*. Vol. 3. 1989: Elsevier.
26. Tropea, C. and A.L. Yarin, *Springer handbook of experimental fluid mechanics*. Vol. 1. 2007: Springer Science & Business Media.
27. Banfill, P. and D. Saunders, *On the viscometric examination of cement pastes.* Cement and Concrete Research, 1981. **11**(3): p. 363-370.
28. Otsubo, Y., S. Miyai, and K. Umeya, *Time-dependent flow of cement pastes.* Cement and Concrete Research, 1980. **10**(5): p. 631-638.
29. Babcock, A.E. and P. Taylor, *Impacts of internal curing on concrete properties.* 2015.
30. Rizwan, S. and T. Bier, *Self-compacting paste systems using secondary Raw Materials.* Pakistan Journal of Engineering and Applied Sciences, 2016.
31. Jensen, O.M. *Water absorption of superabsorbent polymers in a cementitious environment*. in *International Conference on Advances in Construction Materials through Science and Engineering 2011*. 2011. Rilem publications.