EXPLORING THE POTENTIAL OF SAW DUST AS INTERNAL CURING AGENT IN CONCRETE SUBJECTED TO DIFFERENT CURING CONDITIONS

NG SHI KIN

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2021

EXPLORING THE POTENTIAL OF SAW DUST AS INTERNAL CURING AGENT IN CONCRETE SUBJECTED TO DIFFERENT CURING CONDITIONS

by

NG SHI KIN

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)

(CIVIL ENGINEERING)

School of Civil Engineering
Universiti Sains Malaysia

October 2021

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2020/2021

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: Exploring the Potential of Saw Dust as Internal Curing Agent in Concrete Subjected to Different Curing Conditions

Name of Student: Ng Shi Kin

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

Date : 2nd August 2021

Endorsed by:

(Signature of Supervisor)

Name of Supervisor: Megat Azmi Megat Johari

Date: 3rd August 2021

Approved by:

(Signature of Examiner)

Name of Examiner:

Date: 4 August 2021

(Important Note: This form can only be forwarded to examiners for his/her approval after endorsement has been obtained from supervisor)

ACKNOWLEDGEMENT

Firstly, I would like to express my upmost gratitude to my final year project supervisor, Prof. Dr. Megat Azmi Megat Johari for his guidance throughout the project. This research could not be delivered in such organized manner without his patience support and insightful advice. It was an honour to be able to complete this research under his supervision.

Besides, I am extremely grateful to all the lecturers and invited speakers, especially the course manager, Assoc. Prof. Dr. Noor Faizah Fitri binti Md Yusof, for providing me all the useful skills and knowledge needed to accomplish this project.

Thirdly, I would like to express my thankfulness to the laboratory technician of School of Civil Engineering especially Mr. Mohd Fauzi Zulkfle and Mr. Mohd Nazharafiz Mokhtar, who gave the permission and support to use all the required equipment and materials to complete the experiment. Their patience, guidance and assistance in this research work is deeply appreciated.

Moreover, I would like to thank my coursemates, Ooi Jun Hao, Ching Meng Xuan, Khor Cheng Yi, Tee Deng Wang, Mok Tai Han and Toh Wei Jian for giving me support and help throughout the implementation of the laboratory work in this project.

Last but not least, I deeply appreciate the management of School of Civil Engineering for giving me the opportunity and freedom to conduct this research, which will potentially help the existing and future research of the field.

ABSTRAK

Dalam kajian ini, sifat konkrit yang mengandungi agen pengawetan dalaman dalam keadaan berbeza telah disiasat. Debu atau habuk gergaji adalah bahan buangan yang dihasilkan sebagai produk sampingan dari industri yang berkaitan dengan kayu. Habuk gergaji pra-tepu untuk bertindak sebagai agen pengawetan dalaman dan wasap silika ditambahkan dalam penyelidikan ini. Agen pengawetan dalaman (habuk gergaji) sebahagiannya telah diganti pada 2.5%, 5.0% dan 7.5% daripada isi padu pasir dan wasap silika telah digunakan sebagai bahan gentian separa kepada simen Portland pada tahap daripada 15.0% berat simen. Nisbah air / simen yang digunakan dalam penyelidikan ini ialah 0.5. Sampel konkrit telah dikenakan tiga keadaan pengawetan yang berbeza (tangki air, bilik pengeringan kering pada suhu bilik dan ketuhar 40 ° C) setelah dikeluarkan daripada acuan. Hasil kejian menunjukkan kebolehkerjaan konkrit meningkat dengan penggunaan habuk gergaji pra-jenuh. Penambahan wasap silika dalam konkrit yang disembuhkan secara dalaman mengurangkan kebolehkerjaan dan meningkatkan keliangan. Walau bagaimanapun, kekuatan mampatan konkrit dan kebolehtelapan konkrit ditingkatkan dengan penggunaan wasap silika. Kandungan habuk gergaji optimum dalam kajian ini ialah 2.5%. Didapati bahawa di bawah pengawetan dengan bekalan air luaran, konkrit dengan 2.5% habuk gergaji pra-jenuh dapat mencapai kekuatan sasaran 40MPa. Didapati bahawa kekuatan mampatan 2.5% konkrit habuk gergaji setanding dengan sampel kawalan dalam keadaan pengeringan kering dan keadaan ketuhar 40 °C. Walaupun keliangan meningkat kerana peratusan habuk gergaji meningkat. Walau bagaimanapun, dalam keadaan pengawetan yang buruk tanpa bekalan air pengawetan luaran, kebolehtelapan konkrit dengan habuk gergaji 2.5% jauh lebih rendah daripada sampel kawalan. Kesimpulannya, 2.5% habuk gergaji pra-jenuh dapat

digunakan sebagai bahan pengawetan dalaman untuk menghasilkan konkrit yang tahan lasak dan menjimatkan kos.

ABSTRACT

In this study, the properties of concrete containing internal curing agent under different curing conditions were investigated. Saw dust is a waste material generated as a by-product from the wood related industries. The saw dust was pre-saturated to act as an internal curing agent and silica fume was added in this research. The internal curing agent (saturated saw dust) was used to partially replace 2.5%, 5.0% and 7.5% of volume of sand and 15% silica fume was incorporated as partial replacement of the mass of cement. The water/cement ratio used in this research is 0.5. The concrete samples were subjected to three different curing conditions (water tank, dry curing room at room temperature and 40°C oven) after demoulding. From the results, the workability of concrete increases with the use of saturated saw dust. The inclusion of silica fume in internally cured concrete reduced the workability and increases the porosity. However, the compressive strength of the concrete and impermeability of concrete were improved with the use of silica fume. The optimum saw dust content found in this study was 2.5%. It was found that under curing with external water supply, the concrete with 2.5% of saturated saw dust could achieve the target strength of 40MPa. It was found that the compressive strength of 2.5% saw dust concrete was comparable to the control sample under dry curing and 40°C oven condition. Despite the observed increase in porosity with the percentage of saw dust, the permeability of the concrete with 2.5% saw dust was significantly lower than the control mix under adverse curing condition with no external curing water supply. As a conclusion, 2.5% of saturated saw dust can be applied as a cost-effective internal curing material to produce a durable concrete where wet curing is not applied.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is made by mixing Portland cement, water, fine aggregates and coarse aggregates. As the cement is in contact with water, cement hydration occurs and the mixture hardens and gains strengths. Concrete is widely used in construction such as building bridges, houses, dams, highways, skyscrapers and sidewalks (How concrete is made, 2019). Some of the important properties of concrete are workability, compressive strength and impermeability. The durability of concrete is significantly important as it determines the ability of concrete to withstand the adverse condition caused by the external factors. Also, it is critical that concrete possesses sufficiently low permeability to ensure that its durability is preserved as there will be lower rate of penetration by aggressive materials or agents such as sulphate and chloride from the environment (Properties of Concrete in Construction, 2021).

At the early stage after concreting, having a good practice of concrete curing is vital in maintaining the moisture content to ensure the desired properties can be developed. (Raju et al., 2020) Concrete must be properly cured in order to achieve its desired performance and durability. Conventionally, concrete is cured externally whereby the moisture applied after casting on flat open surface such as slab or after striking of formwork (Cusson and J.W. Roberts, 2007). Rapid evaporation, early stiffening and plastic shrinkage are the most common issues after placing of fresh concrete in hot climates. The most significant effects with hot weather concreting for hardened concrete are long-term strength loss, rebar corrosion, and decreased durability (Bella et al., 2017). A study reviewed that concrete experienced cracking in the early age of hardening because of loss of water at early stage of hydration inducing shrinkage which could lead to plastic shrinkage cracking. The shrinkage crack could potentially be reduced by implementing internal curing method (Thamilselvi et al., 2017).

Internal curing (IC) is one of the ways to deliver extra moisture in the concrete mix. Internal curing (IC) improves hydration, reduces chloride ingress, and reduces early age cracking in concrete, allowing it to reach its full potential as a safe construction material by maximizing its serviceability. One of the methods of IC is implemented by using pre-wetted lightweight aggregate to replace some of the aggregate in the concrete mix. The pre-wetted lightweight aggregates will release additional moisture for continuous hydration process. The additional moisture by IC also reduce the moisture lost due to the evaporation or self-desiccation (Wakkad et al., 2019).

Based on a review by Tiough (2014), it was identified that saw dust is a waste material generated as a by-product from the wood related industries, where huge amount of saw dust can be observed near the sawmills and wood related industries. Tiough (2014) also pointed out that concrete containing saw dust can be appropriately used as building construction material. However, the water absorption characteristic of the concrete is increased with the use of saw dust. (Awal *et al*., 2016) A study by Thamsilselvi *et al*. (2017) had shown that concrete containing saw dust can lower the shrinkage cracks as the pre-wetted saw dust act as internal curing agent by providing source of water to sustain cement hydration.

Many studies have shown that saw dust has the potential to be used as internal curing agent by replacing the fine aggregate to produce concrete with high strength and increased durability as a result of lower permeability. This research reports an investigation on exploring the potential of saw dust as internal curing agent in concrete subjected to different curing conditions.

1.2 Problem Statement

The properties of concrete can be controlled if it is placed and cured under favorable conditions. However, in countries with hot climates, certain problems may appear throughout the early stage of concreting. Plastic shrinkage, rapid evaporation, and early stiffening are the most common issues with fresh concrete in hot climates. The most significant effects with hot weather concreting for hardened concrete are long-term strength loss, rebar corrosion, and decreased durability. With the use of IC, internal autogenous stresses due to self-dehydration can be minimized by the additional curing water provided by IC, leading to reduced early age cracking. The loss of moisture from rapid evaporation as well as from self-desiccation due to cement hydration process is reduced as the additional moisture is released from the internal curing agent.

Saw dust has the potential to be used as internal curing agent as it has good water absorption. The use of saw dust can reduce the environmental problem caused by the waste material generated. It can also act as new source of replacement materials to preserve the fine aggregates. Also, there is still lack of scientific evidence to indicate the effect of curing conditions on properties of concrete containing saturated saw dust as internal curing agent. Therefore, the effectiveness of IC by saturated saw dust under different curing conditions is investigated in this research.

1.3 Objectives

The main objectives of the study are:

1) To investigate the effect of internal curing by saturated saw dust inclusion as partial sand replacement on properties of concrete.
2) To observe the effect of silica fume on the properties of concrete containing saw dust
3) To evaluate the effect of curing conditions on properties of concrete containing saturated saw dust as internal curing agent.

1.4 Scope of work

This research investigates the effects of partial replacement of saw dust with the fine aggregates on the properties of grade 40 concrete. The properties assessed in the research are workability, compressive strength, porosity, and permeability. The research method involves the preparation of three batches of concrete mix with partial replacement of cement with 15% of silica fume and different percentage of saturated saw dust at 2.5%, 5.0%, 7.5%, one batch of concrete mix with partial replacement of cement with 15% of silica fume, one batch of concrete mix with 5.0% of saturated saw dust, and a concrete mix without saw dust as a reference. The main binder material used will be ordinary Portland cement (OPC), water, fine and coarse aggregates. The water/cement ratio is fixed in all batches of sample. The sample will be cured under standard curing, dry laboratory condition, and 40°C of dry oven. The compressive strength of concrete will be assessed at 1, 7, 14, and 28 days. The porosity and permeability of concrete will be assessed at 7, and 28 days.

After all the tests have been carried out, the potential of saw dust as internal curing agent in concrete subjected to different curing conditions can be assessed. The overall scope of work is shown in the Figure 1.1.

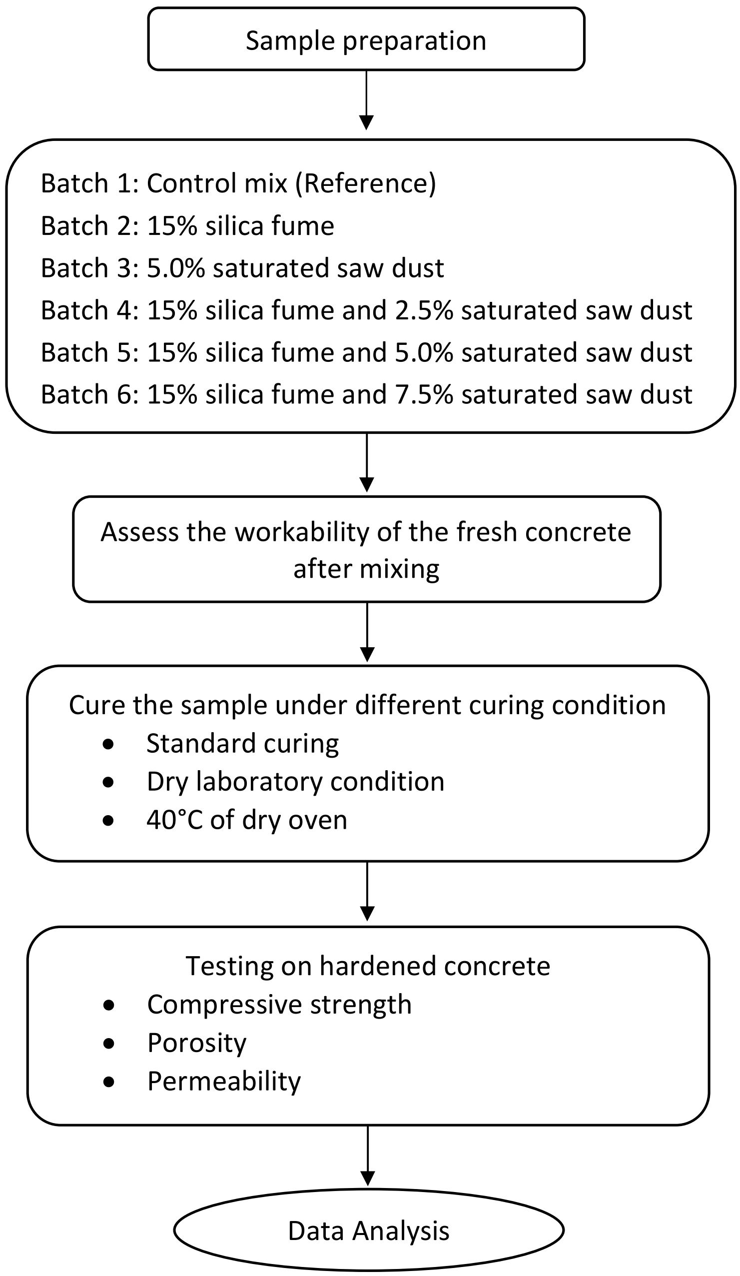

Figure 1.1: Flowchart of overall scope of work

1.5 Dissertation Outline

This dissertation consists of further four chapters and is organized as follows.

Chapter 2: Literature Review

This chapters covers the previous research work done on the saw dust concrete, internal curing, concrete with silica fume and the properties of them. Also, the behavior of normal curing without internal curing is highlighted.

Chapter 3: Methodology

This chapter briefly describes the outline of the research work. The procedure to achieve the objectives of the research project is discussed accordingly.

Chapter 4: Result and Discussion

The results and data obtained from the experiment are analyzed and discussed in this chapter. The data will be illustrated with the use of data, table and chart to describe the results better.

Chapter 5: Conclusion

This chapter summarizes the key findings and reviews the study objectives. Recommendations for future continuous study will be suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

At the early age, concrete requires curing to ensure there are sufficient moisture for cement hydration reaction. Effective concrete curing leads to good strength and durability development. Concrete curing is even more crucial during the critical environmental condition such as when exposed to hot and dry environment at very early age (James et al., 2020).

Recently, internal curing has been applied in normal weight concrete to improve its properties. Internal curing (IC) improves hydration, reduces chloride ingress, and reduces early age cracking in concrete, allowing it to improve its durability and extend its service life (Wakkad *et al*., 2019). During hot weather concreting, problems such as plastic shrinkage and self-desiccation due to cement hydration process are common, which sometimes lead to cracking (Bella *et al*., 2017). Internal curing is a process of applying additional moisture to concrete internally to enhance the effectiveness of cement hydration and minimize self-desiccation (Mousa et al., 2015). Internal curing is proven to be effective when saw dust is used as partial substitute for fine aggregates (Alam et al., 2012).

This chapter briefly summarizes previous studies conducted by other researchers that are relevant to this research. Some studies have been done on the effect of incorporating saw dust as internal curing agent in concrete. The parameters assessed include the strength, porosity, and permeability of concrete. Besides, there are many research works that have been done on the effect of internal curing on the concrete properties.

2.2 Curing of concrete

Curing of concrete is required to maintain sufficient moisture content in concrete at the early stage of hardening. Curing of concrete will impact the development of the properties of hardened concrete such as durability and strength. Concrete curing is even more significant when the concrete surface is exposed to hot and dry environment. Although water content of the fresh concrete is usually sufficient for the cement hydration process, but loss of moisture due to evaporation can disturb the cement hydration process continuously. The concrete surface is more susceptible to loss of moisture as it is the outermost part of the concrete structure. For concrete with low water-cement ratio and high cement content, special curing method may be required. As cement hydration takes place, moisture loss may cause self-desiccation which will adversely affect the properties of the concrete (Taylor, 2013).

There are different methods of concrete curing that are adopted in the construction industry based on the need and condition. The most common curing methods are maintaining the moisture by subjecting the concrete to water pond immersion, spraying and wet covering. Secondly, to prevent the loss of moisture from evaporation as well as self-desiccation due to cement hydration by covering the concrete by plastic sheets. Thirdly, applying hot live steam to accelerate the early strength gain of the concrete. Combination of curing methods can be adopted according to the circumstances. In general, curing of concrete is very crucial for the development of the properties of hardened concrete (Taylor, 2013).

2.3 Introduction to internal curing (IC)

Efficient and complete curing is sometimes not practical in cases such as application of low water-cement ratio concrete. The use of internal curing concrete will tackle the problem (Chand et al., 2015). IC is the process of cement hydration that occurs due to the presence of additional moisture provided by the IC agent that is not included in the mixing water. IC allows the curing to happen from the inside to outside. IC is a good way of distributing extra moisture in the concrete mix (Wakkad *et al*., 2019). Recently, concrete with internal curing has been widely used in the construction markets. The additional moisture in internally cured concrete compensates for the shrinkage of the mix and volumetric changes that cause early-age concrete cracking. Internally cured concrete applies the additional moisture from the lightweight aggregates to counteract the reduced volume of the concrete (Akhnoukh, 2018).

Concrete mixture with internal curing offers the additional moisture required to extend the time in which saturated states are retained within the hydrating cement paste. Retaining these saturated conditions would help to increase the degree of reaction achieved by the cement and any pozzolans, as well as reduce the formation of autogenous stresses and strains, which can lead to early-age cracking (Bentz and Weiss, 2011). Tiny dry pores form in the paste as cement hydration occurs. As the tiny pores are smaller in size compared to the pores in saturated lightweight aggregate, the moisture is forced out from the lightweight aggregate. This prevents chemical shrinkage from occurring and allow continuous hydration process to take place (Ries, 2015).

It is vital to cure the concrete sufficiently to avoid two major negative impacts. First at all, lowering of the strength and durability development of concrete. Secondly, loss of moisture due to the cement hydration process leads to the shrinkage of concrete. With the use of internal curing agents, it can improve the strength development and lower the tendency of cracking in concrete. This contributes to the improvement of the durability of concrete (Paul and Mathew, 2009). A research by Mousa et al. (2015) had reviewed the application of water-saturated saw dust will be used as the internal curing agent to partially replace fine aggregates as a source of additional moisture. A research concluded that the maximum allowable w/c ratio for internally cured concrete is 0.50. Otherwise, the effect of internal curing will not be observed.

2.3.1 Internal curing agent

Internal curing agent is required to achieve the process of internal curing (ELWakkad et al., 2019). Saturated lightweight aggregates (LWA) can be used to partially replace normal weight aggregates as internal curing agent to provide additional moisture. Prior to concrete mixing, LWA is immersed in water to absorb sufficient water. After mixing, the moisture will gradually release and desorb to compensate the moisture loss during the rapid evaporation due to cement hydration (Akhnoukh, 2018).

Desorption capability of the LWA is one of the important properties as an internal curing agent. The pressure in the capillary pores declines as the cement paste hydrates and self-desiccation occurs. As the pressure reduces, suction is developed to extracting the moisture out of the saturated LWA into the cement paste (Babcock & Taylor, 2015).

To ensure the lightweight aggregate absorbs moisture before mixing process, they are immersed in the water 24 hours prior to the mixing process. The moisture absorbed by the saturated lightweight aggregate is not considered as part of mixing water (Torres-castellanos and Rodríguez-Torres, 2019).

2.3.2 Effect of internal curing on the properties of concrete

2.3.2(a) Compressive strength

The study had shown that the concrete with internal curing obtained 20% higher compressive strength at the later age. This is because of the effect of internal curing which promotes the continuous hydration of the concrete at later age. The additional moisture is promoted by the water stored in the lightweight aggregate. The optimum compressive strength is found to happen when 20% of coarse aggregate is replaced by the expanded shale. Figure 2.1 shows the result of the compressive strength test of the samples with partial replacement of internal curing agent in 0%, 10%, 15%, 20% and 25% (Dayalan and Buellah, 2007).

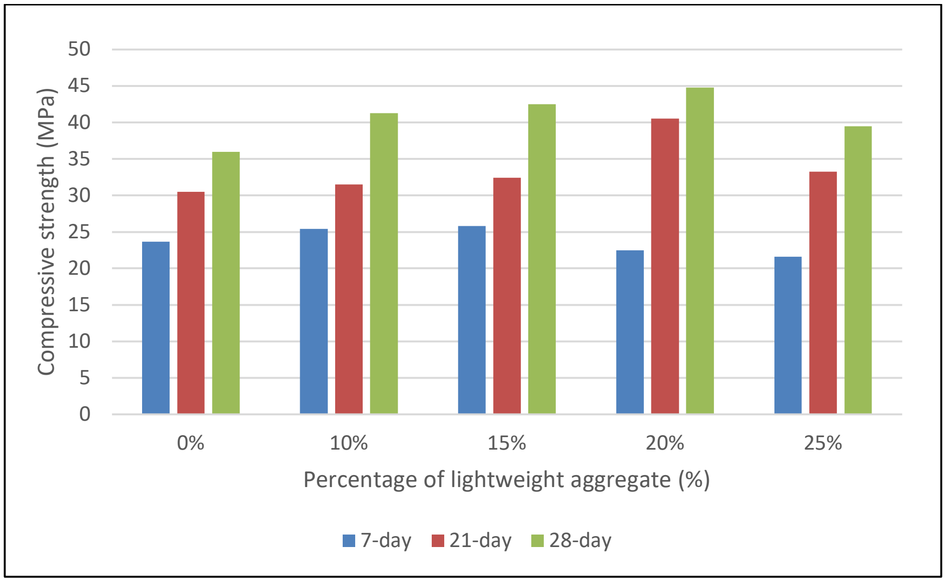

Figure 2.1: Results of the compressive strength test (Dayalan and Buellah, 2007)

2.3.2(b) Permeability

A study had observed a decrease of water permeability by 19% with the use of IC agent. The study showed a higher C-S-H content by 20% on the concrete with internal curing which indicates an improve in cement hydration process. The results of the study are shown in the Table 2.1 (Babcock & Taylor, 2015).

Table 2.1: Comparison of properties of concrete with and without internal curing agent (Babcock & Taylor, 2015)

Property	**Reference concrete (w/c = 0.35)**	**Internally cured concrete (w/c = 0.35)**	**Relative improvement (%)**
w/c_{ic} (kg/kg)	0	0.075	
C–S–H content at 28 days (%)	10.2	12.3	21
Compressive strength at 7 days (MPa)	45	50	11
Compressive strength at 28 days (MPa)	60	65	8
Water permeability (m/s)	2.1 × 10−11	1.7 × 10−11	19
Chloride permeability (Coulomb)	553	415	25
Freeze–thaw resistance, mass loss (%)	0.6	0.26	
Salt scaling resistance, mass loss (%)	0.46	0.3	

A research studied the effect of using pre-saturated lightweight aggregate (leca) as an internal curing agent to improve the performance of concrete. The pre-saturated LWA (leca) was used at 10%, 15% and 20% to partially replace sand volume. The concrete samples were cured in dry-air curing regime with a temperature of 25°C. Table 2.2 shows the reduction of permeability of the sample containing leca as internal curing agent. It was found that the partial replacement of sand with internal curing agent can improve impermeability of the concrete (Wakkad *et al*., 2019).

Table 2.2: Effect of internal curing on the permeability of concrete (Wakkad *et al*., 2019)

Percentage of pre-saturated LWA (%)	Reduction of permeability (%)
10.0	-36.0
15.0	-35.0
20.0	-30.0

In this research, it was found that as the water/cement ratio increased, the water permeability increased. The sample was subjected to internal curing with the substitution of different percentage of saturated lightweight aggregate with fine aggregate. The samples were subjected to different curing condition such as standard curing and in lab curing without polythene (internally cured). The study showed that the control samples which were cured under standard curing condition had lower water permeability compared to the sample subjected to internal curing only. However, when the sample are subjected to in lab curing only, the samples with 20% replacement of pre-saturated lightweight aggregate showed the lowest water permeability. Figure 2.2 shows the coefficient of water permeability of concrete with internal curing under in lab curing without polythene condition and control samples under both in lab curing without polythene condition and normal curing condition (Iffat *et al*., 2017).

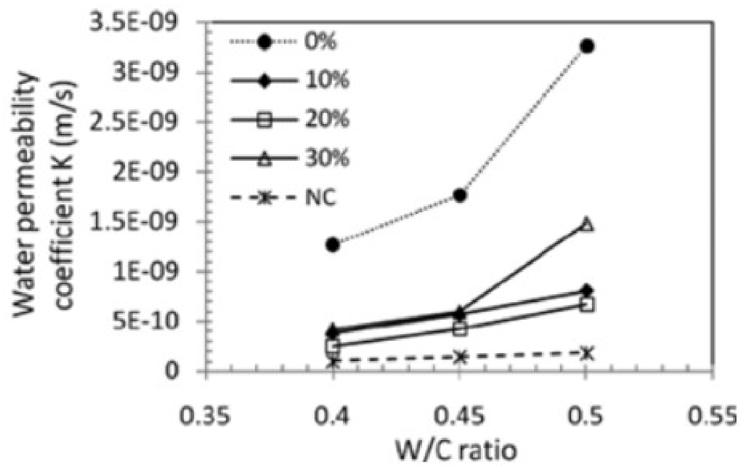

Figure 2.2: Coefficient of water permeability of concrete with internal curing under in lab curing without polythene condition and control samples under both in lab curing without polythene condition and normal curing condition (Iffat *et al*., 2017)

2.4 Introduction to saw dust

Saw dust is a wood by-product produced from the operations of wood-based industries such as wood furniture factory. Huge amount of saw dust can be seen near wood-based factories. Saw dust is generally discarded as waste and not reused. The saw dust wastes that are not utilized cause disposal issues. Disposal of saw dust can cause environmental problem. Utilizing saw dust in construction can potentially reduce the disposal problem of saw dust waste (Tiough, 2014). Saw dust is produced from the activities of wood-based factories. Tiough (2014) have reviewed that huge amounts of saw dust are generated every year all around the world. In Nigeria, the quantities of saw dust waste increases every year and creates severe disposal problems.

2.4.1 The use of saw dust in concrete

The use of industrial waste as part of building construction materials has become common nowadays. The increase population causes higher demand of the building materials. Saw dust is one of the waste materials found to be potential to be incorporated in the concrete mixing. Several researchers have used saw dust as a partial replacement of fine aggregates in the production of concrete.

Workability of concrete containing saw dust is lower due to the high water demand of saw dust. The partial replacement of saw dust with fine aggregates shows decreasing trend of slump value as the percentage of saw dust increases. It was found that saw dust concrete tend to have low workability. Figure 2.3 shows the slump value of saw dust concrete (Memon et al., 2017).

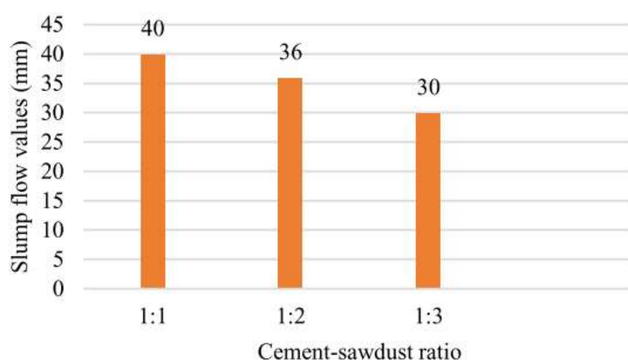

Figure 2.3: Slump value of the saw dust concrete (Memon et al., 2017)

Chitra *et al.*, (2019) carried out a research where they used saw dust to replace fine aggregates at 0%, 5%, 10% and 15% by weight for a M-20 mix. It was found that the compressive strength of saw dust concrete reduces as the percentage of saw dust increases. Figure 2.4 shows the compressive strength of the saw dust concrete as the percentage of saw dust increases.

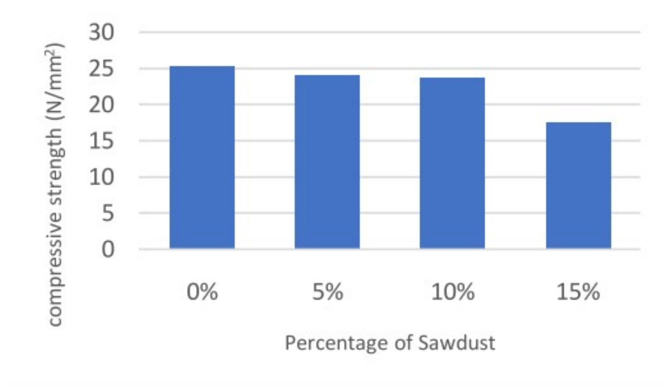

Figure 2.4: Compressive strength (N/mm^2) vs percentage of saw dust (Chitra et al., 2019)

2.4.2 Advantages of using saw dust in concrete

Some researchers have found that the use of saw dust in concrete improve the concrete properties in several ways. Some of the benefits are listed in Table 2.3:

Table 2.3: Advantages of using saw dust in concrete

Source: (Patel et al., 2010)	Source: (Joy et al., 2016)
Saw dust concrete is environment friendly	Saw dust acts as an internal curing agent in the concrete
Saw dust concrete has lighter weight compared to conventional concrete	Reduce the pollution with better way to dispose saw dust waste
Saw dust concrete promotes preservation of the natural resources such as river sand	Better sound proofing properties of saw dust concrete
Saw dust concrete is made up of lower cost material which is economical	Lower self-weight of saw dust concrete
Saw dust concrete has good thermal resistance and sound proofing	

2.4.3 The use of saw dust as internal curing agent in concrete

Study has been conducted to investigate the potential of saw dust as an internal curing agent in high performance concrete. The pre-saturated saw dust is used to partially replace fine aggregates due to its fine particle size. Internal curing can improve the compressive strength of the concrete with the additional moisture supplied by the saturated saw dust. The study found that using saturated saw dust to replace the fine aggregate at 5% by mass can improve the properties due to internal curing (Zim et al., 2015).

Another study was conducted to investigate the properties of concrete containing wood powder self-curing agent. The study postulated that loss of moisture can lead to the reduction of initial water cement ratio. This may lead to incomplete cement hydration process. Due to the ability of lightweight aggregates to absorb moisture, it is potential to partially replace fine aggregate in the concrete mixture and provide additional moisture during the cement hydration process. The research found that the use of wood powder as self-curing agent in concrete by partial replacement of fine aggregates at 5% can meet the targeted characteristic strength of $30 N/mm^2$. (Yakubu & Bukar, 2020)

The use of concrete with low w/c ratio has been common in the construction sector. This is because concrete with low w/c ratio can improve the strength and durability of the concrete. However, the concrete is highly prone to early cracking due to shrinkage. Hence, a study by Thamilselvi *et al.*, (2017) used internal curing agent to reduce the shrinkage cracks. The researchers used saw dust as a source of supplying water to the high-performance concrete during curing the curing period. The research found that saw dust is beneficial in improving the compressive strength of concrete. The research also found that the concrete with 6% of saw dust which partially replaced the fine aggregates gives higher flexural strength of the concrete as compared to the control sample in different curing conditions. The concrete with internal curing by the application of pre-saturated lightweight aggregates can reduce shrinkage cracks. (Thamilselvi et al., 2017)

2.4.3(a) Fresh concrete properties

For concrete with low w/c ratio, the pre-saturated saw dust improve the workability of the concrete due to the additional moisture stored in the saw dust (Zim et al., 2015).

2.4.3(b) Hardened concrete properties

Figure 2.5 shows that concrete with 5% saw dust replacement has a higher compressive strength compared to the control mix at 3, 7, 14 and 28 days. However, as the replacement of saw dust content increased to 10% and 15%, the compressive strength of the concrete reduced. This may be due to the additional moisture absorbed by the saturated saw dust is not completely controlled. This is because internal curing process depends on the ability of internal curing agent to completely absorb the additional moisture. If the moisture is not completely captured, it may affect the w/c ratio resulting in the formation of void or porosity in concrete. This will affect the compressive strength of the concrete (Zim et al., 2015).

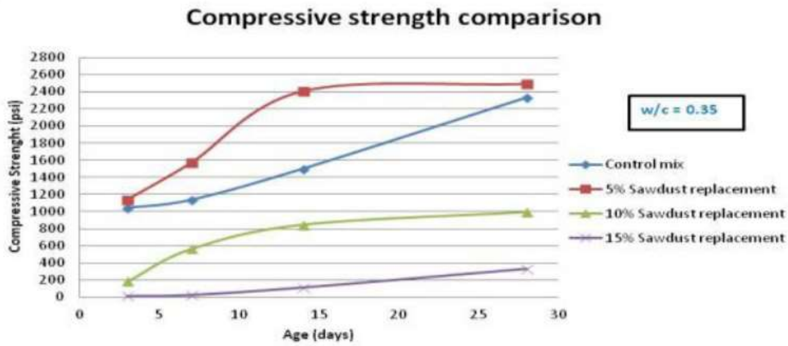

Figure 2.5: Compressive strength vs saw dust content (Zim et al., 2015)

A study by Yakubu and Bukar, (2020) has shown that the use of wood powder as internal curing agent to partially replace fine aggregate by 5% can achieve the targeted characteristic strength of $30N/mm^2$. The 28-day compressive strength of the control sample with internal curing and water immersion curing is $21.36N/mm^2$ and $32.39N/mm^2$ respectively. However, the 28-day compressive strength of the internally cured concrete with 5% wood powder is $30.86N/mm^2$. It can be observed that the concrete with partial replacement of fine aggregate with 5% wood powder is having higher compressive strength than the control sample when subjected to internal curing only. The wood powder is suggested to be used as internal curing agent by using 5% to partially replace fine aggregate in the mix.

Figure 2.6 shows that the concrete containing saw dust can resist higher compressive stress as compared to the control sample. The internally cured concrete by using saw dust improves the compressive strength due to the effectiveness of internal curing. With 6% of saw dust partially replacing the fine aggregates, the concrete achieved optimum compressive strength. Also, the shrinkage value is lowered as compared to the control sample due to the availability of sufficient moisture for the hydration process. The overall performance of the concrete is improved by internal curing in terms of compressive strength and reduction of shrinkage cracks (Raviathulbasariya et al., 2015).

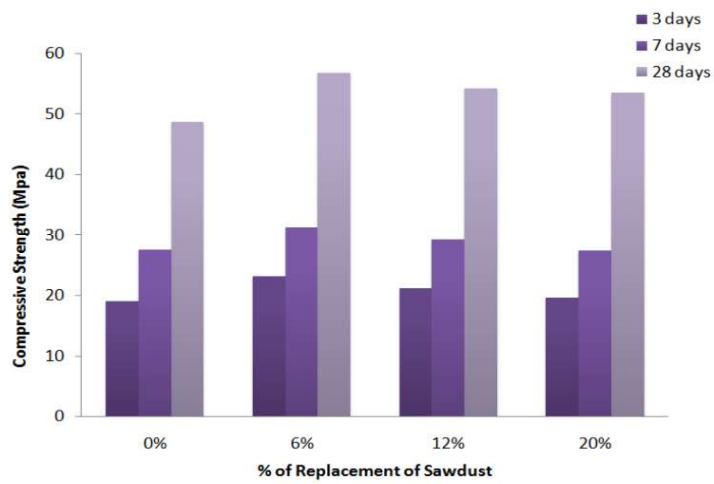

Figure 2.6: Compressive strength (MPa) of sawdust concrete with internal curing (Raviathulbasariya et al., 2015)

2.5 Introduction to silica fume

The use of saw dust in concrete improve the concrete properties in several ways. For instance, the concrete has lighter weight compared to conventional concrete. This is associated to the low density of the saw dust compared to river sand. The mechanical strength of saw dust concrete is reduced compared to conventional concrete. Hence, many research works have been carried out to improve the properties of saw dust concrete by the addition of mineral admixture such as silica fume and fly ash (Patel et al., 2010).

Silica fume is waste material from the silicon and ferrosilicon industry. Silica fume has over 95% of the particles finer than 1μm. The physical properties of the silica fume are shown in Table 2.4. Silica fume primarily consists of pure silica in non-crystalline form. There are high amount of amorphous silicon dioxide and fine particles can be found in the silica fume. Other chemicals that are found in the silica fume is shown in Table 2.5. Silica fume has a very fine size with surface area ranging from 13,000 to 30,000 m^2/kg. The high silica content and fineness make silica fume a very effective pozzolanic material. Earlier research by Khan and Siddique, (2011) has found that the use of silica fume increases the compressive strength, reduces permeability which sustains the durability of concrete. Silica fume has been widely used in high performance concrete for parking decks and highway bridges, high-strength concrete and grouting.

Table 2.4:Typical physical properties of silica fume (Khan & Siddique, 2011)

Property	Value
Particle size (typical)	<1 μm
Bulk density	
(as - produced)	130 – 430 kg/m^3
(slurry)	1320 - 1440 kg/m^3
(densified)	480 – 720 kg/m^3
Specific gravity	2.22
Surface area (BET)	13,000 - 30,000 m^2/kg

Table 2.5: Chemical composition of silica fume samples (Khan & Siddique, 2011)

Oxides	Sandvik and Gjorv (1992)	Hooton and Titherington (2004)	Yazici (2008)
SiO_2	92.1	96.65	92.26
Al_2O_3	0.5	0.23	0.89
Fe_2O_3	1.4	0.07	1.97
CaO	0.5	0.31	0.49
MgO	0.3	0.04	0.96
K_2O	0.7	0.56	1.31
Na_2O	0.3	0.15	0.42
SO_3	-	0.17	0.33
LOI	2.8	2.27	-

2.5.1 Workability of fresh concrete containing silica fume

The use of silica fume influences the properties of concrete including the fresh concrete properties, for example the increase in cohesive property of fresh concrete containing silica fume. Therefore, it is less prone to undergo segregation during the casting process when compared with the normal concrete without the use of silica fume. The increases of the percentage of silica fume will increase the cohesiveness of the fresh concrete (Luo *et al*., 2019).

Research has been carried out to examine the workability of the concrete containing silica fume. The research found that the slump value decreases as the percentage of silica fume increases. The higher the percentage of silica fume will absorb more moisture. The fine particle size of silica fume will absorb more moisture because it has larger surface area. The slump value of the mixture with percentage of silica fume of 5%, 10% and 15% are shown in the Figure 2.7. It was concluded that as the percentage of silica fume increases, the workability of concrete decreases. This is due to the finer silica fume which has a larger surface area, this will absorb additional moisture and reduce the slump value (Jagan and Neelakantan, 2021).

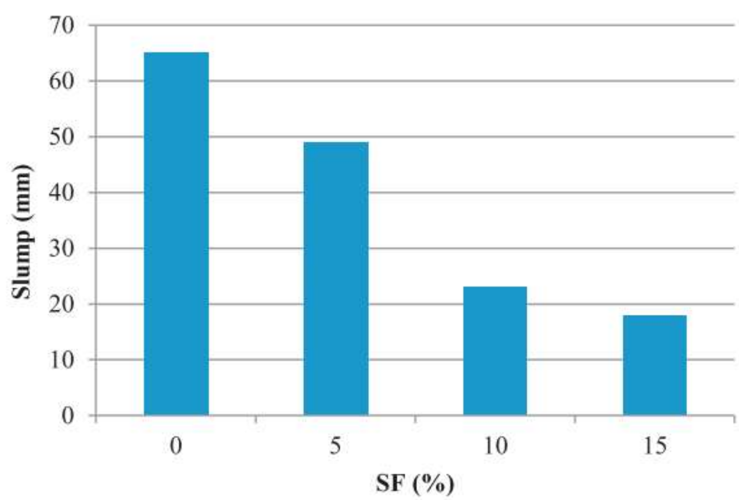

Figure 2.7: Slump value of concrete containing silica fume (Jagan and Neelakantan, 2021)

Another research had found that the increase percentage of silica fume will reduce the slump value of the fresh concrete. Therefore, as the percentage of silica fume increases, the workability decreases. Figure 2.8 shows the graph of slump vs percentage of silica fume (Santosh *et al*., 2017).

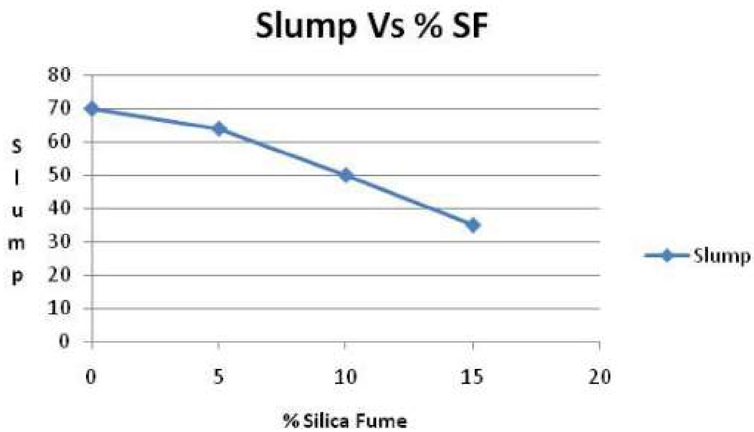

Figure 2.8: Slump vs percentage of silica fume (Santosh *et al*., 2017)

2.5.2 Properties of hardened concrete containing silica fume

2.5.2(a) Compressive strength of concrete containing silica fume

There is obvious improvement on the compressive strength of the concrete if silica fume is added to the concrete mix. Jagan and Neelakantan (2021) found that the optimum strength improvement at 14 days for M25 grade concrete and M40 grade concrete were 14.68% and 13.01% respectively. The graph that shows the strength improvement of concrete at different ages is shown in Figure 2.9. The strength improvement is mainly due to the fineness of the silica fume particles which can fill up the voids in the concrete during mixing process. The concrete with closely packed structure tend to have less void, hence the compressive strength of the concrete is increased. The pozzolanic reaction becomes less effective at later age of the concrete after 28 days. Therefore, the strength improvement of the concrete is less obvious at the later ages (Jagan & Neelakantan, 2021).

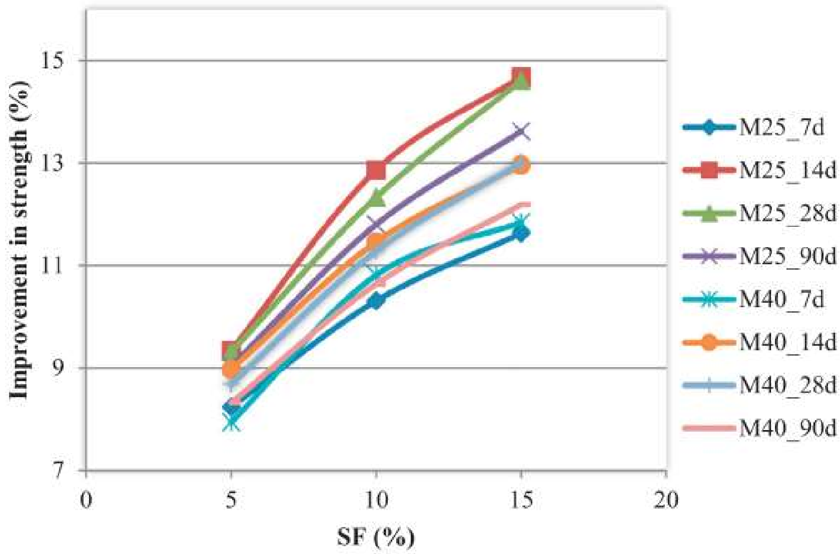

Figure 2.9: Percentage improvement in strength of concrete at different ages (Jagan and Neelakantan, 2021)

Another research had been conducted to study the effect of silica fume on the compressive strength of concrete. The research was done by partially replacing the cement with silica fume by different percentages. It is found that the optimum strength of concrete was achieved when 15% of cement was replaced by silica fume. Figure 2.10 shows the compressive strength of the sample with different percentage of silica fume at 28 days. The research concluded that the strength improvement rate of the concrete is excellent when silica fume is used. The maximum compressive strength was achieved when 15% of silica fume is used to partially replace cement by weight (Qureshi, 2020).

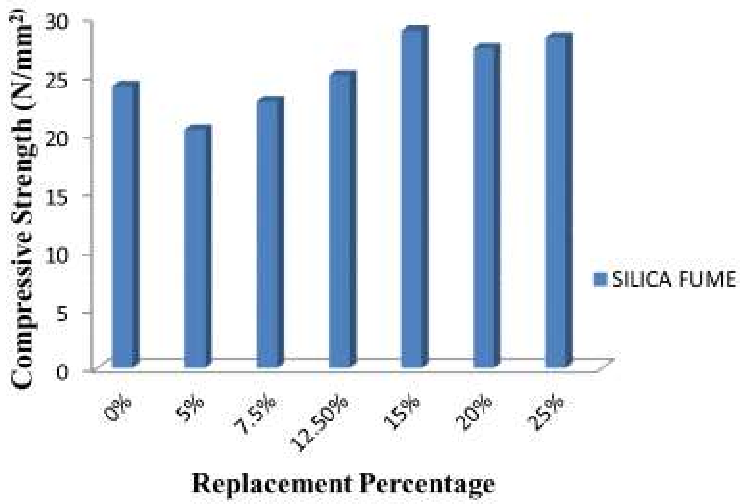

Figure 2.10: Compressive strength of concrete containing different percentage of silica fume (Qureshi, 2020)

2.5.2(b) Permeability

Research by Chaudhary and Sinha, (2020) found that the inclusion of silica fume in concrete improves the resistance of concrete against water penetration. This is due to the fineness of the silica fume which enhances the pozzolanic reaction. Besides, the voids between cement particles are filled by the fine silica fume particles. Figure 2.11 shows the coefficient of water permeability test for concrete containing different percentage of silica fume.

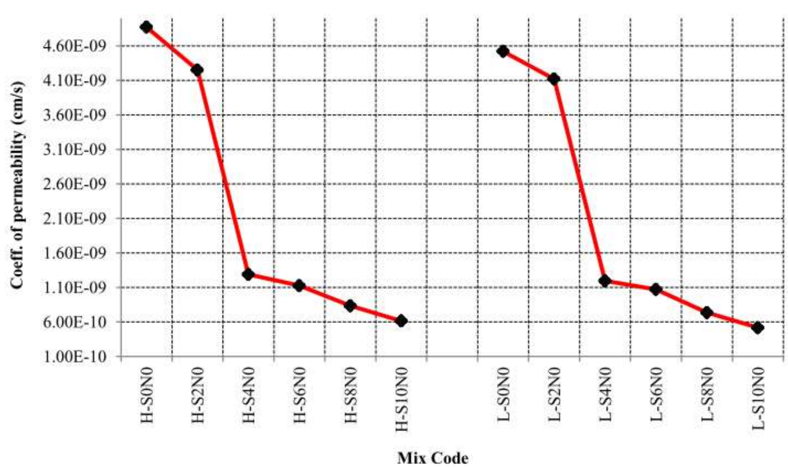

Figure 2.11: Coefficient of water permeability (Chaudhary and Sinha, 2020)